


Volume 26 • TOPICS IN GEOBIOLOGY • Series Editors: Neil H. Landman and Douglas S. Jones

First Floridians and Last Mastodons

The Page-Ladson Site in the Aucilla River

Edited by

S. David Webb

Springer

FIRST FLORIDIANS AND LAST MASTODONS:
THE PAGE-LADSON SITE IN THE AUCILLA RIVER

TOPICS IN GEOBIOLOGY

For detailed information on our books and series please vist: www.springer.com

Series Editors:

Neil H. Landman, American Museum of Natural History, New York, New York, landman@amnh.org
Douglas S. Jones, University of Florida, Gainesville, Florida, dsjones@flmnh.ufl.edu

---

Current volumes in this series

Volume 27: **Neoproterozoic Geobiology and Paleobiology**
Shuhai Xiao and Alan J. Kaufman
Hardbound, ISBN 1-4020-5201-4, 2006

Volume 26: **First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River**
S. David Webb
Hardbound, ISBN 1-4020-4325-2, 2006

Volume 25: **Carbon in the Geobiosphere – Earth's Outer Shell –**
Fred T. Mackenzie and Abraham Lerman
Hardbound, ISBN 1-4020-4044-X, 2006

Volume 24: **Studies on Mexican Paleontology**
Francisco J. Vega, Torrey G. Nyborg, María del Carmen Perrilliat, Marison Montellano-Ballesteros, Sergio R. S. Cevallos-Ferriz and Sara A. Quiroz-Barroso
Hardbound, ISBN 1-4020-3882-8, October 2005

Volume 23: **Applied Stratigraphy**
Eduardo A. M. Koutsoukos
Hardbound, ISBN 1-4020-2632-3, January 2005

Volume 22: **The Geobiology and Ecology of *Metasequoia***
Ben A. LePage, Christopher J. Williams and Hong Yang
Hardbound, ISBN 1-4020-2631-5, March 2005

Volume 21: **High-Resolution Approaches in Stratigraphic Paleontology**
Peter J. Harries
Hardbound, ISBN 1-4020-1443-0, September 2003

Volume 20: **Predator-Prey Interactions in the Fossil Record**
Patricia H. Kelley, Michał Kowalewski, Thor A. Hansen
Hardbound, ISBN 0-306-47489-1, January 2003

Volume 19: **Fossils, Phylogeny, and Form**
Jonathan M. Adrain, Gregory D. Edgecombe, Bruce S. Lieberman
Hardbound, ISBN 0-306-46721-6, January 2002

Volume 18: **Eocene Biodiversity**
Gregg F. Gunnell
Hardbound, ISBN 0-306-46528-0, September 2001

Volume 17: **The History and Sedimentology of Ancient Reef Systems**
George D. Stanley Jr.
Hardbound, ISBN 0-306-46467-5, November 2001

Volume 16: **Paleobiogeography**
Bruce S. Lieberman
Hardbound, ISBN 0-306-46277-X, May 2000

First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River

Edited by

S. DAVID WEBB
Florida Museum of Natural History,
University of Florida, Gainesville, FL, USA

Springer

A C.I.P. Catalogue record for this book is available from the Library of Congress

ISBN-10 1-4020-4325-2 (HB)
ISBN-13 978-1-4020-4325-3 (HB)
ISBN-10 1-4020-4694-4 (ebook)
ISBN-13 978-1-4020-4694-0 (ebook)

Published by Springer
P.O. Box 17, 3300 AA Dordrecht. The Netherlands

www.springer.com

Cover Illustrations:
Central photo:
Paleoindians around sinkhole, photograph by National Geographic Society.

Top row photos:
Palaeolama mirifica right jugal bone and maxillary with M1-M3, UF 180214, crown view, photograph by Erika Simons.
Battering and abrading lithic artifacts; hammerstone sandpaper-like heavily worn abrader stone, photographs by Jim Dunbar.

Printed on acid-free paper.

Aims & Scope Topics in Geobiology Book Series

Topics in Geobiology series treats geobiology – the broad discipline that covers the history of life on Earth. The series aims for high quality, scholarly volumes of original research as well as broad reviews. Recent volumes have showcased a variety of organisms including cephalopods, corals, and rodents. They discuss the biology of these organisms-their ecology, phylogeny, and mode of life – and in addition, their fossil record – their distribution in time and space.

Other volumes are more theme based such as predator-prey relationships, skeletal mineralization, paleobiogeography, and approaches to high resolution stratigraphy, that cover a broad range of organisms. One theme that is at the heart of the series is the interplay between the history of life and the changing environment. This is treated in skeletal mineralization and how such skeletons record environmental signals and animal-sediment relationships in the marine environment.

The series editors also welcome any comments or suggestions for future volumes;

Series Editors:
Douglas S. Jones dsjones@flmnh.ufl.edu
Neil H. Landman landman@amnh.org

To all of those who helped explore the river

Contents

SECTION A: GEOLOGY

SECTION B: PALEOBOTANY

SECTION C: LATE PLEISTOCENE EVIDENCE

SECTION D: EARLY HOLOCENE EVIDENCE

SECTION E: CONCLUSIONS

Contributors

Kurt Auffenberg
Florida Museum of Natural History
University of Florida
Cultural Plaza
SW 34th Street and Hull Road
PO Box 112710
Gainesville, FL 32611-2710
U.S.A.
ka1@flmnh.ufl.edu

Robin C. Brown
2626 Shriver Dr
Fort Myers, FL 33901
U.S.A.
drrcb@aol.com

Brinnen C. Carter
Florida Museum of Natural History
Museum Road
Gainesville, Florida
32611
U.S.A.
bcarter@grove.ufl.edu

Joseph F. Donoghue
Department of Geological Sciences
Florida State University
Tallahassee, FL 32306
U.S.A.
jdonoghu@mailer.acns.fsu.edu

James S. Dunbar
Florida Division of Archaeological
Research
Department of Historical Resources
Gray Bldg, Secretary of State's Office
Tallahassee, FL 32399
U.S.A.
jsdunbar@mail.dos.state.fl.us

Daniel C. Fisher
Museum of Paleontology
The University of Michigan
1535 Ruthven Museums
1109 Geddes Avenue
Ann Arbor, MI 48109-1079
U.S.A.
dcfisher@umich.edu

David L. Fox
Department of Geology and
Geophysics
University of Minnesota
310 Pillsbury Dr. SE, Minneapolis
MN 55455
U.S.A.
mats0159@umn.edu

Barbara C. S. Hansen
Limnological Research Center
220 Pillsbury Hall
University of Minnesota
Minneapolis, MN 55455-0219
U.S.A.
hanse057@tc.umn.edu

C. Andrew Hemmings
Department of Anthropology
University of Texas
Austin, TX 78712
U.S.A.
hemmings@grove.ufl.edu

Kathryn A. Hoppe
Department of Geological and
Environmental Sciences
Stanford University
Stanford, CA 94305
U.S.A.
khoppe@stanford.edu

Douglas S. Jones
Florida Museum of Natural History
University of Florida
291 Dickinson Hall
Museum Road and Newell Drive
Gainesville, FL 32611
U.S.A.
dsjones@flmnh.ufl.edu

David C. Kendrick
Department of Geosciences
Hobart and William Smith Colleges
Geneva, NY 14456
U.S.A.
kendrick@hws.edu

Paul L. Koch
Department of Earth Sciences
University of California
Santa Cruz, CA 95064
U.S.A.
pkoch@earthsci.ucsc.edu

Joseph M. Latvis
Florida Museum of Natural History
University of Florida
Dickinson Hall
Museum Road
Gainesville, FL 32611
U.S.A.
JML7027@yahoo.com

Russell McCarty
Prep Lab Manager
Vertebrate Paleontology
Florida Museum of Natural History
University of Florida
Dickinson Hall
Museum Road and Newell Drive
Gainesville, FL 32611
U.S.A.
cormac@flmnh.ufl.edu

Matthew C. Mihlbachler
Division of Paleontology
Department of Vertebrate Paleontology
American Museum of Natural History
Central Park West at 79th Street
New York, NY 10024
U.S.A.
mihlbach@amnh.org

Mark P. Muniz
Department of Anthropology
University of Colorado
Boulder, CO 80304
U.S.A.
munizm@colorado.edu

Lee A. Newsom
Department of Anthropology
University of Pennsylvania
University Park, PA 16802
U.S.A.
LAN12@psu.edu

Tanya Peres
Program for Archaeological Research
Department of Anthropology
University of Kentucky
U.S.A.
tmpere2@uky.edu

Irvy R. Quitmyer
Florida Museum of Natural History
University of Florida
Museum Road
Gainesville, FL 32611
U.S.A.

Larry Schwandes
Department of Environmental Pedology
Institute of Food and Agricultural Sciences
University of Florida
Florida Museum of Natural History
Museum Road
Gainesville, FL 32611
U.S.A.

Sylvia Scudder
Florida Museum of Natural History
University of Florida
Museum Road
Gainesville, FL 32611
U.S.A.
scudder@flmnh.ufl.edu

Erika Simons
Florida Museum of Natural History
University of Florida
Museum Road
Gainesville, FL 32611
U.S.A.

S. David Webb
Florida Museum of Natural History
University of Florida
Gainesville, FL32611
U.S.A.
webb@flmnh.ufl.edu
and
11 Clear Creek Trail
Anaconda, MT 59711
U.S.A.

James D. Williams
James D. Williams
US Geological Survey
7920 NW 71st Street
Gainesville, FL 32653
U.S.A.

Prologue

The old bull elephant halted his swinging gait. His ears moved to catch the throbbing sub-sonics from a far off female mastodon in estrus – a sound that called to him urgently. But he was puzzled, and he lifted his trunk high above his flattened forehead. Increasingly an acrid and unfamiliar scent had come to him, borne on the moist breeze from a nearby watering hole. The mastodon wheeled and began moving down the dusty path that led to the dry bed of an old river, now only a strip of vegetation surrounding a few pools of water.

At the water's edge crouched a strangely twisted animal, the origin of the unfamiliar smell. With the appearance of the mastodon, the animal rose and in bizarre fashion remained balanced on its hind legs . . .

Foreword

Over the last 20 years the Aucilla River Prehistory Project has been one of the most fascinating stories unfolding in Florida. This project, uncovering the remains of plants and animals from the end of the last Ice Age and the beginning of Florida's human occupation, is answering questions important to the entire western hemisphere. Questions such as when did people first arrive in the Americas? Were these newcomer scavengers or skillful hunters? Could they have contributed to the extinction of the great Ice Age beasts – animals such as elephants – that were creatures native to Florida for the previous million or so years? And how did these first Florida people survive 12,000 years ago at a time when sea level was so low that this peninsula was double its present size, sprawling hugely into the warm waters of the Caribbean? Much of Florida at that time was almost desert. Fresh water – for both man and beast – was hard to find.

The lower reaches of today's Aucilla River are spellbinding. Under canopies of oak and cypress, the tea-colored water moves slowly toward the Gulf of Mexico, sometimes sinking out of sight into ancient drowned caves and then welling up again a few feet or a few miles downstream. Along the river bottom, the remains of long extinct animals and Florida's earliest people lie entombed in orderly layers of peat, sand, and clay.

Fifty years ago the Aucilla's treasure trove of ancient history was discovered by scuba divers. They found, washing out of the bottom sediments, the bones of mastodon and mammoth together with stone points and objects of carved bone and ivory. A few adventurous divers traced the ancient remains into the layers of bottom peat. These underwater explorers eventually convinced two scientists, archaeologist Jim Dunbar and paleontologist David Webb, that the Aucilla held a story of Florida history unobtainable from any other site. And so the Aucilla River Prehistory project was born.

For 20 years this remarkable joint venture has continued: divers learning archaeology and paleontology, and scientists learning underwater river bottom exploration. The techniques developed by this pioneering project will serve as a model and set standards for river bottom archaeology elsewhere in North America.

This book tells what they found.

Robin C. Brown
2626 Shriver Dr.
Fort Myers, FL 33901
U.S.A.

Preface

S. DAVID WEBB
Florida Museum of Natural History, Dickinson Hall, University of Florida, Gainesville,
FL 32611, USA.

---

1 Introduction

This book presents the essential results of two decades of work in a remarkable underwater site in north Florida. The Aucilla River winds slowly southward from Georgia through a hauntingly beautiful and sparsely inhabited part of Florida to the Gulf of Mexico (Balfour, 2002). The swampy river bottom harbors rich records of life spanning the end of the Ice Ages. Stratigraphically these prehistoric resources bracket the first appearances of human cultural remains and the final evidence of mastodons and other megafauna. And these data are closely associated with a rich floristic record of changing environments (see Figs. 1 and 2).

The Aucilla River Prehistory Project (ARPP) devised unique methods to conduct reconnaissance and then properly to excavate the most promising underwater sites. In several instances ARPP was able to demonstrate the availability of nearly continuous accumulations of fine-grained sediments through the late Pleistocene and into the early Holocene. Thus their team of researchers could trace changing natural environments from before, during, and after the appearance of human cultures in the region.

2 Site Genesis and Chronology

Two decades of exploration by ARPP showed that the productive sites in the Aucilla River consisted of nearly circular sinkholes that had filled slowly with clays, silts, and fine sands. Each such site contained a sequence of rich organic sediments that had accumulated during an interval of several thousand years. By the time ARPP had

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, xix–xxv

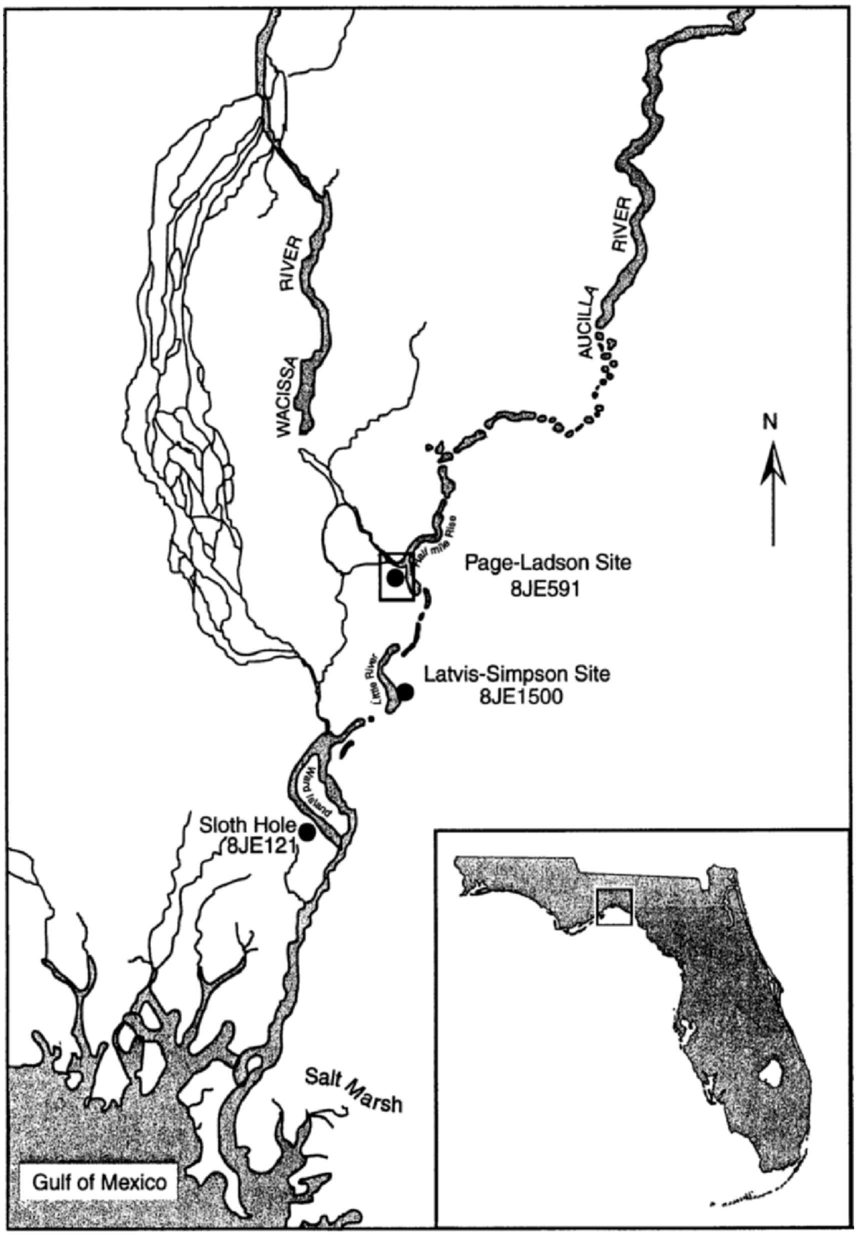


Figure 1 Location map showing Aucilla and Wacissa Rivers in relation to the Gulf of Mexico and the state of Florida. The Page-Ladson site is located in the center of the detailed map on the Aucilla River just below confluence with a branch of the Wacissa River.

Figure 2 Aerial view of operations at the Page-Ladson site, June 1988. Field camp, dive platform, and support boats are located along the west bank. The Aucilla River flows toward the upper left. Two floating screens and airlift pumps are operating. The 4-in. line nearer the center of the river is used for controlled excavations. The 6-in. line to its west is used for bulk removal. Note buoys marking various test pits. Another screen and airlift is partly visible at lower right adjacent to the east bank.
Photo credit: Sandy Young.

sampled and dated some three dozen sites, it became evident that the genesis of these sediments was keyed to lowland water tables and thus indirectly to regional rainfall and eustatic sea level change. When sea level dropped and/or rainfall was reduced, surface drainage became predominantly subterranean. Such a pattern of karst geomorphology is expected in a coastal region in which the surficial geology is dominated by limestone. When the sea transgressed and/or rainfall and runoff raised the water table, surface sinkholes gradually filled with locally derived sediments.

After ARPP had acquired nearly 100 carbon dates from some three dozen inundated sinkhole sites, an interesting pattern emerged. Two times of sediment filling were evident in the middle and lower reaches of the Aucilla River, one lesser cluster of dates around 30,000 years ago and another greater cluster around 12,000 years ago. These clusters of dated sediment accumulation evidently correspond to the last two times of late Pleistocene sea level rise, known to Quaternary stratigraphers as marine isotope stages 3 and 2. In lowland parts of peninsular Florida these interglacial episodes of sedimentation were not confounded by any important tectonic events.

ARPP concentrated most of its efforts on the younger of these two cycles of sinkhole filling, the ultimate eustatic sea level rise of the late Pleistocene and early Holocene. It should be noted, however, that sites corresponding to the older of these two cycles, the penultimate cycle of sedimentation, provide an important control study, representing environmental history of the same region before human influences had appeared.

ARPP devoted its most extensive efforts to the Page-Ladson site for two reasons. First, it yielded an intact stratigraphic column some 8 m long. Secondly, preliminary assays showed it to have outstanding preservation of a great diversity of fossils and artifacts. Ultimately it provided a nearly continuous record from 16,000 radiocarbon years ago (^{14}C BP) to less than 8,000 ^{14}C BP. It yields the richest continuous record of well-dated sediments producing rich faunal, floral, and cultural data in the region. For these reasons the Page-Ladson site complex is the focus of this book.

3 Organization of this Volume

This volume represents the best efforts of a dozen scholars to analyze one site complex in the Aucillla River. The subsequent chapters in this book are grouped into six sections. The Preface sets forth the field methods developed over two decades to recover the rich records hidden in dark underwater sites of the Aucilla River. Secondly four chapters cover the geological aspects of the Page-Ladson site complex. In a third very important section the paleobotanical data, divided into micro- and macrobotanical contributions, are set forth along with their environmental significance.

Most of the remaining chapters are grouped into two multidiciplinary sets on a chronological basis. The late Pleistocene evidence, sampled in the deeper (= earlier) reaches of the site, includes abundant remains of terrestrial and freshwater mollusks and vertebrates including American Mastodons and other extinct megafauna. Along with this native fauna one sees more subtly the first vestiges of early Paleoindian cultures, representing the first Floridians. The early Holocene evidence, sampled in a relatively shallow set of strata in the upper part of the site, lacked extinct megafauna but revealed relatively rich samples of early Archaic cultures and a distinctive set of warmer and more humid environments.

4 A Rich Record of Changing Environments

In peninsular Florida minor changes of topography often signal major changes in habitat, especially where well-drained soils and porous limestones stand above regional water tables (piezometric surfaces). This present observation helps explain why, according to evidence presented in this book, late Pleistocene and early Holocene landscapes experienced very dramatic changes. The overall pattern was a shift from extensive open landscapes with little surface water during the last glacial interval to increasingly closed landscapes with much surface water during the early Holocene and recent. There are, however, many subtle variations on this general theme. The evidence from the Page-Ladson site accords well with data from other studies in Florida during comparable intervals of time. Such sites include pollen profiles from Sheelar Lake 130 miles to the southeast and Camel Pond 60 miles northwest, as well as archaeological and pollen samples from Windover near Titusville and Little Salt Springs from North Port, Florida. The long record of environmental changes at Page-Ladson site, based on various proxy data including pollen, macrobotanical samples, terrestrial and freshwater fauna, sediments, and water table cycles, establishes the longest multidisciplinary record of environmental change in Florida's late Quaternary history.

5 Coincidence versus Consilience

The few bits of hard evidence that come to prehistorians, while digging through a dozen millenia, convey only tantalizing bits of the full complexity of human cultures. They see only dark adumbrations of the environmental interactions that they are seeking. Like detectives at a remote crime scene they patiently accumulate every clue. Twenty years of improving the ARPP's underwater recovery and data-keeping methods have helped. And the greatly increased precision of carbon-dating has profoundly improved correlation from local events to regional and global patterns of climate change. Here we attempt to interrelate all the hard-won evidence we can, and thus paint a broader picture of faunal, floral, and cultural evolution.

But the questions we seek to answer are exceedingly complex. Previous generations, it now seems, rushed too quickly to give answers about the peopling of the Americas and the extinction of the megafauna. The prehistorian must now rework the old evidence and add as much new as possible. And that evidence, both old and new, must be carefully constrained by rules of evidence and logic. For example, when two events occur together in time, within, say, two standard errors of the same carbon dated interval, such correlations must still be regarded as *coincidence*, not as cause and effect. We would not propose that the last appearance of *Mammut* and the first appearance of Bolen points are causally related merely because the former occurs in Unit 4 and the latter in Unit 5. A much stronger bond of evidence comes from *consilience*, that is when two or more independent approaches lead to the same conclusion. The appearance of abundant charcoal in pollen profiles, along with the recovery of burned wood and hearths on the Bolen surface, all at a time when the mesic forests had pulled back somewhat from the site, gives strongly convergent evidence that humans were burning and cutting the forests. That is why we are pleased to bring together a team of specialists to analyze such diverse data as charcoal, pollen, lithics, and fauna, all from the same series of replicate samples.

6 Regional versus International Perspectives

During the same two decades that the ARPP was investigating the faunal, floral, and cultural history of this remote part of north Florida, an intellectual revolution was overturning the textbook accounts of how the Americas were peopled. It is still true, of course, that people reached the New World shortly before the end of the Pleistocene Period, but now the exact schedule and direction of colonization of North and South America by *Homo sapiens* have become increasingly uncertain. We are now in the midst of an exciting scramble for new paradigms (e.g. Haynes, 2002; Meltzer, 2004).

Likewise, in this new millenium, we see intensified debate on the impacts of the first Americans on the last of the Pleistocene megafauna. The time of overlap between humans and megafauna in the New World is critical to our understanding of how humans and other fauna interacted. The Paleoindian/megafauna zone (PIM zone) may have been as short as a thousand years, as suggested by Martin and Klein (1984). In this volume, however, we present data indicating a PIM zone that more than doubles that estimate. Indeed it may be triple, if one recalibrates the radiocarbon dates bracketing the PIM zone into calendar years. These are important data, for the duration of the PIM zone tends to be seen as inversely proportional to the intensity (destructiveness) of the interactions with the first Americans. A considerably milder impression of such interactions would come to mind if one accepted dates as early as 33,000 ^{14}C BP for the establishment of human cultures in South America (Dillehay, 2000). It is also clear, as in all studies of prehistory or paleontology, that the available dates surely underestimate the true overlapping range zone due to sampling errors and inadequacies of the record.

Reliable chronologies and tightly controlled excavations will provide the building blocks for new paradigms about peopling the Americas and extinctions of megafauna. At the moment these topics seem to engender contentious debate rather than simple consensus. It is an excellent time to procure new data in regions that provide crucial tests of new hypotheses. In that spirit this book presents its new set of data, exhumed from the Aucilla River, as a regional cornerstone for whatever new edifice is going to be built.

7 Acknowledgments

The ARPP thanks its two host institutions, the Florida Museum of Natural History in Gainesville and the Division of Historical Resources in Tallahassee, for supporting and sustaining the activities of key personnel in the ARPP and for housing and conserving the resulting collections and archives. The ARPP gratefully acknowledges major support in the form of Special Category grants from the State of Florida Division of Historical Resources, Florida Department of State, Tallahassee, Florida during more than a decade. The ARPP also received critical funding from National Geographic Society, Committee on Research and Exploration during its first five seasons. None of these funding organizations are responsible for opinions or interpretations derived from the archaeological and paleontological research conducted under these grants. The Florida Museum of Natural History generously subsidized production of the color figures in this volume. And the National Geographic Society gave special permission to reproduce its two-page color restoration of a scene at the Page-Ladson Site 14,000 years ago.

The ARPP acknowledges vital support from several dozen volunteer SCUBA divers from Florida and beyond, who freely dedicated their time, energies and personal dive gear to participate in this important research. We especially thank the John Ladson family for extending their hospitality, encouragement, and support of this project's activities on their land. Finally we are deeply indebted to many individual friends of the project who have contributed both emotional energy and material gifts to its success. The following roster of names is probably not complete and so we apologize to those whom we may have forgotten:

Tim Barber, Jody Barker, Robin Brown family, Brinnen Carter, Bob Coughter, Robert Daniels, John Davidson. Robin Denson, John Eveland, William O. Gifford, Steve Glover, Eddie Green, Heather Gunther, Andy Hemmings, Joan Herrera, Mary Gouchnour Hudson, Hank Kratt, Joseph M. Latvis, William B. May, Alyssa Martinelli McManus, Harley Means, Ryan Means, Don Monroe, Mark Muniz, Mike Nolan, Buddy Page, Irvy C. Quitmyer, Thadra Palmer Stanton, Jack Simpson, Dawn Pinder, Gene Rowe, Randy Rush, Don Serbousek, Mike Simpson, Mike Stallings, Jo Ann Suggs, David Thulman, Susan Kane Vizeau, Brian Woods, and Sandy Young.

References

Balfour, R. C., III. 2002. In Search of the Aucilla. 203 pp. Colson Printing Co., Valdosta, GA.

Dillehay, T. 2000. The Settlement of the Americas: A New Prehistory. 324 pp. Basic Books, New York.

Haynes, G. 2002. The Early Settlement of North America: The Clovis Era. 345 pp. Cambridge University Press, Cambridge, UK.

Martin, P. S. and R. G. Klein (eds.). 1984. Quaternary Extinctions: A Prehistoric Revolution. 892 pp., University of Arizona Press, Tucson.

Meltzer, D. J. 2004. Peopling of North America, pp. 539–563, *in* A. R. Gillespie, S. C. Porter and B. F. Atwater, The Quaternary Period in the United States. Developments in Quaternary Science, vol. 1, Eklsevier Press, Amsterdam.

Chapter 1

Underwater Excavation Methods

JOSEPH M. LATVIS and IRVY C. QUITMYER
Aucilla River Prehistory Project, Florida Museum of Natural History, Dickinson Hall,
University of Florida, Gainesville, FL 32611, USA.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 1–28

"Picture yourself in a boat on a river,
where Pleistocene people eat mastodon pies. ..."
(With apologies to John Lennon and Paul McCartney)

1.1 Aucilla River Prehistory Project Background

The Aucilla River Prehistory Project (ARPP) conducted underwater field operations annually (except 1986) since its inaugural expedition to the Page-Ladson Site in November 1983 under the regionally less inclusive "Half-Mile Rise" site/project designation. In 1994 the geographic scope of the project was expanded beyond the Page-Ladson Site at Half-Mile Rise to include the entire lower Aucilla River watershed which was investigated until the final field season in 1999. The evolution of archaeological diving field methods throughout ARPP's 16 years of field seasons was driven by expanding challenges and opportunities in several principal areas:

- research design mission requirements
- environmental conditions
- crew experience
- research vessel options
- air supply system options
- diving operational protocols
- diving supervision
- diving operations procedures
- excavation procedures
- underwater videography

ARPP diving field methods were formulated to prioritize crew safety, research quality and productivity, educational and training opportunity, public outreach, and, whenever possible, appreciation and enjoyment of the pristine natural world that disciplined crews were privileged to inhabit and explore during field seasons cumulating from one to ten weeks annually. The following analysis describes the development of methods by which these field operations were conducted. Sequential diving operational procedures employed during one complete typical dive rotation are then presented, followed by a detailed description of specific excavation and sampling procedures employed at the Page-Ladson Site. The chapter closes with a brief review of the role underwater videography played in documenting project field activities.

The process that drove each field season's evolution of ARPP diving field methods began several months prior to each field campaign with customized research design mission requirements developed by ARPP co-chief scientists Dr. S. David Webb, representing the Florida Museum of Natural History (FLMNH), and Mr. James S. Dunbar, representing Florida’s Bureau of Archaeological Research (BAR). FLMNH archaeologist Dr. Jerald T. Milanich joined the project as a co-chief scientist in 1994. Site-specific tactical details of the scientific objectives were next prepared by designated University of Florida graduate student and FLMNH staff field scientific directors. Site- and mission-specific diving field methods required to safely and efficiently accomplish these research objectives were then generated by the project operations manager and director of diving operations. These detailed scientific and operational field methods were finally incorporated into a comprehensive research, diving and operations plan, which was copied to all field roster personnel prior to their arrival at the site.

1.2 Research Design Mission Requirements

Research design requirements determined many of the field operational techniques and equipment employed by the ARPP. Free ranging river-bottom surveys designed to locate sites in unexplored areas dictated the use of independent scuba equipment instead of surface supplied air (SSA) systems. Survey divers required the greater long-range mobility and freedom from air line entanglement around submerged obstructions that scuba equipment provided. Conversely, long-term deep excavation of a previously identified site of confined spatial expanse was more safely and efficiently conducted utilizing SSA.

The choice of research vessel deployment configuration was likewise dependent on research design particulars. Excavation sites located near a well-consolidated riverbank were best accessed from a dive support vessel made fast directly to the bank, or rafted to a support barge made fast to the bank. Mid-river excavation sites beyond SSA line reach of the shore-bound compressor required its relocation on board the dive operations vessel anchored mid-river and rafted to the dive operations barge. Topside-powered bottom-sediment coring (vibracoring) operations dictated that its operations barge be anchored directly above each designated coring target location in order to maintain the core tube vertically through the hole in the deck.

1.3 Environmental Considerations

ARPP diving operations were also determined in large part by the increasingly diverse riverine environments in which the expanding Aucilla River basin research site options were located. The lower (seaward) reaches of the Aucilla River explored by the project along the border between Jefferson and Taylor counties drain a portion of the Woodville karst plain in northwest Florida. The karst nature of the Aucilla drainage produces successive sets of Oligocene limerock river channels alternating with underground aquifer “runs”. Surficial river runs typically begin at a spring venting from the underground aquifer (often 100 feet beneath the surrounding wilderness swampland), and then meander for one half to one mile before precipitously disappearing underground as a sink that courses similar distances through the porous limestone basement aquifer.

As rainwater percolates through the surficial drainage on its way to feeder creeks and the river channel, tannic acid leaches from ubiquitous organic swamp vegetation. The tannin-stained water takes on a brown/black coloration not unlike domestically brewed tea. Sunlight oftentimes cannot penetrate even 10 feet beneath the surface, resulting in utter blackness at the 15–35-foot depths at which most river-bottom sites were excavated. (Divers familiar with such conditions often refer to the practice colloquially as "blackwater" diving.) Compensating somewhat for the tannic-compromised visibility is a phenomenon also tied back to the karst nature of this region's rivers, negligible sediment loading.

Whether coursing through surficial channels or underground aquifer passages, the tannic-stained water encounters scant particulate to fluidize and transport from within monolithic porous limestone bedrock. This negligible sediment load is manifested physiographically by a distinct absence of deltas and large barrier islands offshore of the mouths of karst rivers like the Aucilla. A fortuitous consequence of negligible particulate loading is the ability of the project's 1000-W underwater work lights (powered by 1400-W generators topside) to penetrate the tannic-stained water column.

Because deep swamp sites investigated by the ARPP were not logistically or environmentally amenable to supporting a field camp crew of 12–14 persons for up to six weeks (and St. Marks National Wildlife Refuge regulations specifically prohibited such camping activities on refuge land) a base tent camp was established at the nearest outpost river village of Nutall Rise. Each day all crew members and site camp consumables were shuttled via boats or vehicles as far as 3 miles between the base camp and primitive site camp.

The remoteness of ARPP's Aucilla River sites from emergency medical services and other logistical support facilities was addressed in each field season's site-specific research, diving and operations plan. (The nearest hyperbaric oxygen chamber and level one trauma facility was located 45 miles distant at Tallahassee Community Hospital. The next nearest similarly equipped facility was 100 miles distant at University of Florida's Shands Hospital in Gainesville.) Detailed emergency evacuation procedures to rescue multiple unconscious divers from an excavation site 35 feet deep to the surface, recover them via a designated chase boat to a designated evacuation vessel, and transport them several river miles to a landing where a designated evacuation vehicle awaited transfer and transport of the injured parties to a previously designated helicopter landing zone were designed and rehearsed with all parties. Remoteness even complicated notification of Lifeflight and Shandscaire medevac helicopter service dispatchers, because cellphone signal strength was usually inadequate when attempted directly from the excavation site. (Contingency "landline" phone links activated by an emergency communications team with their own designated communications vessel and vehicle were designed into the emergency evacuation procedure plan.)

Hydrologic conditions of the Aucilla River were monitored throughout the year via monthly reports from the regional water management district (Suwannee River Water Management District), as well as anecdotal reports from local riverfront residents. Historic hydrologic data compiled by the water management district were also reviewed to establish what seasons of the calendar year statistically produced conditions of rainfall, water level, current, temperature, and visibility most amenable to extended diving operations. Tide charts were consulted on a daily basis to help select times of day for safe vessel passage through limerock shoals and boulder fields that become dangerous at low tides.

Regardless of the particular field season's river site location, National Oceanic and Atmospheric Administration (NOAA) meteorological radio reports were monitored hourly by dive supervisors for signs of approaching foul weather. While simple rainfall did not force suspension of field operations, any evidence of approaching high winds or lightning was considered sufficient cause to recall all personnel, secure the site camp, and retreat to the project base camp at Nutall Rise.

One of the major consequences of hydrologic and meteorological conditions on the diving environment was river current. During severe current conditions a strongline was strung across privately owned sections of the river for divers to pull themselves out to the float on the surface that marks the underwater site below. A downline was then strung between the strongline and the excavation site on the bottom, so divers could ascend and descend without being "blown away" while in midcolumn. Divers also usually wore additional dive weight in such circumstances to maintain station against the bottom current, which was sometimes considerable. The extra weight also lent additional body purchase when operating the dredge head, jet nozzle, or sediment coring device.

The field crew was routinely alerted to the ubiquitous presence of poison ivy, poison oak, acacia thorns, and all manner of biting and stinging insects. Particular care was exercised when surfacing from a dive or when boating around branches that overhang the river, where wasp nests and cottonmouth snakes may be present. Epipen autoinjectors were maintained in each first aid kit to address a severe life-threatening reaction sensitized people can develop with some bites, stings, or envenomations. (Senior emergency medical project staff were trained and certified to administer such interventions.) Encounters with alligators, bears, panthers, wild hogs, and venomous snakes in the wetland environment the field crew inhabited and explored were also noted.

Excavating into organic river-bottom sediments during field seasons often lasting 4–6 weeks, with daily 2-h dives on shared SSA regulators, made infections of the ears, sinuses, and airway a constant concern. "Ear maintenance" kits containing over-the-counter oil, cotton swabs, and a 50/50 solution of rubbing alcohol/white vinegar were maintained at the site camp and base camp for diver and screendeck operator ear care. A bucket with a dilute solution of bleach in water was available on the bow of the diving operations pontoon barge for divers to disinfect SSA second-stage regulators between dive rotations. A second small bucket of clean water was also maintained there to rinse the bleach solution from the regulators.

Due to extended bottom times (2-h dive rotations) permitted by continuous, plentiful SSA supplies and generally shallow operating depths (35 feet maximum) all divers were encouraged to wear full wetsuits with hood, or drysuits to prevent hypothermia. A live campfire for warmup and a camp stove for hot soup and beverages were maintained at the site camp on days which would necessitate such measures. The campfire was extinguished with river water before being left unattended at the end of each diving day. Ironically, screendeck operators, safety divers, and dive supervisors were also susceptible to hyperthermia during long periods of exposure on the sunbeaten screendeck barges and diving operations barge. Wide-brimmed hats, appropriate clothing, attention to proper hydration levels, occasional cooldown “dips” in the river, and sensible duty rotations were effective protection. A personalized drybag was issued to each team member to secure clothing and personal items against the elements while at the site camp. This 2500 cubic inch bag also defined the personal storage space each team member was allotted onboard the close quartered support vessel.

1.4 The Field Crew

From the very first ARPP field season in 1983, the crew was constituted from an ever-changing amalgam of divers and non-divers representing academia and the broad based community beyond. Throughout successive field seasons avocational volunteers proudly subscribed to the rigorous certification requirements demanded by so prestigious a research institution as the FLMNH. On any given daily field assignment roster, a high school student or college undergraduate-, graduate- or postgraduate student could be teamed with a combat wounded Vietnam veteran diving instructor, dentist, veterinarian, hazmat diver, building contractor, corporate motivational businesswoman, tropical plant nurseryman, university radiation officer, emergency medical technician, Florida State Representative, housewife, fossil/artifact collector, retiree, nurse, commercial diver, NOAA hydrographer, blacksmith, former U.S. Navy Seal, Florida Bureau of Archaeological Research archaeologist, or FLMNH Distinguished Curator of Vertebrate Paleontology. Participants hailed from home bases as diverse as their backgrounds, representing Arizona, the Carolinas, Georgia, Idaho, Illinois, Maryland, Minnesota, the Netherlands, Oregon, Sweden, Toronto, Vermont, Virginia, Tennessee, Texas, and Wisconsin, as well as throughout the state of Florida. Volunteers were recruited primarily through ARPP’s annual newsmagazine *Aucilla River Times* and the project’s website (http://www.flmnh.ufl.edu/natsci/vertpaleo/arpp. htm). Project staff and students trained volunteers to recognize Pleistocene/Holocene fossils, diagnostic artifacts, chert debitage, paleobotanical specimens, and sediment colors, textures, and inclusions. Volunteers were also introduced to proper techniques in excavation, mapping, and sampling, as well as the operation and maintenance of all field equipment under their charge.

The collaborative contribution that these talented and multidisciplinary field crews made to the rigorous scientific collection and provenience documentation enabled the academic analysis and interpretation of the Page-Ladson Site represented in the chapters that follow. Approximately 50 ARPP volunteers participated anywhere from a single weekend to six full weeks during each of two annual field seasons, as they rotated into and out of the 12–14 field roster positions available. Many returned year after year, growing in experience and leadership capabilities as they assumed positions of increasing responsibility and authority. Veteran divers and screendeck operators also represented a valuable resource of continuity from year to year, forming a nucleus around which (and by whom) less seasoned volunteers were trained. New recruits infused fresh ideas and diverse skills that increased the crew’s hybrid vigor in problem solving and unyielding enthusiasm. The collective perseverance and camaraderie that was often required in difficult and challenging field circumstances (hurricanes, floods, tornadoes, close quartered camping/working privations, and cumulative fatigue) resulted in mutual respect and many enduring friendships.

1.5 Research Vessels

A diving support vessel (24-foot aluminum-hulled outboard prop-driven pontoon barge) was either made fast and gang planked directly to the riverbank immediately adjacent to the underwater site being explored (Fig. 1.1), or anchored mid-river nearby the site. This vessel provided space for divers and non-divers not involved in the current operating teams. This barge also served as a platform for the SSA compressor, electric generators, and primary emergency medical gear if the operations vessels were rafted together mid-river. Whenever possible both the support barge and diving operations barge were located immediately downstream of the excavation sites, so that divers returned to these vessels with the current.

Diving operations at all sites were conducted from a 20-foot aluminum-hulled outboard prop-driven pontoon barge dedicated to this purpose. This diving operations vessel was rafted outboard of the diving support barge, and served as a platform for the launching

Figure 1.1 Note two sets of SSA hose lines supplied by the air control station on the diving operations barge emanating toward the right foreground, where two dive teams are simultaneously excavating two discrete units. Research vessel deployment at typical riverbank site: (right to left) diving support vessel, diving operations vessel, emergency evacuation vessel, and chase/communications vessel. Colour version of this figure can be found in Appendix on page 553. Photo credit – Susan Verberg.

and retrieval of all dive teams (Fig. 1.2), as well as for the air control station, divemaster station, safety diver station, and emergency medical equipment. All divers' scuba gear was also staged on this pontoon barge. Only personnel directly involved with the current diving operation or its logistical support were permitted aboard this vessel. Otherwise, the diving operations barge was not considered a social gathering place or a venue for any project or personal activity not required to be conducted aboard this working vessel.

A 20-foot aluminum-hulled outboard jet-drive jonboat was rafted outboard of the diving operations pontoon barge to serve as emergency evacuation vessel between the operations site and the emergency evacuation vehicle(s) back at Nutall Rise. Although

Figure 1.2 Safety diver readies on-deck diver for launch from water-level platform at bow of diving operations vessel. Colour version of this figure can be found in Appendix on page 553. Photo credit – Susan Verberg.

this vessel shuttled personnel and equipment to and from the operations site at the beginning and end of each day, its preemptive mission was to serve as the emergency evacuation vessel during daily operations.

A 20-foot wood-hulled outboard jet-drive jonboat was rafted outboard of the emergency evacuation vessel to serve as a chase/communications vessel. Although this vessel also shuttled personnel and equipment to and from the operations site at the beginning and end of each day, its preemptive mission was to serve as chase boat for the recovery of a drifting diver in distress during daily operations.

A 17-foot fiberglass wide-beam outboard prop-driven canoe was rafted outboard of the chase/communications vessel, to serve as a local service/shuttle vessel. However, this vessel was also available throughout the day for shuttle service between the operations site and the base camp at Nutall Rise.

Two 8-foot custom built unpowered wooden screendeck barges with fiberglass-encapsulated flotation were stationed immediately down current of the sites being excavated. These vessels independently supported their own dredge pump, couple jet and tailings screen operation (Fig. 1.3).

One aluminum canoe provided unpowered local service/shuttle transportation among the various project vessels and screendeck barges at the operations site. This canoe was usually tied off to the screendeck barges mid-river for screendeck operator shift changes.

Figure 1.3 Typical screendeck barge deployment midriver: (right to left) 18-hosepower dredge pump (on separate flotation) powering 6-inch couplejet dredge mounted into screendeck barge. Mirror image arrangement powers 4-inch couplejet dredge on far left. Colour version of this figure can be found in Appendix on page 553. Photo credit – Krister Efverstrom.

1.6 Air Supply Systems

During the project's initial years recreational scuba air systems were the only equipment available; however, the difficulty encountered in operating and maintaining gasoline-driven high pressure (3000 psi) compressors in the remote swamp environment too often resulted in lost field productivity. A two-diver high pressure airbank-supplied Kirby Morgan bandmask system was utilized for excavation purposes between 1987 and 1992, when lighter weight and more easily deployable two-diver gasoline powered surface supplied "hookah" systems were adopted. Low pressure (120 psi) hookah compressors supply breathing air via hoses directly to the diver's low pressure regulator. In 1995 a Brownies Third Lung®© portable diesel-driven 10 cfm/120 psi SSA compressor became available as the primary air source, capable of simultaneously supporting two two-diver excavation teams. The compressor was stationed in the woods beyond the underwater site, to keep diesel fumes and noise away from topside crew. A 125-foot long reinforced air hose strung overhead from tree to tree delivered compressor output to a custom-designed air control station (Fig. 1.4) located on the stern platform of the diving operations pontoon barge. The SSA system included 9 gallons of low pressure (120 psi) accumulator tank capacity as well as 80 cubic feet of high pressure (3000 psi) scuba tank emergency backup supply.

Completely independent well-maintained standard recreational scuba systems supplied by each diver for their own personal use were utilized as redundant safety backup bailout by all SSA divers. Scuba tanks (80 cubic foot capacity aluminum or 72 cubic foot steel) also served as primary air supply for ancillary scuba-only divers.

Figure 1.4 Surface supplied air control station showing monitoring/distribution instrumentation directly (behind divemaster), accumulator tanks (right), and high pressure backup cylinder (left). Colour version of this figure can be found in Appendix on page 553. Photo credit – Susan Verberg.

A bailout bottle was considered spent when it returned from a dive with less than 1500 psi. All spent tanks were removed from service and flagged with a short piece of surveyor's tape tied around the base of the valve until refilled.

To avoid the operating and maintenance problems previously encountered with gasoline-driven high pressure compressors in the field, scuba tanks were filled using a trailer-mounted unpowered bulk storage system stationed at the Nutall Rise base camp. The 4500 psi manifold cascade system, consisting of six "K" bottles, a pressure control valve, pressure gauges and two fill whips, was recharged at the Florida State University's Academic Diving Program facility located 45 miles distant on the Tallahassee Campus. Cascade system recharging and scuba tank-filling were performed only by individuals who had been checked out on such procedures by divemaster staff. All Department of Transportation safety regulations were followed whenever the cascade system was transported on public roads.

1.7 Diving Operational Protocols

The ARPP was sponsored by the FLMNH, located at the University of Florida in Gainesville. All dive operations were conducted under standards established by the University's Diving Science and Safety Program (DSSP) and the American Academy of Underwater Sciences (AAUS). It was the responsibility of every diver to establish and maintain current and active status with DSSP for the duration of their participation on the dive roster. All DSSP certification requirements were satisfied before a diver reported to the field, with the following exception: If the diver lived so great a distance from Gainesville (as many ARPP volunteers did) that it was impossible for him/her to perform the DSSP written exam, swim test, and scuba skills test in Gainesville beforehand, these tests were administered in the field during the initial day(s) of roster assignment. Divers already certified with an AAUS research institution other than the University of Florida were required to establish their reciprocity status with DSSP before reporting to the project dive roster.

The buddy system was employed on all dives, with the additional proviso that divers-in-training could not dive unless paired with a fully certified research diver. Daily buddy team assignments designated the senior diver of each pair, who assumed the lead in any unanticipated decisions required to be made while on the bottom. U.S. Navy dive tables were used in the calculation of all no-decompression and repetitive dive limits. No decompression diving was scheduled, and none was conducted. Prospective new excavation sites were initially inspected by veteran divers for any overhead risk situations. No cave, spring or siphon diving was scheduled, and none was conducted. All dives were logged in accordance with University of Florida's DSSP requirements. Upon their return to the diving operations barge, divers were responsible for reporting the maximum depth of their dive, as well as their final tank pressure to the divemaster. All divers and divemasters were reminded of the DSSP requirement to sign every log entry.

Repetitive diving was conducted on a voluntary basis only. Even when U.S. Navy dive tables and diver enthusiasm permitted back-to-back dives, they were normally not scheduled, so that all repetitive dives were separated by a surface interval of at least two hours. Dive team members who wanted to be considered for a repetitive dive assignment on any given day notified the dive scheduler not later than the end of the preceding day. That notification of intent notwithstanding, if a diver's readiness status was compromised in any way (hypothermia, ear problems, fatigue, or simply changing his/her mind) after the first dive was completed, the diver was required to withdraw his/her commitment to perform the repetitive dive by simply notifying the current divemaster of record.

1.8 Diving Supervision

All dives were supervised from the diving operations vessel by a safety diver on the bow (safety diver station) and a divemaster on the stern (divemaster station). The safety diver was required to remain alert and prominently visible at the safety diver station throughout the 2-h dive rotation, although the divemaster could "spell" him/her for a comfort break. While the divemaster usually monitored and directed all operations from the divemaster station (where the SSA control station was located), he/she would also circulate among the various centers of topside activity and equipment within the immediate vicinity of the diving operation. It was the divemaster's primary responsibility to monitor and control the performance of the SSA system throughout his/her watch.

The primary responsibility of the safety diver was to maintain continuous visual tracking of all divers' bubbles throughout every dive. If any of the scuba-only operating teams became separated by so great a distance from the dive operations pontoon barge vantage point that the safety diver's ability to monitor the divers' bubbles was compromised, a second safety diver with a complete set of scuba gear was dispatched in the chase/communications vessel to accompany and monitor this remote dive team. It was the responsibility of all divers (particularly those using scuba only) to anticipate, consider, and remain within the capability of the safety diver to adequately monitor their bubble streams whenever excursions beyond the excavation proper were made. All SSA lines were tended by the safety diver throughout each dive.

It was the responsibility of the safety diver to audibly announce (amid the din of multiple internal combustion engines) all significant dive-related operational events as they occurred:

> "Diver in the water" whenever a diver entered the water from the operations barge.
> "Diver down" whenever a diver departed the surface.
> "Diver up" whenever a diver returned to the surface.

In order to isolate the safety diver from routine operational distractions, any team member with a need to transact legitimate operational matters with the active dive supervision crew was required to broker such communication through the current divemaster of record. Non-time-critical strategic operational decisions were made by the current divemaster of record in consultation with the operations manager, operations supervisor, and field scientific director whenever possible. Tactical decisions regarding matters of urgency or immediate safety were made without consultation or delay by the current divemaster of record. Regardless of the mechanism by which an operational decision was made, operational orders so developed were issued by the divemaster of record to all affected parties. Crew chiefs standing by on the diving support barge then assembled teams of off-duty personnel as required to execute such orders.

1.9 Diving Operations Procedures

1.9.1 Site Evaluation

A fathometer survey of prospective Aucilla River sites was initially conducted, revealing bathymetric profiles (Fig. 1.5) of what later would become the Page-Ladson Site. Vibracoring of bottom sediments at prospective sites (Fig. 1.6) was subsequently conducted to identify and locate deposits of cultural interest. Selected sites were next inspected by veteran project divers on scuba who were familiar with traditional bottom condition safety hazards. Crews were then constituted to bow-saw and lift-bag underwater logs and snags that might pose air line entanglement threats to subsequent SSA diving operations. High profile sediment deposits were evaluated for their structural integrity and resistance to slump or collapse. Leaf litter or backfill overburden sometimes required pumping out using one or more hydraulic dredges. Compacted overburden deposits could be loosened for removal using a balanced divers jet nozzle, powered by one of the 4-in. dredge pumps.

Figure 1.5 Fathometer survey records Aucilla River bathymetry at Half-Mile Rise sites. Photo credit – James Dunbar.

Figure 1.6 Note steel tripod with chain hoist for extracting coretube. Bottom sediment coring team hoists vibracore tube into position aboard operations barge. Colour version of this figure can be found in Appendix on page 553. Photo credit – Thadra Palmer Stanton.

1.9.2 Float-Marking Unit Location(s)

Sites selected for excavation were marked with a uniquely identified float on the surface whenever operations were in progress. The downline from this float marker was tied off to a stake or bottom landmark independent of all spatial control elements (site stakes, datums, PVC units, or gridframes) and located immediately outside the corner of the unit most distal from the operations barge (from whence the SSA lines emanated).

1.9.3 Establishing Excavation Unit(s)

Excavation units measuring 1 × 1 m, 1 × 2 m, or 2 × 2 m were delimited by 1-in. PVC pipe frames nailed through corner elbows into the river bottom with landscape spikes. Each PVC leg was painted alternating 10-cm bands of gray and black. Larger units were delimited by a 2 × 3-m metrically marked "railtrack" device, an aluminum-angle frame, corner-mounted onto vertically adjustable 1 in. metallic tubing driven into the river-bottom sediment. Bubble levels attached at the midspan of each aluminum-angle rail facilitated leveling the frame by adjusting the height of each corner. A metrically marked 4-wheeled aluminum-angle traveling bridge spanned between the longitudinal rails of the frame, permitting Cartesian coordinates of any point within the unit to be determined directly from the longitudinal rail and transverse bridge scale readings. The vertical coordinate of any location on the pit floor was simply obtained by placing the zero end of a meter scale at that location and reading its distance below the traveling bridge.

Relating river-bottom coordinates to the terrestrial geodetic system was accomplished by surveying from known terrestrial datums to the riverbank adjacent to the site. A meter scale fastened to a wooden post was driven into the shallows nearby the bank, establishing a river gauge datum (Fig. 1.7) that was then surveyed back to

Figure 1.7 Rod man sets location for river level datum in shallows adjacent to Page-Ladson Site. Colour version of this figure can be found in Appendix on page 553. Photo credit – Joseph M. Latvis.

the terrestrial riverbank datum (Fig. 1.8). All depth measurements made from the river surface to the excavations below were then related to the terrestrial survey by the river gauge datum.

1.9.4 Unit Illumination

Each excavation was illuminated by a 1000-W underwater work light (Fig. 1.9) powered by a gasoline driven 110-V, 1400-W generator running on the riverbank (or onboard the dive support barge when anchored mid-river). Electrical output of each generator was routed through its own ground-fault circuit interrupter to protect personnel handling the waterproof cable/light assembly from injury. The divemaster assured that the light was powered on before approving the divers' signaled intention to begin their descent.

1.9.5 Basic Operating Team Assignments

Breathing on the SSA regulators (and independently backed up by recreational scuba gear), the basic dive team consisted of a dredge/trowel operator and a light operator in the

Figure 1.8 Surveyor shoots terrestrial elevation down to Page-Ladson Site river level datum. Colour version of this figure can be found in Appendix on page 553. Photo credit – Joseph M. Latvis.

excavation, supported by a screendeck operator, safety diver, and divemaster on the surface. When sufficient divers and surface support personnel were available two such operating teams independently excavated two spatially discrete units simultaneously. All operational assignments were gender neutral.

1.9.6 Basic Dive Team Assignments

The primary excavator would hold the dredge suction hose in one hand while troweling or bare-fingering through intact sediments with the other hand. The buddy diver directed the work light to illuminate the surface being troweled. A variant of this routine had the buddy diver tending the dredge hose while the excavator used the trowel and work light. Divers would switch activities occasionally during the dive to prevent hypothermia in the less-active light operator and fatigue in the dredge/trowel operator. Additional underwater responsibilities of the basic excavation crew(s) also included sediment sampling and hammer coring, as well as associational and stratigraphic mapping (Fig. 1.10). Note-taking and sketches on mylar sheets was often required during the dive (Fig. 1.11) so that critical observations and measurements could be accurately reported to supervisory staff and the on-deck team following each dive rotation.

Figure 1.9 Diver excavating an Aucilla River site beneath the cone of visibility of the 1000-W underwater work light. Colour version of this figure can be found in Appendix on page 553. Photo credit – Tim Barber.

Both excavation team divers would look, listen and feel for fossil/artifact "hits", paleobotanical specimens, or sediment changes throughout the dive. Fossil remains and artifacts encountered *in situ* within any given sediment horizon were left in place initially. The item or assemblage was then tagged, mapped, photographed (still and video) and sediment sampled before being collected. Due care was exercised that all samples collected from the bottom were secured in containers bearing complete waterproof identification regarding their context. All excavation team divers were required to fill out an excavation log form, documenting (with written descriptions and sketches) activity and observations in the excavation during each dive.

1.9.7 Ancillary Dive Team Assignments

Archaeological supervisors, photo/video teams, and/or bathymetric mapping teams would occasionally dive simultaneously with the basic operating teams; however, these ancillary activities were conducted on scuba only, to avoid entanglement with operating team SSA lines.

Figure 1.10 Diver utilizes bubble level and metric tape to map magafaunal fossil bone exposed on pit floor. Colour version of this figure can be found in Appendix on page 553. Photo credit – Tim Barber.

1.9.8 Screendeck Operations Assignments

Screendeck operators were responsible for starting and stopping the dredge pump engines in coordination with dive team requirements. They continuously monitored and sampled tailings streams discharging from the hydraulic dredges onto screendeck barges (Fig. 1.12) at anchor down-current of the excavation. Operators would be vigilant to notify the field scientific director immediately whenever an item of significance (chert, worked bone, ivory, fossils, paleobotanical specimens, sediment changes) appeared on the screendeck. Due care was exercised that all samples collected on the screendeck were kept in containers bearing complete waterproof identification regarding their context.

1.9.9 Assignment Rotations

Divers and divemasters rotated into and out of the various assignments for which they were qualified, in the course of the three-to-four 2-h dive rotations normally scheduled each diving day (crew size, personnel stamina, and hypothermia permitting). Crew rota-

Figure 1.11 Diver recording observations of excavation details on mylar clipboard. Note SSA hose line supplying diver's low pressure regulator. Colour version of this figure can be found in Appendix on page 553. Photo credit – Tim Barber.

tions were intentionally scheduled with a 20–30-min interval for briefing between the incoming and outgoing teams. These briefing sessions were attended by the incoming and outgoing: divers, screendeck operators, standby divers and dive supervisors involved, as well as the field scientific director(s), operations manager and diving officer, whenever practical. To provide updated continuity across team rotations, a cumulative record of significant progress in each survey or excavation was graphically represented with plan and elevation sketches on a dry erase board maintained on the dive operations vessel, and on mylar records taken underwater. Additional responsibilities shared by all personnel also included duty on the screendeck, terrestrial excavation, equipment repair/maintenance activities, written documentation of daily activities, field specimen logging, and general camp support chores.

1.9.10 Launching Divers

After donning their personal scuba gear and SSA line regulator, divers entered the water from a seated position on the dive platform at the bow of the dive operations barge, and then surface swam to the float marking the excavation unit. Divers then signaled the safety diver of their intention to begin the dive, and awaited signaled approval to proceed.

1.9.11 Beginning the Dive

The divers switched on their personal dive lights and then descended alongside each other by looping their thumb and index finger loosely around the float line and

Figure 1.12 Screendeck operator monitors tailings delivered from dredge excavation. Colour version of this figure can be found in Appendix on page 553. Photo credit – Robin Brown.

following it to its anchorage on the bottom, where the work light, dredge head, tool crate and supplemental weight belts had been secured by the previous outgoing dive team. Divers would fin into the current during ascents and descents on this marker line, to avoid pulling it off the bottom.

1.9.12 Arriving on the Bottom

As divers approached the bottom they would slow their rate of descent, and orient their bodies so as not to touch down inside the excavation unit, or disturb the other excavation team that may be operating nearby. They would then deflate their buoyancy compensators and/or don a supplemental weight belt to maintain negative buoyancy for working.

1.9.13 Dredge Operation

Site excavation was accomplished utilizing 4- and 6-in. hydraulic dredges powered by gasoline-driven engines floating on the surface. The suction created by the dredges is considerable (especially the 6-in. dredge), and divers were alerted to exercise constant vigilance so that body parts, dive consoles, regulators, trowels, lights, camera housings, large rocks, or long branches were not accidentally vacuumed. Unsecured backup scuba regulators were potentially hazardous, because if captured by the dredge head they could rapidly purge, filling the 60-foot long suction hose with scuba air, and resulting in a runaway buoyant ascent with the attached diver in tow. This eventuality was precluded by instituting a policy requiring all divers to secure their scuba regulators to their buoyancy compensator shoulder straps.

As rocks, logs, or dive lights accelerated unintentioned toward the suction they acted as pinch points with the dredge pickup hose end, endangering fingers trapped therein. If immediate extrication from the pickup hose was not possible the diver's buddy was trained to recognize the entrapment situation and signal the screendeck operator (using the float marker line) to shut off the dredge pump. It was the responsibility of the screendeck operator to quickly shut down this pump in the event that a diver on the bottom should be unable to extricate him/herself from the intake hose. For this reason, the dredge pump was never left running unattended by the screendeck operator. Owing to the screendeck barge's mid-river location (overhead and slightly down-current of the excavation dive team), the screendeck operator would also be prepared to render the most immediate assistance to a diver in distress on the surface.

1.9.14 Securing the Unit

Securing the unit at the end of the dive, excavation divers would signal the screendeck operator to shut down the dredge engine, tie the dredge head off to a nearby stake or natural bottom feature immediately adjacent to the float marker line anchorage, cache the supplemental weight belts, return all tools to the toolcrate, untangle the work light cable, inspect both SSA lines and the float marker line for unfouled clearance to the surface, turn on their personal dive lights, signal their buddy to surface, and finally stage the work light at the bottom of the float line.

1.9.15 Retrieving Heavy Loads to the Surface

Any underwater load (bags of fossil bones, steel tools, mesh bag full of sediment samples) estimated to weigh more than 10 pounds (out of water) was secured to a utility line, the free end of which was delivered to the surface for load retrieval by screendeck personnel or the utility vessel.

1.9.16 Ending the Dive

Excavation divers departed the bottom when the backup scuba air supply of either buddy dropped to 1500 psi, or when the scheduled two hours of bottom time had elapsed, whichever occurred first. The divers would then ascend side-by-side, looping their thumb and index finger loosely around the float line and following it to the surface. Because divers usually preferred to wear more dive weight than normal when operating equipment like the dredge head, jet nozzle, or sediment coring device, all team members were admonished to be especially vigilant when surfacing, so that their buoyancy was controlled to an ascent rate not exceeding 30 feet per minute.

1.9.17 Vessels Overhead

Care was exercised when surfacing to avoid contact with project or public vessels on the river. It was the responsibility of the safety diver to alert passing vessels to the presence and location of the divers throughout the dive. Dive flags were posted mid-river immediately upstream and downstream of the diving operation to alert approaching vessels of the diving activity. One unpowered aluminum canoe provided shuttle service in the immediate vicinity of the diving operation to minimize powered vessel traffic above the divers.

1.9.18 Shoal Hazards

Each diver was responsible for assuring that they did not enter a shoal area where clearance with vessels passing overhead could create a potential risk of injury. Additional precautions (multiple dive flags and more safety lookouts) were deployed whenever such shoal areas were intentionally explored.

1.9.19 Returning to the Diving Operations Vessel

Once both divers arrived at the surface and signaled their status to the safety diver they swam to the bow of the diving operations barge one at a time. Here they delivered their weight belt, backpack, SSA line, mylar clipboard, and sample bags to the safety diver aboard. The unencumbered divers then exited the water by finning up onto the dive platform at the bow of the barge. Independent scuba divers (mainly photographic, bathymetric mapping, and survey/reconnaissance personnel) followed the same routine. Cameras were always the last item the safety diver handed to an underwater photographer being launched, and the first item surrendered back upon retrieval.

1.10 Excavation Procedures at the Page-Ladson Site

The ARPP developed its most intensive excavation and sampling procedures during the 1991, 1992, and 1993 field seasons. At that time the purpose was to develop detailed stairstep excavations downward as deep as practical along the sloping west bank of the river in a new area known as Test F. Stratigraphically sampled radiometric dates had already demonstrated that the sediment bank had accumulated during the latest Pleistocene and into the early Holocene. As in previous years divers using scuba or SSA excavated with a 4- and a 6-in. gas-powered dredge (see Latvis, this volume). The dredged materials were sieved through a 1/4 in. screen located on a surface platform, allowed to dry, bagged and transported to the FLMNH for study. For each sample, collectors recorded the last two digits of the year of their excavation season, followed by a decimal point and a sequential field sample (F.S.) number that linked the sample to a horizontal and vertical location. During the 1991–1992 seasons a letter suffix accompanied the F.S. number so as to identify the sampling method. For example, F.S. 91.50A was sampled in 1991, with sample number 50, and the letter “A” identified materials collected in the dredge screen. Table 1.1 provides a listing of the letter suffixes and their related excavation methods.

In the 1991 fall season the excavation team secured botanical, faunal and bulk-sediment samples from the dated stratigraphy of the Page-Ladson Site along a 2-m wide

Table 1.1 Letter designations applied to numbered field samples

A = Specimens recovered in the dredge screen (1/4)
B = Hand collected radiometric (^{14}C), pollen, and bucket core samples
C = Bulk samples collected with the hydraulic dredge
NP = Non-provenienced specimen. These are specimens collected from the river bottom where no provenience could be determined
M# = Map specimen. Materials that were mapped *in situ* and then hand recovered

transect known as Test F. The transect followed a west to east course and was defined by a 3/8 in. yellow polypropylene line. This line was staked into the sediments. The polypropylene line was maintained for the three field seasons. The loose overburden (silts and modern plant materials) in Test F was removed from the excavation surface with a 6-in. hydraulic dredge. This general cleaning also extended 1 m on either side of Test F. This process minimized the risk of loose debris contaminating the excavation unit. Periodic cleaning was performed; as needed, throughout the course of the excavation.

Twenty-seven 1 m × 1 m × 20 cm squares were excavated down slope within the 2-m transect of Test F. The 20-cm units represented arbitrary levels that gave way to natural stratigraphy. Each square was advantageously positioned to avoid debris (e.g. fallen trees, large rocks) or disturbances that were located along the slope. The resulting excavation produced an undulating stairway within the 2-m transect extending into the deepest part of the site.

After each square was excavated four, 1-l box core samples of the sediments (four liters total per unit) were taken from the base of each corner of the unit. These samples were submitted to Lee Newsom for macro-botanical analysis. Four sediment samples were also taken from each corner of the excavation unit base. These were obtained by cleaning the excavation profile and pushing a 12 dram, amber vial into the sediments. The sample vials were removed from the profile and capped. These samples were submitted to Barbara Hansen for pollen analysis. Finally, four additional samples of the sediments were taken in 12 dram, amber vials from each corner of the excavation unit base for possible radiometric (^{14}C) analysis. The pollen and radiometric samples were refrigerated to retard biological growth in the samples prior to analysis.

The 1992 field season ran from 18 October to 30 October and 8 December to 12 December. It extended the work of the previous season, but focused intensively on the most productive levels of the early Holocene (see Section D of this volume) and of the latest Pleistocene (see Section C of this volume). In the deeper levels (23 through 27) excavators placed a 2 m × 3 m aluminum rail-track on the northeast corner of Test F, and began controlled excavations about 20 cm above level 23. Six 1 m × 1 m squares were marked and excavated in 20-cm units within the rail-track. As the excavation progressed, a 1-m perimeter was excavated around the border of the rail-track and sand bags were placed along the profile to help maintain the integrity of the sediments and to minimize contamination of the excavation.

By the end of the field season levels 23 through 26b had been removed, exposing a considerable amount of large animal bone in the surface of level 27. A field team of divers mapped and removed these remains for study in December 1992.

The goal of the field season of 1993 from 17 October to 30 October was to continue to extend the Test F excavation along the west bank of the river. The 2 m × 3 m rail-track was placed at the west border of the 1992 excavation unit and is referred to as F South. The 1993 excavation was successful in exposing an even greater expanse of the late Pleistocene sediments including the critical tusk of a *Mammut americanum* discussed in Chapters 11 and 12.

The fauna, flora, artifacts, and bulk samples that were recovered between 1991 and 1993 are curated in the collections of the FLMNH, Gainesville. Archived field notes, maps, photographs, and videos also accompany these collections.

1.11 Underwater Videography

1.11.1 Aucilla River Prehistory Project Video Background

Few underwater photographic images of any type were obtained during the initial years (1983–1987) of the ARPP. The extreme darkness usually encountered on the river bottom made illuminating and recording fossils, artifacts, and sediments difficult and elusive. Decaying organic vegetation in the swamp drainage of rivers like the Aucilla produces a dissolved tannic acid stain in the water column, which must be penetrated by artificial light if visible spectrum images are to be recorded at depth. Fortunately the karst geologic nature of the river channels adds little suspended particulate to the water. This combination of circumstances permits the effective application of intense artificial light to illuminate faint details, without the deleterious backscatter consequences of suspended particulate in the image. Normal Aucilla River dry season visibility, even without particulate degradation, allows not the faintest hint of a bright Florida sun directly overhead, once the diver descends below 15 feet. Most ARPP sites are 15–35 feet beneath the surface, and must surely be among the earth's most utterly dark places.

Motion photography on film remained elusive, owing to slow film speed and conventional battery powered underwater lighting capabilities. During the later-1980s, consumer quality 8 mm videotape cameras possessing excellent low light sensitivity became available at affordable prices. Mounted in underwater housings, and combined with 1000-W incandescent underwater work lights (powered by gasoline- driven 110-V generators on the surface), these videocameras permitted excellent capture of obscure scenes. Videographers routinely saw greater detail in what they were recording when looking through the camera's viewfinder than was visible with the naked eye. This low light sensitivity was especially effective in capturing images of fossils and artifacts often exposed in sediments of low contrast.

These videocameras were in fact so sensitive to low light situations that burnout of brightly colored subjects in the field of view became a problem. Consequently a translucent diffuser was fabricated and installed over the underwater work light's clear glass lens, to soften the light's intensity and glare. Additionally any manmade objects that invariably appeared in the camera's field of view were modified to eliminate burnout. This was accomplished by replacing traditional white PVC pipe excavation unit gridframes (traditionally painted with alternating 10-cm bands of high gloss black paint) with gray electrical conduit PVC pipe painted with flat black bands. North arrows and centimeter scale video props (also originally painted in starkly contrasting black and white for high visibility) were repainted to alternating flat gray and black.

As "blackwater" video techniques developed and the quality of the images improved, additional roles for underwater videography of prehistoric sites were incorporated into excavation strategies. Video documentation of progressive stages of excavation became routine, by capturing images of fossils and artifacts as they became revealed in sedimentary context. This adjunct to (although certainly no replacement for) traditional measured drawing documentation was accomplished by recording plan views of pit floors, as well as stratigraphic columns revealed in elevation views of pit walls. These images captured associational spatial relationships between and among fossils and artifacts, the colors, textures and inclusions of sediments, as well as contact surfaces and transitions between sediment horizons. Date, site name, Florida Master Site File Number, unit designation, and view orientation information were recorded on a plastic menu board, along with north orientation and scale references. Archaeological procedures employed in the excavation and sampling of underwater sites were also documented with videotape recordings.

1.11.2 Porting Live Underwater Video Topside

As part of ARPP's longstanding commitment to public outreach and education, an open house was conducted during many field seasons. Scientists, governors, state representatives, students, river divers, families, and children from around the southeastern United States were shuttled to the current remote excavation site, where they observed topside aspects of the field operation firsthand. Screendeck operations on the surface necessarily became the visual focus of attention; however, river-bottom excavation diving activities remained "unvisible" to the non-diving public. Project video capabilities were consequently expanded to communicate the compelling underwater component of the archaeological excavation to topside visitors in real-time. This was accomplished by porting the "video-out" signal from the camera to a bulkhead fitting that passed the signal through the underwater housing. A waterproof coaxial cable then transmitted the video signal to a television monitor located onboard the adjacent riverbank or diving operations support vessel, where underwater activities were narrated to the viewing audience (Fig. 1.13).

1.11.3 Cataloging and Archiving ARPP Videotape

Once a videotape master was removed from the camera, it was physically labeled with the dates and sites of recording, as well as being write protected on the cassette to avoid any possibility of accidental overwriting. A VHS format dupe was then produced from the 8 mm master to provide a more conventional format for subsequent replays, as well as eliminating the need to replay the master tape (and the inescapable attendant degradation). The VHS dupe was then reviewed and logged on a computerized video edit log spreadsheet, identifying every start and stop location on the tape (in hours, minutes, and seconds), as well as a brief scene description, and subjective quality rating of recorded activity and technical recording aspects. Such documents were then able to be searched for the location on the master tape of any descriptive attribute so cataloged. All ARPP 8 mm videotapes have been subsequently digitized to a harddrive, before final archiving to Digital Video Disc.

Figure 1.13 Chief scientist Dr. Webb (holding leather hat) narrates live-action underwater video to open house audience on riverbank adjacent to an Aucilla River site. Photo credit – Tim Barber.

1.11.4 Framegrabbing Still Images

Computer hardware and software capable of capturing still images from videotape has been employed to further expand ARPP's underwater still archive. A search of the scene descriptions listed in the video edit log spreadsheet is first conducted to identify the location(s) of any subject to be framegrabbed. The resulting target scene(s) are next reviewed on the digital video disc until the best scene location on the disc is selected. This same location is then cued up on the master 8 mm videotape for final high quality playback and framegrabbing utilizing digital technology. The quality of these still images (Fig. 1.14) was suitable for publications, as well as slides for presentations.

1.11.5 Mosaicking Large Areas

Recording underwater excavation surfaces in well-lighted detail dictated that the lens of the videocamera housing be not more than 1-m distant from the subject surface. Even with the 1000 W underwater video lighting described above, the camera's effective field of view at this distance was limited to a square area 50 cm on a side. Detailed documentation of even a modestly sized one square meter excavation unit would therefore require mosaicking four separate images together. A truncated pyramid frame stand was constructed of 1-in. diameter PVC pipe to hold the videocamera motionless over each of the four successively videotaped quadrants of the one square meter pit floor or wall, maintaining the constant 1-m distance from the object surfaces.

The base of the frame stand was a square measuring 50 cm on a side (inside dimensions), connected at the corners by 90° pipe elbows. The truncated top of the pyramidal stand was a square whose inside dimension equaled the outside diameter of the

Figure 1.14 A curious freshwater Coastal Shiner (*Notropis petersoni*) interlopes between the camera and a Kirk corner-notched projectile point lying in situ on a 10,000 RCYBP paleosol submerged in 3 m of water at the Page-Ladson Site. Photo credit – Original image was captured on 8 mm videotape by Joseph M. Latvis. Framegrabbing by William O. Gifford.

underwater housing lens. These two PVC pipe squares were separated vertically the requisite 1-m distance by four PVC pipe legs inserted into pipe Tees located at the centerline of each side of each square. The base of the camera housing was mounted to a platform that projected vertically upward from one side of the upper square, thereby centering the lens of the housing in the opening formed by the upper square. The 50-cm sides of the gray PVC base square were painted with alternating 10-cm bands of flat black paint. In order to deliver more evenly distributed lighting and constant light angles in each panel, the hand-held 1000-W light was replaced with four 200-W battery powered video lights mounted on each of the vertical frame stand legs. These four lights were directed downward, illuminating the 50-cm square base surface evenly and at constant angles.

This mosaicking assembly was deployed by setting it up in one quadrant of the excavation unit. The menu board displaying all relevant context information was inserted immediately outside the base of the frame, but still within the lateral field of view of the videocamera. A diver positioned the suction dredge pickup hose (normally used for excavation) immediately beyond the videocamera's field of view of the quadrant surface being mosaicked. The dredge served to improve visibility between the videocamera and the object surface by setting up currents that drew clear water down from higher up in the water column. The videographer would focus the camera, start recording, and back away from the entire assembly (to eliminate any camera motion). After approximately 15 s of recording, the videographer stopped recording. Thirty frames per second of that quadrant were then available for subsequent frame-grabbing. The assembly was then relocated to record successive quadrants, each time updating the locational information displayed on the accompanying menu board, until images of the entire unit had been captured.

Framegrabbed quadrant images were then available for cropping and assembly into a well-lighted close up mosaic of expansive excavations.

1.11.6 Applications of ARPP Underwater Video

Underwater video footage recorded by the ARPP has been incorporated into many documentary, educational, and public outreach applications:

Broadcast video productions

- FLMNH's "Expedition Florida" series
- Florida Anthropological Society's "Shadows and Reflections on the Past"
- University of Florida's WUFT "Archie Carr: A Naturalist in Florida"
- Tallahassee's CBS affiliate WCTV Channel 6 News

Museum display video productions

- FLMNH's "Hall of Fossils"
- FLMNH's "Hall of South Florida People and Environments"

Framegrabbed video image publications

- FLMNH's *First Floridians and Last Mastodons*
- Center for the Study of the First Americans newsletter *Mammoth Trumpet* Vol. 12 No. 2
- FLMNH's ARPP educational poster
- ARPP's *Aucilla River Times* newsmagazine front cover (Vol. XI No. 1, 1998)

1.12 In Conclusion

ARPP director Dr. S. David Webb long ago charged staff and volunteers with the pursuit of three simple project objectives, dubbed "the 3 S's" (Safety, Science, and Smelling the roses). The foregoing field methods made significant contributions to accomplishing these important goals. Sixteen years of diving operations without a single dive-related (decompression illness or arterial gas embolism) injury speak for the project's safety record. The project was also featured twice (1993 and 1996) by the American Academy of Underwater Sciences in its "Spotlight on Research Diving" series. The scientific analysis presented in succeeding chapters of this volume is testimony to the quality of the field work accomplished utilizing these methods. And within the context of safety-conscious, scientifically rigorous operations, the field crew was indeed able to appreciate and enjoy the pristine environment they were privileged to inhabit and explore each field season.

SECTION A: GEOLOGY

> "In Xanadu did Kubla Khan
> A stately pleasure dome decree:
> Where Alph, the sacred river, ran
> Through caverns measureless to man
> Down to a sunless sea."
>
> **Samuel Taylor Coleridge**.

This section provides the essential geologic framework for this book. These four chapters center on the Page-Ladson site complex, yet they also readily scale up to regional and global perspectives. Such grand extensions from one small site are warranted by two critical facts, both clearly documented in this section. First, the sequence of sediments at Page-Ladson were nearly continuously deposited during an interval of some 10,000 years. And secondly that sequence is well dated by a robust set of carbon dates, permitting century–scale correlations with the absolute chronology of the Quaternary Period. This stratigraphic and chronologic framework permits preliminary correlations of local events with broader climatic, evolutionary, and cultural changes elsewhere.

At present the Aucilla River flows centrally through the Woodville Karst Plain in northwestern corner of the Florida Peninsula. This expanse of about a thousand square kilometers of swampy lowlands is underlain by limestone formations of Eocene and Oligocene age. During the last glacial interval, when sediments accumulated in the Page-Ladson site complex, that same karst plain was approximately three times larger than its present size and extended far into what is now the Gulf of Mexico. The sea lay about 150 km south of the present coastline, and the PaleoAucilla River, extended, partly surface and partly subterranean, across that broad apron of exposed lowland limestone. The increased hydrologic head that flowed seaward through the region accelerated the rate of subterranean dissolution, producing some of the largest underground cavern systems in the world, well exemplified by Wakulla Springs. As continental ice sheets retreated, the seas rose and coastal sinkholes such as Page-Ladson backfilled with fine-grained sediments.

The description of sediments from the Page-Ladson site complex is fully detailed as the essential framework for all other inferences and interpretations. The next chapter indicates the methods by which carbon dates were obtained, and considers their strengths and weaknesses. Finally, local depositional episodes, with their associated carbon dates, are correlated with the full range of climatic events in the Gulf of Mexico, the North Atlantic and the world ocean.

These geologic chapters feature the last phases of the Ice Ages. The Quaternary Period spans about 1.6 million years, representing the most recent and most variable chapter in earth history. Hominids had already appeared in Africa where they interacted with Elephantidae, Equidae, and other animal groups in savanna settings. The final deglacial hemicycle embodies the most fully studied set of glacial episodes. And the Page-Ladson evidence falls within that final series of events. The first Floridians appear and interact especially with American Mastodons. These records fall between 14,000 and 15,000 calendar years before present. The last appearances of mastodons, horses, camelids, and other extinct megafauna at this site are recorded about 13,000 calendar years before present. The basis for these and subsequent events is framed in these geologic chapters.

Chapter 2

Geography and Geomorphology of the Aucilla River Region

JOSEPH F. DONOGHUE
Department of Geological Sciences, Florida State University, Tallahassee, FL 32306, USA.

2.1 Regional Geology

The modern landscape of north Florida lies above a thick sequence of carbonate-rich rocks. These limestones and dolomites were deposited on the floor of the ocean from mid-Mesozoic to Miocene time, a period of approximately 150 million years. During that interval plate tectonic movement slowly carried the Florida platform northward from the equator to sub-tropical latitudes. (Chen, 1965; Corso *et al*., 1989; Galloway *et al*., 1991; Scott, 1992). In the northern half of the Florida platform these ancient carbonates reach a thickness of approximately 1 km (Wicker and Smith, 1978). During most of this long interval of geologic time sea level stood higher than present – at times considerably higher. The bulk of the carbonates therefore accumulated on the Florida platform in warm and relatively shallow tropical seas (Haq *et al*., 1988).

Lying unconformably above these marine carbonate sedimentary rocks is another series of sediments of quite different character and origin. These sediments are non-carbonate clastics – sand, mud and organic debris – representing an environmental transition from sub-tropical seas to estuaries, coastal wetlands, rivers and lakes. The thickness of these clastic sediments in north Florida varies from 0 to 60 m. Their thickness in the lower Aucilla and Wacissa River region ranges from 0 to 15 m (Yon, 1966; Rupert and Spencer, 1988). Rupert and Arthur (1997) depict the stratigraphic

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 31–48

relationships between the carbonate bedrock and the overlying clastic sediments which rest beneath the Aucilla River watershed in the Florida Panhandle.

2.2 Geomorphology

Most of the Aucilla River watershed lies within the Gulf Coastal Lowlands geomorphologic province (Yon, 1966; Rupert and Arthur, 1997). The Gulf Coastal Lowlands extend from the western portion of the Florida Panhandle to southern Florida, forming a coastal fringe that averages 40 km in width (White, 1970). In the Aucilla River region, the Gulf Coastal Lowlands are bounded on the north by the Tallahassee Hills – part of the Northern Highlands province – and on the south by the present-day coast of the Gulf of Mexico. The northern boundary of the province is known as the Cody Scarp, an east–west trending relict marine escarpment with as much as 16 m of relief in the Aucilla region (Puri and Vernon, 1964). The lowlands south of the Cody Scarp are characterized by low elevations – generally less than 15 m above sea level. As a consequence, the region has undergone repeated erosion and deposition in response to Quaternary sea-level fluctuations, as described later in this chapter. The result has left a thin cover of sandy sediments above the limestone bedrock (Puri and Vernon, 1964; Hendry and Sproul, 1966).

2.3 Hydrology

The carbonate bedrock of the region serves as an aquifer for much of north Florida's abundant groundwater reserves, a consequence of extensive dissolution and the resulting high degree of secondary porosity. Rainfall in the region is high, averaging 165 cm/year. Most of the precipitation percolates through the thin cover sediments and passes into aquifers in the carbonate sequence. The carbonate rocks form part of the massive Floridan Aquifer system, carrying freshwater south to the Gulf of Mexico (Rupert, 1993).

Springs are characteristic of limestone dissolution regions, or *karst*, which are described in the following section. The state of Florida possesses 27 first-magnitude springs, defined as those which discharge more than 100 cubic feet per second (cfs), or 245 million liters per day. Due to the high annual rainfall, the Aucilla River region includes seven of these large springs. This number includes the spring that gives birth to the Wacissa River, the chief tributary of the Aucilla. In addition, the largest spring in Florida, Spring Creek Springs – discharging 2003 cfs, or 490 billion liters per day – releases a torrent of groundwater at the Wakulla County coastline just 30 km west of the mouth of the Aucilla River (Rosenau *et al.*, 1977; Lane, 1986). By comparison, the 20 largest rivers of Florida combined produce a discharge of 70,123 cfs (Fernald and Purdum, 1992). Springs are therefore a significant component of freshwater flow to the ocean in Florida and particularly in the Aucilla River region.

Another important component of the regional groundwater system is discharge to the Gulf of Mexico via seepage. Groundwater seepage through the floor of the continental shelf has not been well studied, but has proven to be a significant constituent of groundwater flow to the ocean in the cases where it has been reliably measured. For example, seepage through the shelf floor has been found to account for approximately 30% of all freshwater input to the ocean in South Carolina (Moore, 1996). In Great South Bay, New York, Bokuniewicz (1980) found that 15–20% of the total freshwater discharge occurred via seepage. It is not surprising therefore that similar results were found in tracer studies of seepage rates through the inner shelf floor off the northwest Florida coast (Cable *et al.*, 1996, 1997).

The unusually large quantities of water available at the earth's surface in north Florida also result in extensive wetland development. This includes a nearly continuous coastal marsh system bordering Apalachee Bay, including the marshes found near the modern Aucilla River mouth. The northeastern coast of the Gulf of Mexico – which accounts for 17% of Florida's total coastline – includes 41% of the state's tidal marshes (Montague and Odum, 1997). Coastal marshes act as important nurseries for crustaceans, shellfish and finfish. They therefore have exerted strong influence upon the siting of human settlements, both in the modern and the prehistoric era.

The hydrologic factors described above – some of which are peculiar to the region – have combined to produce a karst-dominated Aucilla River landscape which is unique in the southeastern United States. The first factor is the unusually large volume of water that is transported via the groundwater system, a direct result of the high regional precipitation and recharge rates. This condition brings large volumes of meteoric water – which is undersaturated with carbonate minerals – in contact with limestone, enhancing dissolution of the limestone (Thrailkill, 1968). A second factor is sea-level change, the history of which is also described later in this chapter. The wide swings of sea level in the Aucilla River region during Quaternary time have driven the water table up and down repeatedly, likewise enhancing karst development. The third factor is the nearness of the Gulf of Mexico coast and the consequent mixing of salt and freshwater within the coastal aquifer via springs and seepage. As will be discussed below, this condition further intensifies karstification of the limestone within the Floridan Aquifer. The final factor is the abundance of wetlands and marshes in the region. Such environments are sources of carbon dioxide to the groundwater system, a condition which also encourages karst development. These factors will be discussed in detail in the next section.

2.4 Karst Processes

Close proximity of carbonate-rich rocks to the land surface combined with abundant and slightly acidic groundwater creates ideal conditions for dissolution of the carbonates. Groundwater removes the calcium carbonate in solution, leaving voids in the once-solid rocks. Growth of the voids creates weakness in the near-surface rocks and often results in slumping and collapse of the surficial sediments. Such conditions create characteristic surface features such as sinkholes, springs, disappearing streams, natural bridges, swales and hummocky terrain (Lane, 1986). Over time, the landscape becomes dominated by such features and the drainage becomes controlled by them. A landscape of this type is termed *karst*, after similar geomorphologic features found in the Dinaric Alps of northwestern Yugoslavia (Demek *et al.*, 1984).

As karstification intensifies, sinkholes replace part or all of the pre-existing fluvial drainage system. In the extreme case, virtually all of the flow of water through the landscape is controlled by karst. Such a condition is known as a karst plain (Thornbury, 1964). The Aucilla River watershed is part of one such landscape, the Woodville Karst Plain.

Karst landscape is characterized by underground drainage, combining sinkholes, springs and solution passages. Sinkholes can be classified into four types: solutional, collapse, subsidence and buried, or filled, sinkholes (Fig. 2.1). *Solution sinkholes* result from surface lowering in a karst landscape, where the limestone is relatively close to the surface. *Collapse sinkholes* are formed in similar terrain, and involve collapse of overburden into underground caves. *Subsidence sinkholes* are the most common type resulting from subsidence of cover soil or rock into limestone cavities. They occur typically in cases where the cover is less than 20 m thick. The subsidence rate can be either rapid or slow, depending on whether the overlying sediments are non-cohesive (sand-rich, creating slow subsidence), or cohesive (clay-rich, creating rapid subsidence) (Sinclair *et al.*, 1985). *Buried sinkholes* result from the infilling of normal subaerial sinkholes by sediment (Culshaw and Waltham, 1987). In the lower Aucilla River region solution sinkholes are the most common type (Sinclair and Stewart, 1985).

The development of karst is enhanced by mixing of fresh and salt water, which occurs in coastal regions. In coastal limestone aquifers, the most important control

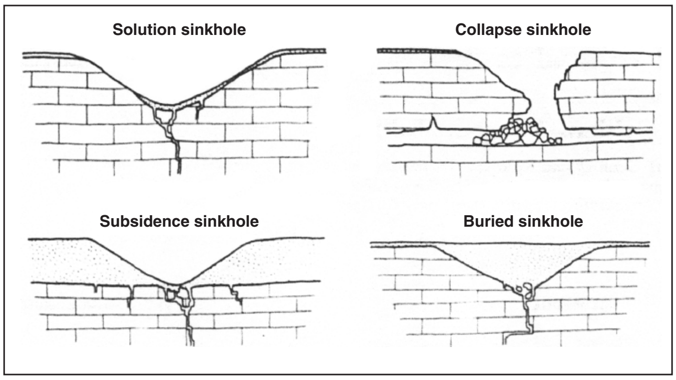


Figure 2.1 Types and development of sinkholes (after Culshaw and Waltham, 1987).

on karst formation is the presence of a mixing zone of fresh groundwater and brackish seawater (Hanshaw and Back, 1980; Back *et al.*, 1986). Depending on the relative concentrations of fresh and salt water, the mixing zone typically becomes undersaturated with respect to calcite and aragonite. Generally, the greater the quantity of discharging fresh groundwater, the greater the solubility of limestone (Dreybrodt, 1988; Panno and Bourcier, 1990). Regions with high annual precipitation, such as the Yucatan peninsula (up to 1500 mm/year) and north Florida (1650 mm/year), consequently have high rates of discharge of fresh groundwater to the shelf. The groundwater mixing zones which develop near the coast – including the entire lower Aucilla River watershed – are therefore ideal locations for karst development (Back *et al.*, 1986).

A related factor in karst development is the presence of marshes and wetlands. Such environments supply carbon dioxide to the groundwater system. The dissolved carbon dioxide increases the ability of groundwater to dissolve limestone (Back *et al.*, 1986). As described above, the northeastern Gulf coast of Florida includes a high concentration of wetlands and marshes. These environments supply substantial carbon in various forms, including dissolved carbon dioxide. When combined with the high groundwater transport rates, the result is intensified dissolution of the limestone bedrock.

2.5 Karst Geomorphology in North Florida

More than any other geologic factor, the underlying carbonate rocks define the character of the landscape of north Florida. Large parts of north Florida and adjacent regions of Georgia and Alabama present a classic example of karst terrain (Johnston, 1993). The most intensely karstified areas of Florida are the west-central portion of the peninsula and the eastern part of the panhandle (Sinclair and Stewart, 1985; Beck, 1986; Lane, 1986). In the middle of this region lies the Woodville Karst Plain of which the Aucilla River watershed forms a part.

The Woodville Karst Plain, which includes portions of Leon, Wakulla and Jefferson counties of north Florida, is a broad topographic lowland comprising an essentially flat veneer of unconsolidated sand overlying karstic bedrock (Hendry and Sproul, 1966). Its areal extent is approximately 1000 km^2, lying entirely within the Gulf Coastal Lowlands province, south of the Cody Scarp, as described above (Yon, 1966; Lane, 1986).

The Aucilla River crosses the Cody Scarp approximately 8 km south of the town of Lamont. The course of the Wacissa River lies entirely within the Gulf Coastal Lowlands. Thus the lower 30 km of the combined Wacissa–Aucilla watershed lies within the Woodville Karst Plain. As a consequence, both the hydrology and the geomorphology of the river system have been heavily influenced by the karstic nature of the underlying limestone. In the lower Aucilla River valley karstification has partially replaced the original fluvial drainage system with an underground drainage system employing sinkholes and springs, or rises, to connect isolated portions of the fluvial system. At the same time, the land surface has been rapidly lowered as a result of the extensive dissolution (Yon, 1966).

The magnitude of the dissolution of the near-surface carbonate rocks of north Florida can be estimated by measuring the amount of dissolved calcium being carried each year by the rivers and springs of the Florida platform. A conservative estimate of the mass of dissolved limestone removed annually from the northern part of the platform is 1.2 million tons (Rosenau and Faulkner, 1975; Rosenau *et al.*, 1977; Slack and Rosenau, 1979; Opdyke *et al.*, 1984). To put this figure in perspective, the largest river in Florida, the Apalachicola, drains 51,000 km^2 of the Gulf Coastal Plain. Bisecting the Florida Panhandle, the Apalachicola transports sediments weathered from the Southern Appalachians and Gulf Coastal Plain. The mass of suspended sediment that the river carries annually to the Gulf of Mexico is comparable to the mass removed by dissolution from the northern Florida platform, approximately 1 million tons per year (Donoghue, 1992, 1993).

Dissolution of the limestone substrate at this rate removes mass from the landscape rapidly, and strongly influences landform development. Various investigators have measured dissolved solids in north Florida springs as a means of estimating the apparent surface lowering rate. Estimates generally fall within the range 1–6 cm/1000 year (Sellards, 1909; Brooks, 1967; Fennell, 1969; Opdyke *et al.*, 1984; Lane, 1986). More recent studies indicate that the previous estimates of the frequency and intensity of karst processes in Florida are probably conservative, implying that the apparent surface lowering rate may be even higher (Wilson *et al.*, 1987; Wilson and Beck, 1992). It is clear that karst activity has had a profound influence on the Aucilla River landscape, especially during late Quaternary time.

The extensive dissolution of the limestone bedrock is evidenced also by the fact that the Woodville Karst plain contains some of the longest underwater cave passageways in the world. Continuous passageway of more than 6 km has been mapped by cave divers, at subsurface depths which in some cases have exceeded 60 m (Rupert, 1993).

2.6 Quaternary Sea-level Change

Dramatic and relatively short-period climatic fluctuations have been the hallmark of the Quaternary period, the last approximately 1.6 million years of geologic time. During the latter part of the preceding Tertiary period, a long period of global cooling began, ultimately leading to cycles of growth and decay of continental icecaps. It is commonly held that the deterioration of global climate – which continues to the present day – is a response to long-term astronomic cycles (Mesolella *et al.*, 1969; Hays *et al.*, 1976; Imbrie and Imbrie, 1979). Oxygen isotope ($^{18}O/^{16}O$) records from the carbonate shells of microfossils found in deep-sea sediment cores serve as a proxy record of continental ice sheet volume changes during the glacial eras. According to oxygen isotope records, glacial ice volumes increased and ocean bottom water temperature decreased beginning about 2.7 million years ago. This marked the beginning of the period of climate deterioration that led directly into the Pleistocene Ice Ages. Glacial and interglacial stages have alternated in dozens of climate cycles throughout the intervening time. For most of that time global ice sheet volume has been considerably greater and temperatures cooler than at present. According to the oxygen isotope record, the present interglacial period, the Holocene – the last approximately 10,000 years – is quite anomalous in Quaternary history. Only a few of the earlier interglacials have been as warm (Raymo, 1992).

Drastic sea-level fluctuations have accompanied these changes in continental ice volume. The most recent full-glacial cycle began approximately 135,000 years ago (Baranola *et al.*, 1987), marking what is known as Marine Isotope Stage 5e. Global sea level and temperatures at that time were perhaps slightly higher than present levels. Recent evidence from the West Indies indicates that Stage 5e sea levels stood 2.5–6 m above present sea level (Vezina *et al.*, 1999). During the subsequent glacial period, global sea level and temperatures fluctuated but generally fell, reaching a minimum approximately 18,000 radiocarbon years ago. At that time of maximum extent of the ice sheets, the surface of the world's oceans stood about 120 m below present-day sea level (Fairbanks, 1989, 1990). The glaciers began to retreat and sea level underwent a rapid rise during the period from 18,000 to 11,000 radiocarbon years ago, at an average rate of approximately 9 mm/year. The rise of sea level slowed briefly during a brief cooling period known as the Younger Dryas from 11,000 to 10,000 radiocarbon years ago (Flower and Kennett, 1990). The more rapid rate of rise then recommenced until approximately 6,000–7,000 radiocarbon years ago. Over the past 7,000 radiocarbon years global sea level has risen considerably more slowly (Fig. 2.2) from about –15 m to the present level, averaging 2 mm/year (Fairbanks, 1989, 1990).

The effect of the slowdown in the rate of postglacial sea-level rise has been to enable the extensive development of coastal environments, most notably river-mouth environments such as deltas, estuaries, coastal wetlands and barrier islands. Such environments are conducive to human occupation due to their proximity to both riverine and marine food resources. Rapid sea-level rise – such as that which occurred during the early part of the deglaciation – discourages development of such environments due to the swift landward retreat of the shoreline. During the period 18,000–7,000 radiocarbon years ago, a shoreline on a continental shelf with gradient 1:1,000 would have been retreating landward at a rate of 9 m/year. The slowdown of sea-level rise beginning about 7,000 radiocarbon years ago brought considerably slower rates of shoreline retreat and enabled coastal environments to develop in greater abundance. The rapid development of coastal environments and the proliferation of their associated human populations on a global basis, beginning during the period 8,500–6,500 radiocarbon years ago, have been documented by Stanley and Warne (1994). The Aucilla River cultural sites and their submerged analogs on the inner continental shelf are in part a product of this global phenomenon.

2.7 Sea-level Change in the Northeastern Gulf of Mexico and Northwest Florida

The glacially driven fluctuations in global sea level during the past 2.7 million years have had their greatest effect on the inner margins of the continents. The lower parts of the present-day coastal plains and inner continental shelf have witnessed dozens of excursions of the shoreline, as sea level has responded to the waxing and waning of the continental glaciers.

Figure 2.2 includes three late Quaternary sea-level curves from the northern Gulf of Mexico, as defined by carbon-dated samples of peat and shell collected from the Louisiana-Texas shelf (Curray, 1960; Nelson and Bray, 1970; Frazier, 1974). It can be observed that, in general, the Gulf of Mexico sea-level curves are similar in trend to the "global" curve from Barbados (Fairbanks, 1989, 1990), although there is some evidence that sea level may have risen episodically in the northern Gulf of Mexico during the latest Quaternary deglaciation (Nelson and Bray, 1970; Frazier, 1974).

Due to the unusually wide and low-gradient (less than 1:2000) shelf, few places in the world have been as profoundly affected by these sea-level excursions as the Apalachee Bay region of the Gulf of Mexico. Figure 2.3 shows the bathymetry of the inner continental shelf of northwest Florida. For most locations on the western coast of the Florida peninsula and the eastern panhandle, the shoreline during the last glacial maximum – 18,000 radiocarbon years ago – stood approximately 150–200 km offshore from the present coastline. During the period of rapid sea-level rise 18,000–7,000 radiocarbon years ago the shoreline at the Aucilla River mouth was probably retreating northward across the continental shelf at a rate of approximately 18 m/year.

Just as with global sea-level records, sea level on the west coast of Florida slowed in its rate of rise during the past 7000 years. Sea-level data from the southwest Florida indicate that Florida sea level slowed even further over the past 4000 years (Scholl *et al*., 1969). On parts of the west Florida coast where productivity is high or sediment influx is great, this slowdown has enabled some coastal environments to begin to prograde seaward during that time (Evans *et al*., 1985; Hine *et al*., 1988; Parkinson, 1989; Stapor *et al.*, 1991).

2.8 The Paleo-Aucilla River

On the northwest Florida shelf, radiocarbon-dated samples generally fall near the northwestern Gulf of Mexico sea-level curves. Locations of some of these samples, including a few from Apalachee Bay, are shown in Fig. 2.2 (see Faught and Donoghue, 1997). During the time of the earliest human occupation of Florida, approximately 10,000–11,000 radiocarbon years ago, the position of the Apalachee Bay shoreline can be estimated from the sea-level curves. The earliest Floridians would have found the coast at approximately the location of the modern 40–60 m isobath. Off the present Aucilla River mouth the paleo-coastline would have been approximately 150 km south

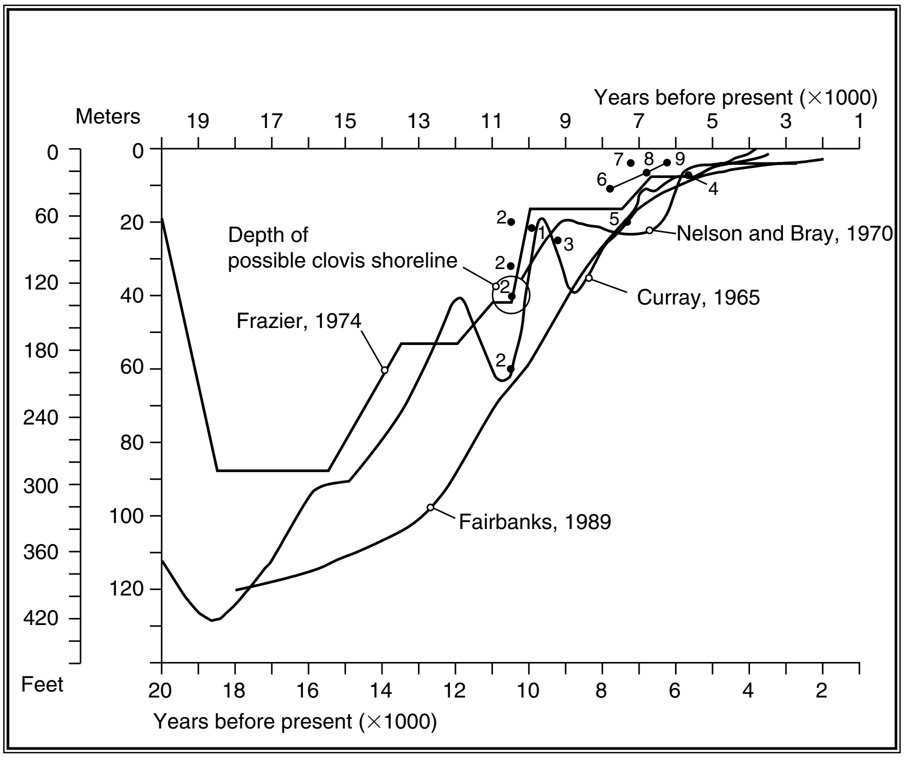


Figure 2.2 Late Quaternary sea-level curves. Depth in meters below present mean sea level is shown at left. Chronology is in radiocarbon years before present (B.P.). “Global” sea-level curve (Fairbanks, 1989) is based on radiocarbon-dated shallow water corals from Barbados. Three sea-level curves for the northwestern Gulf of Mexico (Frazier, 1974; Curray, 1965; Nelson and Bray, 1970) are based on radiocarbon-dated peat and shell from the continental shelf off Texas and Louisiana. Numbered points refer to individual dated sea-level indicators from the Florida shelf: 1 = Apalachicola River area, Florida (Schnable and Goodell, 1968); 3 = Santa Rosa Island, Florida (Otvos, 1991); 6 = mean of two dates (wood and shell) from Ray Hole Spring archaeological site in Apalachee Bay, Florida (Anuskiewicz, 1988); 7–9 = dated wood and shell materials from submerged cultural sites in Apalachee Bay (adapted from Faught and Donoghue, 1997).

of the present shoreline. The earliest occupants of the cultural sites on the lower Aucilla River, therefore, would have been many days’ walking distance from the marine resources of the Gulf of Mexico.

There is strong evidence for early human occupation of the Apalachee Bay inner continental shelf during the past 11,000 years. A buried paleo-river drainage system has been discovered there via sub-bottom seismic profiling and vibrocoring (Faught, 1996; Faught and Donoghue, 1997). The seismic data indicate that the

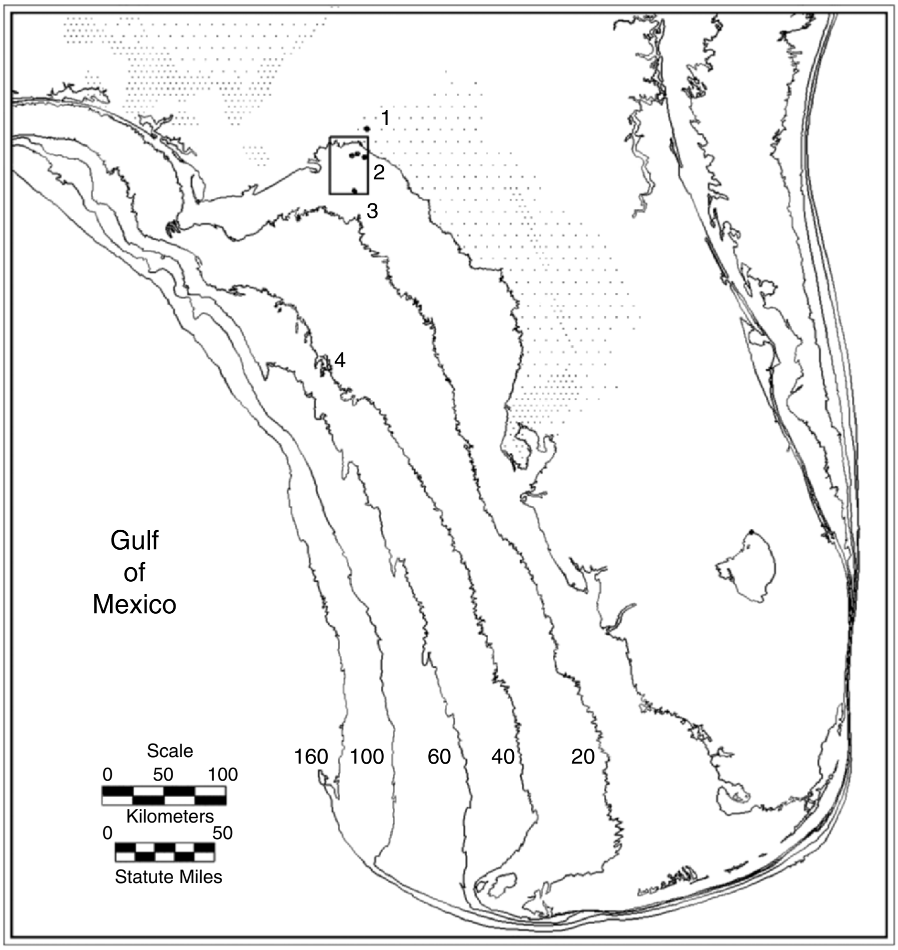


Figure 2.3 The Gulf of Mexico coast of Florida, showing the bathymetry of the continental shelf, in meters. Location of the west Florida shoreline at the time of the glacial maximum, approximately 18,000 years ago, lies at a depth of 120 m. Location of Page-Ladson site is indicated by "1". Location of Ray Hole Spring site, as described in text, is shown by "2". Rectangular outline in upper center, labeled "3" shows location of Fig. 2.4. Florida Middle Ground reef is indicated by "4". Paleoindian findspots (from Dunbar, 1991) are shown by dots (Faught and Donoghue, 1997).

Aucilla–Wacissa system extended offshore to combine with the other coastal plain rivers draining into Apalachee Bay. The smaller systems at that time appear to have been tributaries of the Ochlockonee River, the largest river in the Apalachee Bay region. Figure 2.4 presents a reconstruction of the paleodrainage system off the Aucilla River mouth at that time, based on the sub-bottom seismic data. The sub-bottom records also reveal that the paleo-river channel width was generally larger than

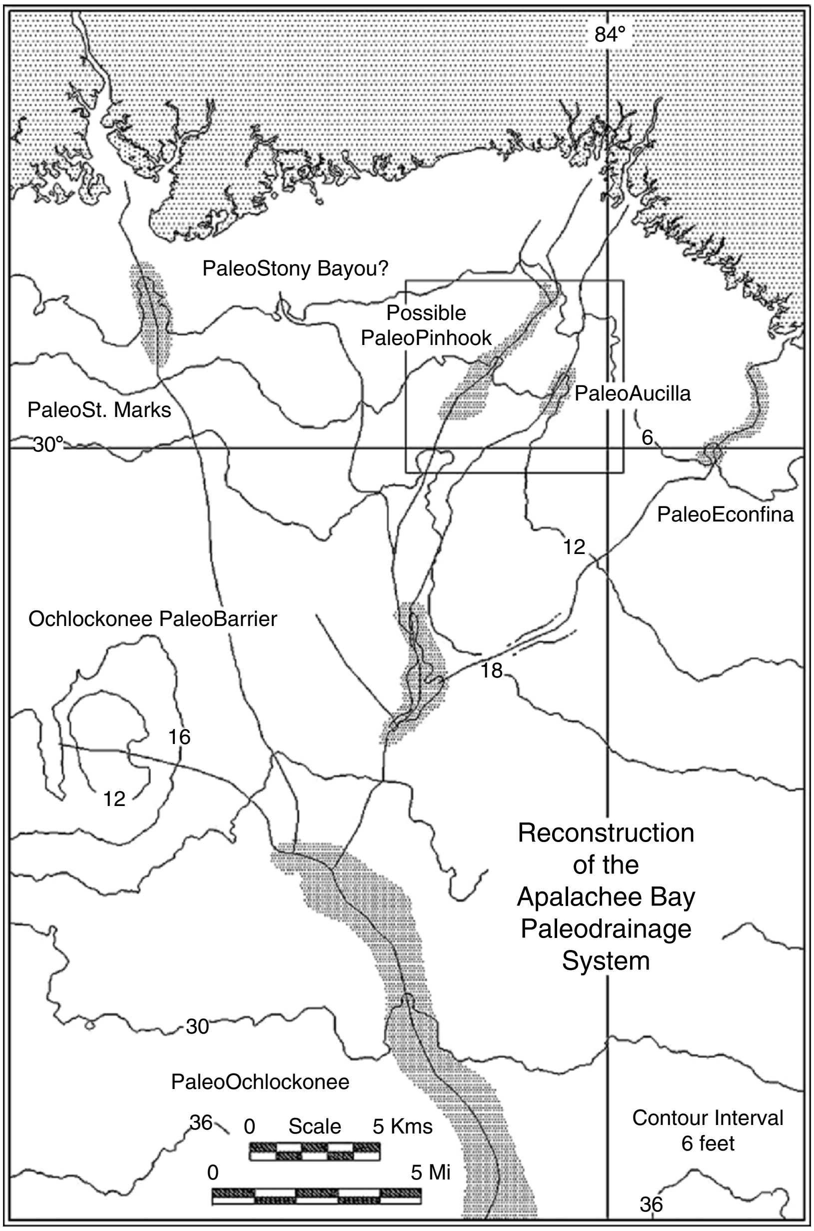


Figure 2.4 Paleodrainage system of the Aucilla River, Apalachee Bay and northeastern Gulf of Mexico – during the latter stages of the last deglaciation, approximately 10,000 years ago. Location of figure is indicated by rectangular outline in Fig. 2.3. Reconstruction based on sub-bottom seismic data and bathymetry (Faught and Donoghue, 1997). Patterned areas are paleochannel segments that were well defined by seismic data. Outlined area in the top center portion of the figure encloses cultural sites described in text. Contour interval 6 feet.

at present and that the drainage was in many places dominated by karst (Faught and Donoghue, 1997; Chen *et al.*, 2000). The paleo-Aucilla River of 11,000 years ago was probably a larger river and was tributary to the paleo-Ochlockonee as part of a more extensive drainage system which terminated at mid-shelf. It was, nonetheless, similar to the present-day Aucilla in that the fluvial hydrology was strongly influenced by karst.

A comparable history has been recorded for Florida's largest river, the Apalachicola, which enters the northeastern Gulf 100 km to the west of the Aucilla. Sub-bottom seismic records from the inner shelf off the modern Apalachicola River mouth reveal a drainage system that existed during the deglaciation, coeval with the paleo-Ochlockonee/paleo-Aucilla system. The paleo-Apalachicola was significantly larger than the modern river system, and incorporated many karst features (Donoghue, 1993).

The enlargement of the paleo-Aucilla river system during the deglaciation is reflected even further west in the Mississippi River paleodrainage system. Various lines of evidence indicate that the Mississippi was a considerably larger river during parts of the deglaciation, with discharge perhaps as much as six times modern levels. Paleo-Mississippi discharge peaks have been recorded at 13,000 and again at 10,000 years B.P., based on oxygen isotope and sediment studies (Emiliani *et al.*, 1978; Leventer *et al.*, 1982; Perlmutter, 1985). These large variations in river magnitude – seen on a small scale in the Aucilla and on a large scale in the Apalachicola and Mississippi – are a reflection of the fact that the retreat of the ice caps did not occur without interruptions. The interruptions – times of stagnation or even minor advance of the ice front – were reflected not only in river discharge but also in climate and sea level.

During the deglaciation, just prior to the beginning of the Holocene, when humans first appeared in Florida, the fluvio-karst features of the Apalachee Bay inner shelf would have been attractive to hunter-gatherers. Some of these now-inundated features have been investigated and found to possess evidence of human occupation. Outlined in upper center of Fig. 2.4 is the location of some of the early human sites which have been investigated on the continental shelf south of the modern Aucilla River mouth. Included among these are the J&J Hunt Site 6 km offshore from the modern river mouth, in 4 m of water, an Early Archaic (9,000–10,000 years old) sinkhole site along the course of the paleo-Aucilla River; and the Fitch Site, a probable chert quarry 10 km offshore from the river mouth, in 5 m of water, a possibly Paleoindian or Early Archaic (9,000–11,000 years old) site. Both of these sites were probably upland sites, somewhat removed from the Gulf of Mexico coast during the time of occupation, but subsequently drowned by postglacial sea-level rise (Faught, 1996; Faught and Donoghue, 1997). Further offshore lies the Ray Hole Spring site, where lithic debitage has been unearthed in a sinkhole at 10.6 m water depth (Anuskiewicz, 1988; Donoghue *et al.*, 1997; Faught and Donoghue, 1997).

Interestingly, in the now-drowned lower reaches of the paleo-Aucilla River, there is evidence that the development of karst features during times of lowered sea level was even more intense than at present. As described above, the modern Woodville

Karst Plain covers an area of approximately 1000 km^2. Sub-bottom acoustic surveys, however, indicate that the offshore extension of the karst plain, which lies primarily in Apalachee Bay (Fig. 2.4), is far more extensive. The submerged offshore equivalent of the Woodville Karst Plain covers approximately 3000 km^2. It is for the most part buried under a meter or more of marine sediment (Chen *et al*., in press).

The chief factors in the development of this major geomorphologic feature have been sea level and climate change. Sea-level fall during glacial episodes exposed the present inner continental shelf and caused the coastal groundwater mixing zone to migrate seaward. Additionally, during certain parts of the glacial stages precipitation levels were significantly higher. The result would have been greater amounts of freshwater moving through the groundwater system and discharging at the coast, mixing with salt water and dissolving the limestone bedrock. The fact that these extensive karst features are now buried is a result of the recent history of sea level. Late Pleistocene and Holocene sea levels rose rapidly from 18,000 until about 7,000 radiocarbon years, but much more gradually thereafter, as described above. For the past approximately 7,000 years, therefore, slow sea-level rise has been depositing sediment on the continental shelf, filling and covering the former fluvial and karst landforms.

2.9 Effect of Hydrogeologic Changes on Human Occupation of North Florida

As discussed above, global climate began to deteriorate approximately 2.7 million years ago, in response to astronomic cycles. The climate deterioration led to alternating periods of growth and decay of continental ice sheets, which in turn led to cycles of sea-level fall and rise. The early stages of the present interglacial warm period, the Holocene, coincided with the first arrival of humans in Florida, approximately 10,000–11,000 years ago.

The specific effects that global climate change had on human settlement of north Florida during the time of earliest occupation are discussed by Dunbar in Chapter 20. In general, as might be assumed, climate became more favorable for human settlement between the period of maximum glaciation – approximately 18,000 years ago – and 11,000 years ago. At the latitude of the Aucilla River −30° north – climate became warmer and generally wetter during that time. A recent global climate modeling study indicates that terrestrial temperatures at this latitude rose approximately 3°C during that interval, while annual precipitation levels rose by about 20%. Additional changes of a similar magnitude occurred during the interval from 11,000 years ago to the present (Kutzbach *et al*., 1998). The net result was to make the north Florida environment more favorable for successful human habitation and resource exploitation.

The deglacial climate change coincided with the longer-term geologic and hydrologic changes affecting the north Florida landscape. The rapidly rising sea level of the late Quaternary Gulf of Mexico flooded the lower reaches of the paleo-Aucilla River valley, creating estuaries and wetlands. The slowdown in the rate of sea-level rise, which began with the Younger Dryas (11,000–10,000 years ago) and decelerated significantly after 7,000 years ago, enabled the newly created coastal ecosystems to develop and proliferate.

The various hydrologic factors that enhanced karst processes during the deglaciation (increased precipitation, fluctuation of water tables in response to sea-level change, lateral migration of the freshwater–saltwater mixing zone and the contribution of dissolved organics to the groundwater by wetlands) all served indirectly to encourage human occupation of the north Florida landscape at that time and more or less continuously since then. Karst features, such as the Page-Ladson site and much of the lower Aucilla River drainage, have served as a focus for animal life and vegetation, as well as a source of chert. All of these resources were valued by early humans. It has been noted (Dunbar and Waller, 1983; Faught, 1996) that most of the Paleoindian sites in Florida have been discovered in karst settings, as illustrated in Fig. 2.3.

The unique combination of events – climatic, geologic, geomorphologic and hydrologic – that led to the development of the Aucilla River valley during the late Quaternary resulted in a proliferation of ecologic niches. One such niche was readily occupied by an opportunistic species – early humans – which advanced into North America and north Florida as the glaciers were retreating. The importance of these changes in the geohydrologic system on human history in North America cannot be overemphasized.

References

Anuskiewicz, R.J., 1988. Preliminary archaeological investigations at Ray Hole Spring in the eastern Gulf of Mexico. *Florida Anthropologist*, **41**, 181–185.

Back, W., Hanshaw, B.B., Herman, J.S., and VanDriel, J.N., 1986. Differential dissolution of a Pleistocene reef in the ground-water mixing zone of coastal Yucatan, Mexico. *Geology*, **14**, 137–140.

Baranola, J.M., Raynaud, D., Korotkevich, Y.S., and Lorius, C., 1987. Vostok ice core provides 160,000-year record of atmospheric CO_2. *Nature*, **329**, 408–414.

Beck, B.F., 1986. A generalized genetic framework for the development of sinkholes and karst in Florida, USA. *Environmental Geology and Water Science*, **8**, 5–18.

Bokuniewicz, H., 1980. Groundwater seepage into Great South Bay, New York. *Estuarine and Coastal Marine Science*, **10**, 257–288.

Brooks, H.K., 1967. Rate of solution of limestone in the karst terrain of Florida, Publication No. 6 of the Florida Water Resources Research Center, 16 p.

Cable, J.E., Bugna, G.C., Burnett, W.C., and Chanton, J.P., 1996. Application of Rn-222 and CH_4 for assessment of groundwater discharge to the coastal ocean. *Limnology and Oceanography*, **41**, 1347–1353.

Cable, J.E., Burnett, W.C., and Chanton, J.P., 1997. Magnitude and variations of groundwater seepage along a Florida marine shoreline. *Biogeochemistry*, **38**, 189–205.

Chen, C.S., 1965. The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida, Florida Geological Survey Bull. No. 45, Florida Bureau of Geology, Tallahassee,105 p.

Chen, Z.Q., Donoghue, J.F., Hoenstine, R.W., Rupert, F., Spencer, S., Ladner, L.J., and Lane, E., 2000, a buried karst plain on the northeastern Gulf of Mexico shelf, NW Florida: Origin and relation to onshore karst: p. 22–35 in Schmidt, W., Lloyd, J.M., and Collier, C., (eds.), Woodville Karst Plain Symposium Transactions: Florida Geological Survey Special Publication No. 46.

Corso, W., Austin, J.A., and Buffler, R.T., 1989. The early Cretaceous platform off northwest Florida: controls on morphologic development of carbonate margins. *Marine Geology*, **86**, 1–14.

Culshaw, M.G., and Waltham, A.C., 1987. Natural and artificial cavities as ground engineering hazards. *Quarterly Journal of Engineering Geology*, London, **20**, 139–150.

Curray, J.P., 1960. Sediments and history of the Holocene transgression, contental shelf, northwest Gulf of Mexico, in: *Recent Sediments, Northwest Gulf of Mexico* (F.P. Shepard, F.B. Phleger, and T.H. van Andel, Eds.), pp. 221–266. Am. Assoc. Petroleum Geol., Tulsa, Oklahoma.

Demek, J., Gams, I., and Vaptsarov, I., 1984. Balkan Peninsula, in: *Geomorphology of Europe* (C. Embleton, Ed.), pp. 374–386. John Wiley & Sons, New York.

Donoghue, J.F., 1992. Late Quaternary coastal and inner shelf stratigraphy, Apalachicola Delta region, Florida. *Sedimentary Geology*, **80**, 293–304.

Donoghue, J.F., 1993. Late Wisconsinan and Holocene depositional history, northeastern Gulf of Mexico. *Marine Geology*, **112**, 185–205.

Donoghue, J.F., Anuskiewicz, R.J., Dunbar, J.S., Faught, M.K., Gerrell, P.R., and Garrison, E.G., 1997. Ray Hole Spring and other early human sites on the northeastern Gulf of Mexico continental shelf. *Geological Society of America Abstracts with Programs*, **29**, no. 3, 14.

Dreybrodt, W., 1988. *Processes in Karst Systems*: *Physics, Chemistry and Geology*, Springer-Verlag, Berlin.

Dunbar, J.S., 1991. Resource orientation of Clovis and Suwannee age Paleoindian sites in Florida, in: *Clovis: Origins and Adaptations* (R. Bonnichsen and K.L. Turnmire, Eds.), pp. 185–214. Center for the Study of the First Americans, Corvallis, Oregon.

Dunbar, J.S., and Waller, B.I., 1983. A distribution analysis of the Clovis/Suwannee Paleo-Indian sites in Florida: a geographic approach. *Florida Anthropologist*, **36**, 18–30.

Emiliani, C., Rooth, C., and Stipp, J.J., 1978. The late Wisconsin flood into the Gulf of Mexico. *Earth and Planetary Science Letters*, **41**, 159–162.

Evans, M.W., Hine, A.C., Belknap, D.F., and Davis, R.A., 1985. Bedrock controls on barrier island development: west-central Florida coast. *Marine Geology*, **63**, 263–283.

Fairbanks, R.G., 1989. A 17,000-year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation, *Nature*, **342**, 637–642.

Fairbanks, R.G., 1990. The age and origin of the "Younger Dryas climate event" in Greenland ice cores. *Paleoceanography*, **5**, 937–948.

Faught, M.K., 1996. Clovis origins and underwater prehistoric archaeology in northwestern Florida. Unpublished Ph.D. dissertation, University of Arizona, Tucson, Arizona, 665 p.

Faught, M.K., and Donoghue, J.F., 1997. Marine inundated archaeological sites and paleofluvial systems: examples from a karst-controlled continental shelf setting in Apalachee Bay, Northeastern Gulf of Mexico, *Geoarchaeology*, **12**, 417–458.

Fennell, E.L., 1969. The relation of gravity to structural geology and hydrological features in parts of Gadsden, Leon, and Wakulla counties, Florida. Unpublished MS thesis, Florida State University, Tallahassee, Florida, 146 p.

Fernald, E.A., and Purdum, E.D., Eds., 1992. *Atlas of Florida*, University Press of Florida, Gainesville, Florida, 280 p.

Flower, B.P., and Kennett, J.P., 1990. The Younger Dryas as a cool episode in the Gulf of Mexico. *Paleoceanography*, **5**, 949–961.

Frazier, D.E., 1974. Depositional episodes: their relationship to the Quaternary stratigraphic framework in the northwestern portion of the Gulf basin, Geologic Circular 74-1, Austin, TX, Texas Bureau of Economic Geology, 28 p.

Galloway, W.E., Bebout, D.G., Fisher, W.L., Dunlap, J.B., Cabrera-Castro, R., Lugo-Rivera, J.E., and Scott, T.M., 1991. Cenozoic, in: *The Gulf of Mexico Basin (Vol J), The Geology of North America* (A. Salvador, Ed.), pp. 245–324. Geological Society of America, Boulder, Colorado.

Hanshaw, B.B., and Back, W., 1980. Chemical mass-wasting of the northern Yucatan Peninsula by groundwater dissolution. *Geology*, **8**, 222–224.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change, in: *Sea-Level Changes: An Integrated Approach* (C.K. Wilgus, H. Posamentier, C.A. Ross, and C.G. Kendall, Eds.), pp. 71–108. Soc. Econ. Paleont. and Mineralogists, Tulsa, Oklahoma.

Hays, J.D., Imbrie, J., and Shackleton, N.J., 1976. Variations in the earth's orbit: pacemaker of the Ice Ages. *Science*, **194**, 1121–1132.

Hendry, C.W. Jr., and Sproul, C.R., 1966. Geology and groundwater resources of Leon County, Florida, Florida Geological Survey Bulletin 47, Florida Geological Survey, Tallahassee, Florida, 178 p.

Hine, A.C., Belknap, D.F., Hutton, J.G., Osking, E.B., and Evans, M.W., 1988. Recent geological history and modern sedimentary processes along an incipient, low-energy, epicontental-sea coastline: Northwest Florida. *Journal of Sedimentary Petrology*, **58**, 567–579.

Imbrie, J., and Imbrie, K.P., 1979. *Ice Ages: Solving the Mystery*, Enslow Publ., Hillside, New Jersey, 224 p.

Johnston, R.H., 1993, Historical development of concepts of regional groundwater flow in the Floridan aquifer system, southeastern United States, in: *Hydrogeological Processes in Karst Terranes* (G. Gunnay, A.I. Johnson, and W. Back, Eds.), pp. 351–357. Intl. Assoc. Hydrological Sciences Publ. No. 207, IAHS, Wallingford, U.K.

Kutzbach, J., Gallimore, R., Harrison, S., Behling, P., Selin, R., and Laarif, F., 1998. Climate and biome simulations for the past 21,000 years. *Quaternary Science Reviews*, **17**, 473–506.

Lane, E., 1986. Karst in Florida, Florida Geological Survey Special Publication No. 29, Florida Geological Survey, Tallahassee, Florida, 100 p.

Leventer, A, Williams, D.F., and Kennett, J.P., 1982. Dynamics of the Laurentide ice sheet during the last deglaciation: evidence from the Gulf of Mexico. *Earth and Planetary Science Letters*, **59**, 11–17.

Mesolella, K.J., Mathews, R.K., Broecker, W.S., and Thurber, D.L., 1969. The astronomical theory of climatic change: Barbados data. *Journal of Geology*, **77**, 250–274.

Moore, W.S., 1996. Large groundwater inputs to coastal waters revealed by Ra-226 enrichments. *Nature*, **380**, 612–614.

Montague, C.L., and Odum, H.T., 1997. The intertidal marshes of Florida's Gulf coast, in: *Ecology and Management of Tidal Marshes: A Model from the Gulf of Mexico* (C.L. Coultas and Y.P. Hsieh, Eds.), pp. 1–33. St. Lucie Press, Delray Beach, Florida.

Nelson, H.F., and Bray, E.E., 1970. Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico, in: *Deltaic Sedimentation, Modern and Ancient, SEPM Spec. Publ. 15* (J.P. Morgan, Ed.), pp. 48–77. SEPM, Tulsa Oklahoma.

Opdyke, N.D., Spangler, D.P., Smith, D.L., Jones, D.S., and Lindquist, R.C., 1984. Origin of the epeirogenic uplift of Plio-Pleistocene beach ridges in Florida and development of the Florida karst. *Geology*, **12**, 226–228.

Otvos, E.G., 1991. Northeastern Gulf Coast Quaternary,. in: *Quaternary Nonglacial Geology of the Conterminus United States, Vol. K-2 of The Geology of North America*, (R.B. Morrison, Ed.), pp. 588–594. Geological Society of America, Boulder, Colarado:..

Panno, S.V., and Bourcier, W.L., 1990. Glaciation and saline–freshwater mixing as a possible cause of cave formation in the eastern midcontinent region of the United States: a conceptual model. *Geology*, **18**, 769–772.

Parkinson, R.W., 1989. Decelerating Holocene sea-level rise and its influence on southwest Florida's coastal evolution: a transgressive–regressive stratigraphy. *Journal of Sedimentary Petrology*, **59**, 960–972.

Perlmutter, M.A., 1985. Deep water clastic reservoirs in the Gulf of Mexico: a Depositional Model. *Geo-Marine Letters*, **5**, 105–112.

Puri, H.S., and Vernon, R.O., 1964. Summary of the geology of Florida and a guidebook to the classic exposures, Florida Geological Survey Special Publication 5 (Revised), 311 p.

Raymo, M.E., 1992. Global climate change: a three million year perspective, in: *Start of a Glacial* (G.J. Kent and E. Went, Eds.), Springer-Verlag, Heidelberg, 353 p.

Rosenau, J.C., and Faulkner, G.I., 1975. An index to springs: Florida Bureau of Geology Map No. 63 (rev.), Florida Bureau of Geology, Tallahassee.

Rosenau, J.C., Faulkner, G.I., and Hendry, C.W., and Hull, R.W., 1977. Springs of Florida, Florida Bureau of Geology Bull. 31 (rev.), Florida Bureau of Geology, Tallahassee, 461 p.

Rupert, F., 1993. Karst features of northern Florida, in: *Geologic Field Studies of the Coastal Plain in Alabama, Georgia and Florida* (S.A. Kish, Ed.), pp. 49–61. Southeastern Geological Society Guidebook 33, Tallahassee, Florida.

Rupert, F.R., and Arthur, J.D., 1997. Geology and Geomorphology, in: *Ecology and Management of Tidal Marshes* (C.L. Coultas and Y.P. Hsieh, Eds.), pp. 35–52. St. Lucie Press, Delray Beach, Florida.

Rupert, F.R., and Spencer, S., 1988. Geology of Wakulla County, Florida, Florida Geological Survey Bulletin No. 60, Florida Bureau of Geology, Tallahassee, 46 p.

Schnable, J.E., and Goodell, H.G., 1968. Pleistocene-Recent Stratigraphy, Evolution, and Development of the Apalachicola Coast, Florida. Geological Society of America Special Paper No. 112.: Geological Society of America, Boulder, Colorado, 72 p.

Scholl, E.W., Craighead, F.C., and Stuiver, M., 1969. Florida submergence curve revisited: its relation to sedimentation rates. *Science*, **163**, 562–564.

Scott, T.M., 1992. A geological overview of Florida, Florida Geological Survey Open File Report No. 50, 78 p.

Sellards, E.H., 1909. Mineral industries. Florida Geological Survey 2nd Annual Report, pp. 235–293.

Sinclair, W.C., and Stewart, J.W., 1985. Sinkhole type, development and distribution in Florida, Florida Bureau of Geology Map Series 110, Florida Bureau of Geology, Tallahassee.

Sinclair, W.C., Stewart, J.W., Knutilla, R.L., Gilboy, A.E., and Miller, R.L., 1985. Types, features and occurrence of sinkholes in the karst of west-central Florida: U.S. Geological Survey, Water-Resources Investigations Report 85-4126, 81 p.

Slack, L.J., and Rosenau, J.C., 1979. Water quality of Florida springs, Florida Bureau of Geology Map No. 96, , Florida Bureau of Geology, Tallahassee, Florida.

Stanley, D.J., and Warne, A.G., 1994. Worldwide initiation of Holocene marine deltas by deceleration of sea-level rise. *Science*, **265**, 228–231.

Stapor, F.W., Mathews, T.D., and Lindfors-Kearns, F.E., 1991. Barrier island progradation and Holocene sea level history in southwest Florida. *Journal of Coastal Research*, **7**, 815–838.

Thornbury, W.D., 1964. *Principles of Geomorphology*, Wiley, New York, 618 p.

Thrailkill, L, 1968. Chemical and hydrologic factors in the excavation of limestone caves. *Geological Society of American Bulletin*, **79**, 19–45.

Vezina, J., Jones, B., and Ford, D., 1999. Sea-level highstands over the last 500,000 years: evidence from the Ironshore Formation on Grand Cayman, British West Indies. *Journal of Sedimentary Research*, **69**, 317–327.

White, W.A., 1970. The geomorphology of the Florida Peninsula, Florida Bureau of Geology Bull. 51, Florida Bureau of Geology, Tallahassee.

Wicker, R.A., and Smith, D.L., 1978. Re-evaluating the Florida basement. *Gulf Coast Association of Geological Societies*, **28**, 681–687.

Wilson, W.L., and Beck, B.F., 1992. Hydrogeologic factors affecting new sinkhole development in the Orlando area, Florida. *Groundwater*, **30**, 918–930.

Wilson, W.L., McDonald, K.M., Barfus, B.L., and Beck, B.F., 1987. Hydrogeologic factors associated with recent sinkhole development in the Orlando area, Florida, Florida Sinkhole Research Institute Report 87-88-4, University of Central Florida. Orlando, Florida, 104 p.

Yon, J.W., 1966. Geology of Jefferson County, Florida, Florida Geological Survey Bulletin No. 48, Florida Bureau of Geology, Tallahassee, 119 p.

Chapter 3

Stratigraphy and Sedimentation

DAVID C. KENDRICK
Department of Geoscience, Hobart and William Smith Colleges, Geneva, NY 14456, USA.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 49–82

3.1 Introduction

Winding, sinking, and reappearing, the Aucilla River flows southwestward from southern Georgia into the Florida Panhandle and on to the Gulf of Mexico. The placid beauty of this dark-colored river masks a rich and varied geological, paleontological, and archeological history. Excavations conducted from 1983 to 1997 at the Page-Ladson archeological site (8JE591) in the Aucilla River in Jefferson County, Florida, by researchers and volunteers from the Florida Museum of Natural History and the Florida Department of State, reveal new and detailed information about patterns of Late Pleistocene floral, faunal, and climatic change and how humans interacted with their changing environment. This chapter details the geomorphologic and geologic settings, the local environment, and the stratigraphic framework of the Page-Ladson Site.

3.1.1 Geomorphology

3.1.1.1 Geomorphologic Setting

The southern half of Jefferson County and most of Taylor County, including the Page/Ladson locality, are encompassed within the broad Gulf Coastal Lowlands geomorphic province (Puri and Vernon, 1964; Schmidt, 1997). This region, a low, flat, often swampy, gently seaward-sloping plain, is primarily ancient marine terrain (Rupert, 1996). At least three ancient marine terrace elevation zones (Healy, 1975) record the ebb and flow of Pleistocene seas over these lowlands. Relict Pleistocene coastal marine features composed of white quartz sand (Rupert, 1996) dot this inland area as well, testifying to past marine incursions. A thin veneer of unconsolidated Plio-Pleistocene sands covers the irregular and highly karstified Eocene and Oligocene bedrock carbonates (Yon, 1966; Rupert, 1996). Solution processes are common in this area, including the formation of sinkholes, the prevalence of freshwater springs, and the disappearance (and reappearance) of river systems.

The Aucilla River occupies a variable-breadth dissolution valley (Rupert, 1996), usually less than 1.5 km wide, cut through underlying Oligocene carbonates. The steep-walled channel, together with the adjacent topographic lowlands, composes the Aucilla River Valley Lowlands (Yon, 1966). At flood stage, the Aucilla spreads over much of this area. Sediments in these adjacent lowlands consist largely of thin, reworked Pleistocene and Miocene quartz sands and clayey quartz sands draped over the underlying carbonates (Yon, 1966; Rupert, 1996).

The Aucilla Lowlands, in turn, lie within the Woodville Karst Plain (WKP), a 1000-km^2 region (Lane, 1986) of complex hydrogeological processes centered in the area of Florida’s Big Bend (Rupert, 2000). The karstic nature of the WKP explains many of the Aucilla valley’s remarkable features. The Aucilla flows on the surface through northern Jefferson County until 7.25 km north of US Highway 98, where the river dives underground; closely spaced sinks define its underground path until its re-emergence nearly 3 km further south. The Page-Ladson Site lies within the next subaerial segment of the river, called Half Mile Rise. The Aucilla sinks at the foot of

Half Mile Rise and rises twice more before completing its course to the Gulf of Mexico. The penultimate 1-km surface segment, called Little River, begins approximately 2.5 km downstream of Half Mile Rise. The river sinks at the foot of Little River and emerges once and for all 50 m away at Nutall Rise; from here, the river flows 7 km to the Gulf of Mexico. A series of large and small sinks provide glimpses of the river's underground path between Half Mile Rise and Little River. The Aucilla and many of the nearby sinks are tidal, rising and falling in delayed lockstep with the tides in the Gulf. In spite of this marine influence, the Aucilla's waters are fresh, not brackish.

The Aucilla enjoys an intimate relationship with the nearby Wacissa River and has captured multiple channels from it. The clear waters of the most headward of these segments pour into Half Mile Rise over a shallow ledge of limestone just upstream of the Page-Ladson Site (see Fig. 3.1). Other captured segments of the Wacissa empty into the Aucilla below Nutall Rise (see Fig. 5.1 in Dunbar, this volume).

The river bottom is characterized by a bimodal bathymetry consisting of circular or elongate sediment-filled basins, 9–12 m below Mean Low River Stage (MLRS), linked together by shallow rapids of silicified limestones or dolostones. This bathymetric pattern is echoed in a system of dry topographic valleys winding among

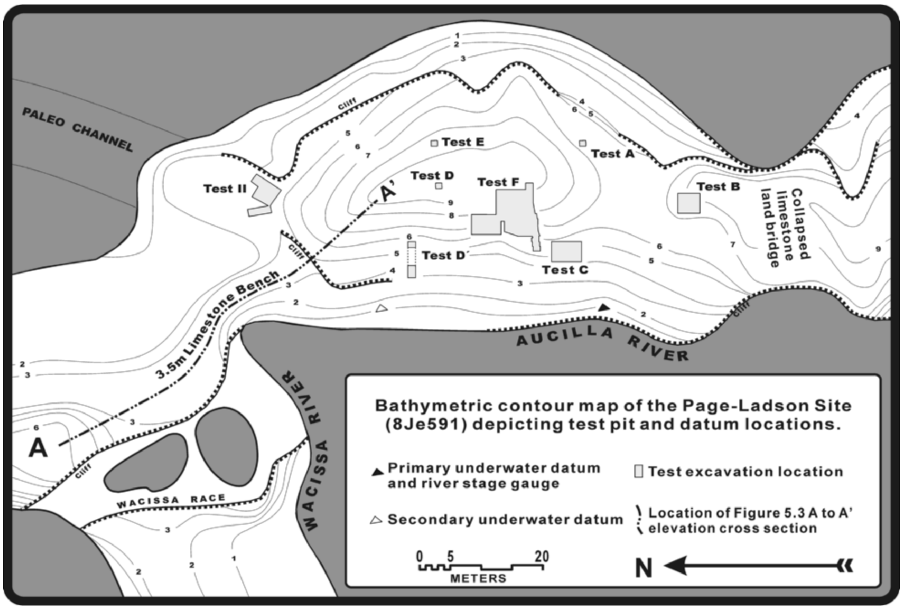


Figure 3.1 Bathymetric contour map of Page-Ladson Site showing locations of test pits and the primary and secondary underwater benchmarks. Note the shallow limestone ledges and steep drop-offs on the east and northwest sides of the site, the paleosurface channel entering on the north end, and the Wacissa River flowing into the Aucilla over a shallow ledge. Contour interval is 1 m.

sinkholes roughly paralleling the course of the subterranean river; these dry valleys may be relictual channels of a former surface course occupied during a previous interglacial highstand of the sea. Although typically dry, these channels do fill and flow during high water events.

3.1.2 Geologic Setting

The oldest rock exposed in the vicinity of the Page-Ladson Site is the Oligocene Suwannee Limestone (Cooke and Mansfield, 1936). In its subaerial courses, the Aucilla River flows in an incised channel cut into this thick Oligocene formation. Its subterranean segments pass through that formation's interior, as does the regional flow of the Floridan aquifer. Undifferentiated Pleistocene and Holocene clastics are the youngest sediments in the area. No continuous Miocene or Pliocene units are present; however, some discontinuous sand and clay deposits may represent reworked Miocene strata (Rupert, 1996).

3.1.2.1 Oligocene Series

The Oligocene Suwannee Limestone (Cooke and Mansfield, 1936) is the oldest rock formation cropping out in Jefferson and northwestern Taylor counties (Yon, 1966; Rupert, 1996). As such it is the oldest rock present in the Page/Ladson area. The Suwannee is a skeletal to micritic marine limestone, typically white to yellowish-gray to grayish-brown. Silicified boulders of the Suwannee are common in the area. Thicknesses vary across the area, from a probable maximum of approximately 100 m in the west of Jefferson County to around 30 m in the vicinity of Page/Ladson. The Suwannee is underlain by the Eocene Ocala Limestone (Puri, 1957; Scott, 1991). Yon (1966) reports that dolomitization occurs in the subsurface at different depths, especially along the Aucilla. Commercial mining of one such dolomite deposit occurs just east of Nutall Rise. Echinoids, notably *Cassidulus gouldii* (*Bouv*) and *Clypeaster rogersi* (*Morton*), foraminifera, mollusks, bryozoans, and ostracodes comprise the dominant invertebrate fauna in the Suwannee (Puri and Vernon, 1964; Yon, 1966). Sirenian skeletal remains (near *Halitherium*) are not uncommon. In the Page-Ladson vicinity the Suwannee is unconformably overlain by Pleistocene clastics.

3.1.2.2 Pleistocene–Holocene Series

Thin, undifferentiated Pleistocene marine sands unconformably overlie the Suwannee Limestone in the River Valley Lowlands in the Page/Ladson vicinity. These deposits are typically very fine to medium quartz sands with blue-green to light olive montmorillonitic clay lenses (Yon, 1966). Thicknesses vary across the region, with a maximum of 15 m to less than 1 m near the coast and in the River Valley Lowlands. Many of the larger sand bodies across the Gulf Coastal Lowlands area are relict barrier islands, dunes, and bars associated with Late Pleistocene sea-level high stands associated with periods of aridity (Rupert, 1996). Discontinuous lenses of weakly phosphatic, clayey sands scattered across the Gulf Coastal Lowlands in Taylor and Jefferson counties are likely reworked sediments of the Middle Miocene Torreya Formation – Rupert (1996) suggests that at least some of these deposits may represent Plio-Pleistocene paleosinkhole fill.

Sinkhole and paleosinkhole fill are of primary interest to this study. Many layers of undifferentiated sediments filling basins in river channels and neighboring sinkholes are demonstrably complex, *in situ* records of Pleistocene flora, fauna, and climate. The general lithology of these deposits includes a broad range of clastic sediments ranging from massive to blocky gray and brown clays to quartzose and calcareous silty sands to dense peats and digesta mats. Thicknesses range from 0.5 m to more than 5 m. Although often traceable and continuous within the confines of a local basin, e.g. sinkhole, paleosinkhole, or channel basin, these deposits are by nature discontinuous among basins. Shared sedimentary and stratigraphic patterns do, however, suggest that processes among basins are quite similar.

3.2 Page-Ladson Site

3.2.1 Physical Description

The Page-Ladson Site lies in the Half Mile Rise section of the Aucilla River in southeastern Jefferson County, Florida where the river forms the border between Jefferson and neighboring Taylor County. As shown in Fig. 3.1, the site itself occupies a broad elliptical expanse, approximately 60 m long by 45 m wide, within the river channel. The western bank of the south-flowing river is relatively straight and is aligned approximately north–south. The opposite bank bows eastward in a broad arc away from the center of the site, marking the exposed vertical wall of a large sinkhole. Immediately to the north of the site, one branch of the clear Wacissa River flows from over a silicified ledge of the Suwannee Limestone into the dark, tannin-stained water of the Aucilla.

Exposed Suwannee Limestone makes up the eastern bank of the site; the eroded limestone contours form a shallow shelf that breaks to a 3-m vertical scarp. At the base of the scarp, the profile softens, inclining downward toward the deepest part of the site at 9 m below datum. The channel floor is broad and flat. Proceeding westward, the floor steepens to an approximately constant incline leading back up to the western bank. Upstream of the site (north), the Aucilla crosses a shallow, exposed limestone shelf. Downstream, the channel is constricted as it passes over another shallow shelf and a narrowing of the enclosing limestone banks, before it drops off and widens again. Quaternary sediments cover the site from just below the base of the scarp face on the eastern side of the site up to the river's surface on the western bank. Sediments shallow to the north, but do extend up an abandoned surface channel (Fig. 3.1). Recent river sediments on the west bank dip to the east; Quaternary strata underlying the Recent sands and leaf mats dip strongly or weakly southeast and east.

3.2.2 Quaternary Geology

Quaternary and Recent peats, silts, sands, and mats of proboscidean digesta (Newsom and Mihlbachler, Chapter 10) comprise the sediments at Page/Ladson. Neither excavation nor coring has penetrated to the underlying Suwannee Limestone. The sediments in the deepest parts of the channel are at least 3 m deep, while thick accumulations of more than 9 m of sediment clothe the western bank.

Seven different units characterize the Quaternary and Recent sediments at Page-Ladson, all but the deepest unit (Unit 1 is illustrated in Fig. 3.2). From oldest to youngest the units appear as follows: (1) gray to white quartz and shell sands interbedded with brown silts and digesta mats; (2) a brown to red peat; (3) gray to white quartz and shell sands with interbedded digesta; (4) a tan to gray sandy, shelly silt; (5) a brown, clayey, sandy silt; (6) a gray, sandy, shelly silt; and, at the top; and (7) a sequence of dark sands interbedded with leafy peats.

Table 3.1 presents lithological descriptions of each sedimentary unit. Variations in thickness, dip, and lithology of beds between test excavations are discussed in Sections 3.3.1 and 3.3.2. Note that we conducted all in-place observations of the Page-Ladson sediments underwater, in full SCUBA kit, using 1000-W tungsten-filamented

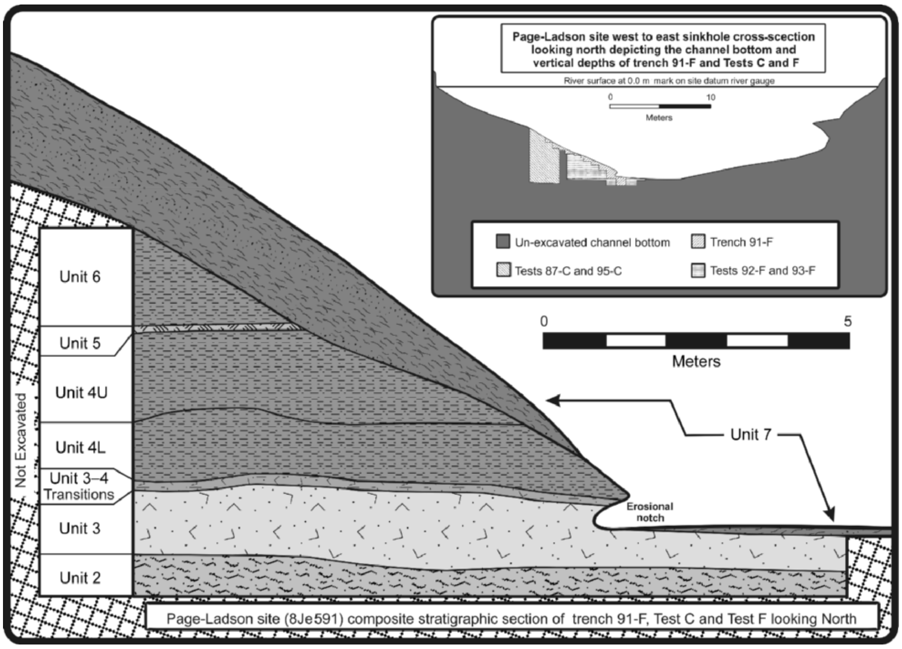


Figure 3.2 Simplified composite stratigraphic section of Page-Ladson, west to east profile, looking north. Lithologic units are described in the text. Note erosional truncation of Units 3–6 by the increased flow of the Aucilla. Unit 7 represents Recent river sands and peats.

Table 3.1 Composite lithologic column for Page/Ladson

Unit	*Thickness (m)*	*Lithology*
7	1.9–2.0	Alternating (1) peat and (2) quartz sand horizons, 0.01–0.20 m thick. Peats black to dark brown (5YR 2.5/1), composed of leaf litter, twigs. Sands dark to very dark (10YR > 2/2), predominantly fine, well-sorted, loose. Abrupt contact with Unit 6
6	1.8–1.1	Sandy silt, gray (2.5Y 3/2) to tan (2.5Y 4/2). Sands fine to very fine, well-sorted, gastropods, fish scales, wood, leaves, limestone pebbles. Upper surface erosionally truncated. Abrupt, undulating contact with Unit 5
5	0.05–0.25	Sandy, clayey silt, brown (10YR 2/1), sands fine to very fine, fairly well-sorted, gastropods, fish scales, wood, cultural materials. Upper surface undulatory. Abrupt, undulating contact with Unit 4
4	2.5–2.3	Sandy silt, gray (10YR3/1), sands quartz, medium to very fine, fairly well-sorted, fragmentary and complete gastropods, complete leaves, intact insects, small (0.03 m) to large (>1 m) wood fragments increasing in frequency toward bottom of unit. Distinct color break at horizon 1.3 m below contact with bed 5: gray above, tan below. Lowermost 0.10–0.16 m grades into bed 3, marked by increase in quartz and shell sands and series of 3–4 continuous, peaty stringers composed of compressed digesta. Gradational, undulating contact with Unit 3, marked by sequence of peaty stringers comprised of compressed digesta interbedded with tan to gray sandy silts
3	1.0–1.5	Silty to pure quartz and shell sands interbedded with continuous and discontinuous proboscidean digesta mats. Sands light gray, coarse to very fine, fair to poorly sorted. Basal sands coarser, include poorly rounded, low sphericity limestone pebbles and cobbles, 0.01–0.30 m length wood and twig fragments, fragmentary and whole gastropod shells. Digesta mats contain chopped vegetation and greater and lesser amounts of sandy silt matrix. Contacts between sand and digesta horizons highly undulatory and discontinuous. Clear, irregular contact with Unit 2, sections of contact appear as conglomeratic admixture of sands and digesta mat fragments with red peat matrix
2	0.15–0.35	Dense, cohesive, red to orange woody peat, many seeds, many small, unstained 0.5–3 cm wood fragments, silty matrix. Abrupt, undulating contact with Unit 1
1	0.15–0.5[1]	Silty to pure quartz and shell sands interbedded with gray to brown sandy silts and digesta mats. Sands light gray, coarse to very fine, fair to poorly sorted, typically occurring as thin laminae within silts. 2–4 cm wood fragments, gastropod shells, and poorly to moderately rounded limestone pebbles locally common within sandy stringers. Silts brown to gray, sandy, with sandy lenses and stringers. Thin digesta mats with gray sandy silt matrix interbedded with red to brown silts. Maximum thickness unknown

[1] We did not penetrate to the bottom of Unit 1 anywhere in the site; its maximum thickness remains unknown.

Snooper Lights for illumination. When possible, we later identified Munsell colors of these sediments from core samples under fluorescent light in indoor conditions.

The deepest sediments on the western bank dip east and south, up to 40°, revealing a steep paleobathymetry. Beds are continuous or lenticular. Beds typically thin down-dip, although lenticular beds may pinch out to west and east. Sediment thicknesses vary laterally and adjacent units may interfinger. Up column, dips shallow and approach horizontal. Unit 5, though undulatory and of variable thickness, does not evidence a strong dip. Units 3–6 are truncated eastward by the present river channel bottom. East-dipping alternating layers of Recent leaf muck and sandy stringers (Unit 7) unconformably overlie this eastward-dipping erosional surface.

Excavations (Tests D and D′) and core data (Core 88.6) suggest that the upper Pleistocene sands and underlying red peats and interbedded silts lie horizontal in the channel (and paleosinkhole) center. Shallow excavations on the east side of Page-Ladson (Test A, Tests E and E′, Tests I and II) suggest shallow westward dips for the sediments on the far eastern side of the site. Sandy sediments containing Pleistocene megafaunal remains seem to have covered the bottom of the channel until recently. Sandy Pleistocene sediments thin toward the east and thicken westward into the bank. Sandy silts above Pleistocene sands appear to thin westward, squeezed between thickening sands and horizontal upper surfaces.

There are few or no indicators of strong currents[1]: no cross bedding, tool marks, or aligned wood or bone appears throughout the preserved sediments at Page/Ladson. Sands are typically unglazed. Limestone pebbles, cobbles, and boulders show little sign of transport, exhibit low sphericity, and are poorly rounded. Larger pieces may have angular breaks. Thin (2–20 cm), inclined (15°–30°) lenticular beds do show fining upward sequences that begin with limestone pebbles and cobbles associated with coarse to medium calcareous sands mixed with fine quartz sands and grade into fine calcareous and quartz sands. These beds could be interpreted as evidence for flowing water, perhaps representing pulses of falling current velocity; however, the continuous original dips of these beds over several meters of distance, dips tilted into the basin away from the banks, the increasing size and frequency of limestone rock nearer to the exposed limestone shelf on the western bank, and the absence of other current indicators strongly suggest that most of these sediments were locally derived and that much of the preserved sediments are colluvial, having slid down a steep embankment, probably underwater, into a quiet pool, rather than being transported in by flowing water. They may well represent small-scale turbidites.

3.3 Section and Core Descriptions

Eighteen years of work at the Page-Ladson Site have resulted in an extensive excavation record. Section 3.3.1 lists the excavation units in the order they were established and describes the sediments encountered in each. Table 3.2 lists UTM coordinates (NAD83, Zone 17 metric [meters]) for each excavation and its vertical position in meters relative to the Aucilla River Prehistory Project River Gauge datum (ARPP RG) and to mean sea level (MSL).

---

[1] The modern Aucilla River can produce strong currents that move sand and produce ripples.

Table 3.2 Page/Ladson excavation locations[1]

Excavation unit	*East*	*North*	*ARPP RG*[2]	*MSL*
A	224752	3341086	–6.5	–3.52 est
B	224744	3341074	–8	–5.02
C	224737	3341091	–3.5	–0.52
D	224746	3341106	–9.7	–6.72
D′	224738	3341110	–8.53	–5.55 est
E	224752	3341107	–8.68	–5.7
E′	224761	3341108	–6.1	–3.12 est
F-91	224746	3341093	–5.63	–2.65
F-93	224745	3341096	–9.2	–6.22
F-95	224745	3341098	–8.4	–5.42
F.97-1	224741	3341099	–6.61	–3.63
F.97-2	224741	3341101	–6.61	–3.63
G (part of D′)	224734	3341110	–8.66	–5.68
I	224748	3341139	–2.33	0.65
II	224749	3341131	–4.13	–1.15
Core 87.6	224736	3341089	–5.9	–2.92
Core 88.1	224736	3341085	–2.98	0
Core 88.2	224730	3341072	–3	–0.02 est
Core 88.3	224742	3341094	–8.17	–5.19
Core 88.4	224731	3341112	–5.5	–2.52 est
Core 88.5	224743	3341135	–3.5	–0.52 est
Core 88.6	224746	3341106	–9.73	–6.75
River gauge datum	224727	3341084	0	2.98
Primary datum[3]	224720	3341034	N/A	On land
ARPP-1 Datum[4]	224708	3341063	N/A	On land

[1] UTM NAD83, Zone 17 metric (meters).
[2] ARPP RG 0 m = +2.98 m MSL.
[3] Primary datum established 1984.
[4] ARPP-1 datum was GPS position tie-in.

The ARPP RG measurement records the vertical distance between 0.0 on ARPP RG (mean low river stand is approximately 0.0 m) and the sediment/water interface at the location of the excavation along the river bottom.

3.3.1 Test Pits

3.3.1.1 Test A

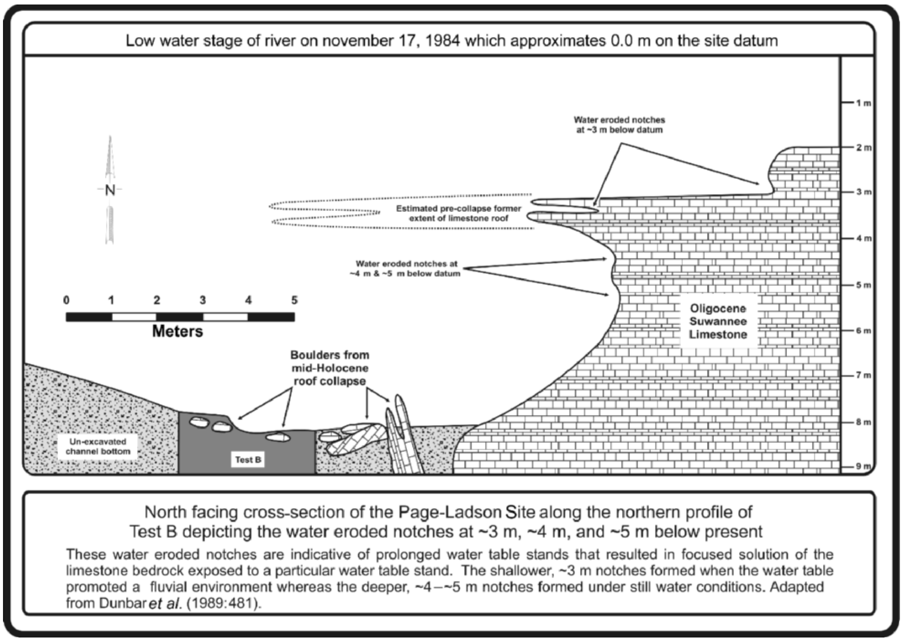
Test A, the first test excavation at Page-Ladson by the Aucilla River Research Project, was hand-dug 30-50 cm deep on the southeastern side of the site in 1983 (Fig. 3.1), between –6 and –7 m ARPP RG. This excavation revealed two conformable units: an upper stratum of compact peat consisting almost entirely of matted twigs that graded into a lower stratum of peaty clay (Dunbar *et al.*, 1989) containing wood, chert artifacts, and bone, including an upright standing proboscidean rib. A stratum of unconsolidated channel lag consisting of quartz sands, limestone pebbles, and forest leaf litter unconformably overlay the surface. Radiocarbon dates from the upper and lower units varied between 10,500 ^{14}C BP (bone) to 13,100 ^{14}C BP (wood) (Dunbar *et al*., 1989).

3.3.1.2 Test B

Test B, excavated during the 1984 and 1985 seasons, was a 2 × 3 m test unit located –8 m ARPP RG at the southern edge of Page/Ladson (Figs. 3.3 and 3.4). Comprising over 4 m of section, this unit presents a complex stratigraphic column of peats, clays, and sands, as well as limestone boulders probably representing the collapse of a limestone overhang or natural bridge. Bone, wood, and artifacts, including Deptford age pottery, an Antler Flaker, and a Bolo Stone are all present in this unit. Radiocarbon dates span a range from 12,330 ^{14}C BP to 9,450 ^{14}C BP in the lower 3.5 m of section, while dates from 4,070 ^{14}C BP to 3,440 ^{14}C BP in the uppermost 0.75 m of section indicate an erosional unconformity or hiatus in deposition. Dunbar *et al*. (1989) published detailed descriptions of Test B stratigraphy, lithology, and radiocarbon chronology.

3.3.1.3 Test C

Set –3.5 m ARPP RG on the sloping west bank of the river (Fig. 3.1), Test C represents the longest continuous vertical section of sediments at Page/Ladson and contains over 8 m of interbedded peats, silts, and sands (Figs. 3.5 and 3.6). These strata document



North facing cross-section of the Page-Ladson Site along the northern profile of Test B depicting the water eroded notches at ~3 m, ~4 m, and ~5 m below present

These water eroded notches are indicative of prolonged water table stands that resulted in focused solution of the limestone bedrock exposed to a particular water table stand. The shallower, ~3 m notches formed when the water table promoted a fluvial environment whereas the deeper, ~4 – ~5 m notches formed under still water conditions. Adapted from Dunbar *et al.* (1989:481).

Figure 3.3 East to west profile across southern end of Page/Ladson, showing location of Test B adjacent to limestone rock wall and collapse debris. View is upstream (north).

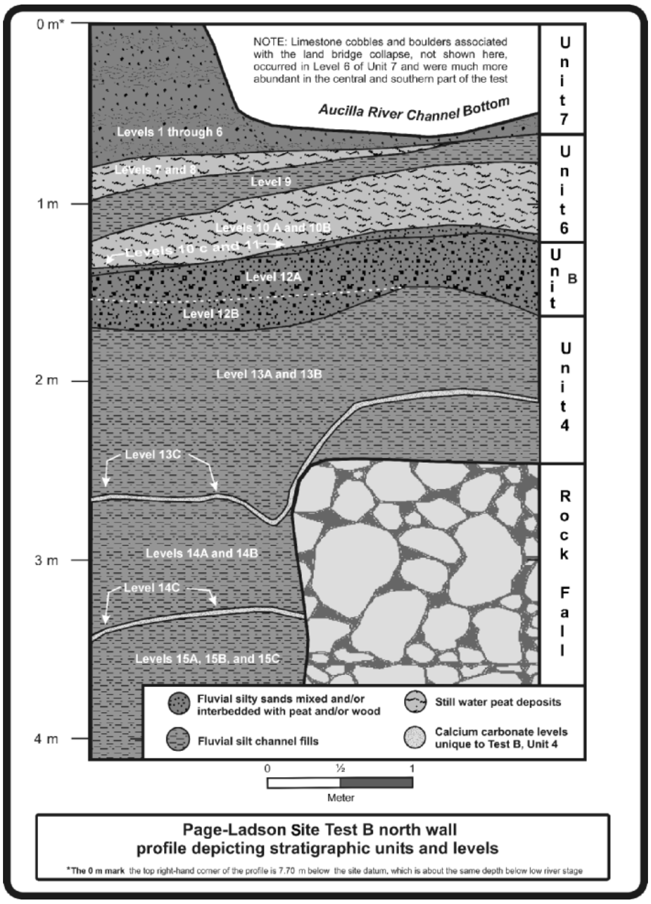


Figure 3.4 Test B north wall profile. Levels labeled 1 through 15c within the figure correspond to levels described in Dunbar et al. (1989). Labels on the right: Units 7, 6, and 4, refer to the stratigraphic units described in this chapter. Unit B on the right is unique to Test B. See Dunbar et al. (1989) for description.

several different depositional environments and include lithic and wooden artifacts, as well as Pleistocene megafaunal bone and digesta. Nineteen individual radiocarbon dates from Test C establish a chronological framework stretching from nearly 15,000 ^{14}C BP in Unit 2 at the base to 8,905 ^{14}C BP in Unit 6 near the top of the test. Webb and Dunbar, this volume, detail the Page/Ladson radiocarbon chronology.

Three primary sediment packages, excluding the modern river bottom sediments, compose the sedimentary column in Test C: a red to brown peat at the base, a sequence of interbedded coarse sands and digesta mats, and a long sequence of tan to gray to brown sandy silts on top.

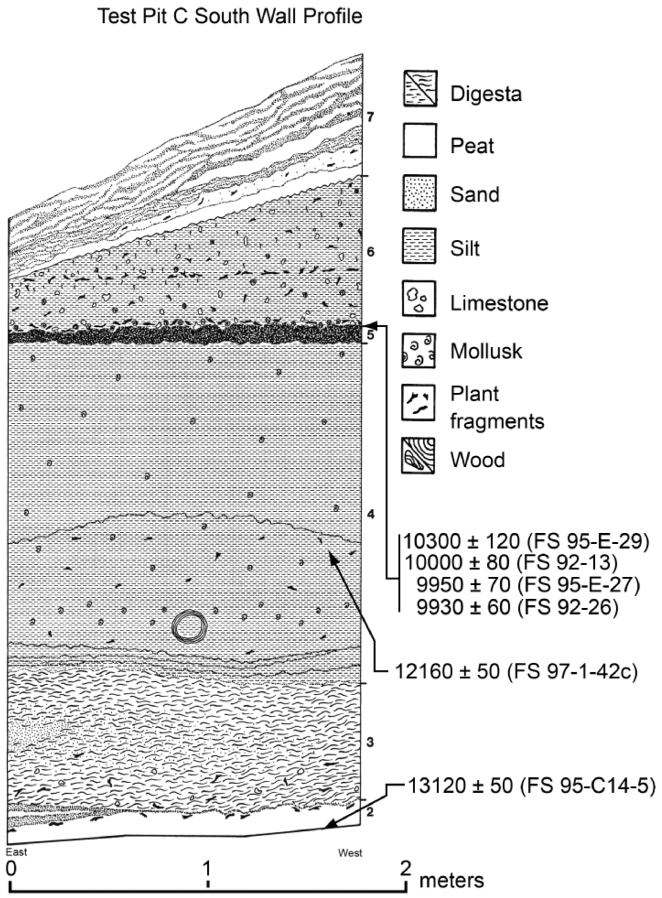


Figure 3.5 Stratigraphic profile of Test C 1995 south wall. Numbers on right are stratigraphic units and their boundaries. Selected carbon dated horizons are noted by solid arrows and identified by FS#. (See Table 4.2 in Webb and Dunbar, this volume.) This profile shows an almost complete section of the Page/Ladson column, from the upper part of the red, quiet-water peat deposits of Unit 2 through the Recent leafy peat and sand couplets of Unit 7. Unit 6 is truncated by erosion of the modern Aucilla. See text for description.

A dense, red, woody still-water peat horizon (Unit 2 in Table 3.1) is exposed at the bottom of Test C to a thickness of 0.20 m (Table 3.3). Excavations in Test C did not penetrate below this level, so the recorded thickness is a minimum estimate. The red peat horizon is densely laden with small wood fragments and many seeds. *Taxodium* seeds and wood were so common that this horizon was dubbed the "cypress peat" by excavation crews. The upper surface of this unit dips shallowly to the south. The dip steepens in the southeastern corner of Test C. A sharp, irregular contact between the

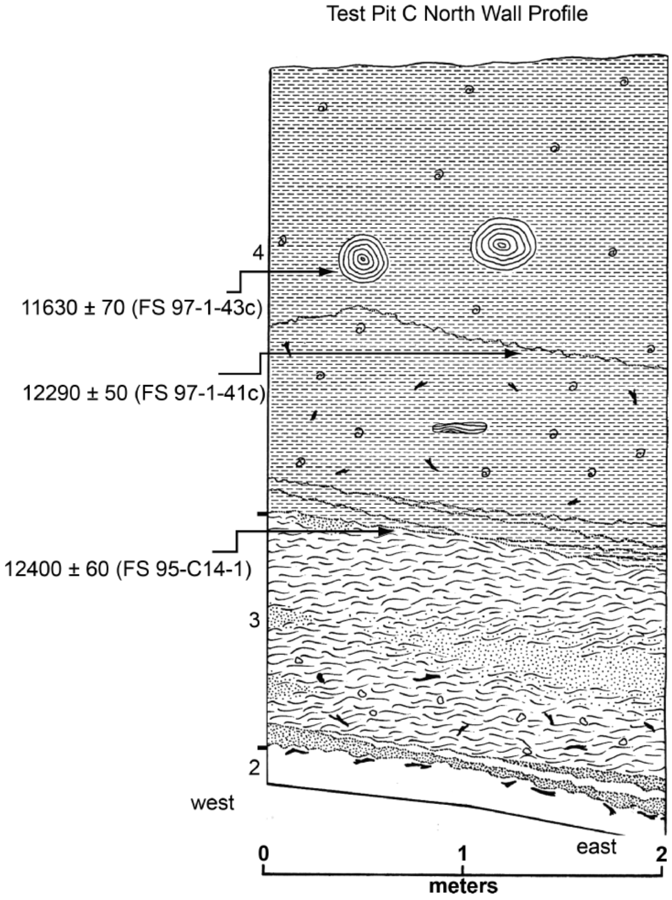


Figure 3.6 Stratigraphic profile of Test C 1995 north wall. Numbers on left are stratigraphic units and their boundaries. Selected carbon dated horizons are noted by solid arrows and identified by FS#. (See Table 4.2 in Webb and Dunbar, this volume.) This profile spans the upper part of Unit 2 through the top of Unit 4. (Unit 5 and overlying strata had been removed during excavation.) Digesta mats intermixed with sand comprise most of Unit 3.

red peat horizon and the overlying sands and digesta marks the boundary between Units 2 and 3. Unit 2 represents still-water conditions.

Four horizons, identifiable by varying fractions of clastic sediments and digesta, as well as several lenses of pure quartz and shell sands, lie within the 1.05–1.25 m thick Unit 3. Vertebrate fossils diagnostic of the latest Pleistocene are found throughout the unit, but are concentrated in the gravely sand horizon at the bottom. A thin (0.01–0.07 m), gray to white, gravely sand horizon (3a) composed of coarse quartz and calcareous shell sands, limestone pebbles and occasional cobbles, and small to large (0.02–0.30 m

Table 3.3 Test C sediment column

ARPP RG[1]	*MSL*	*Unit*	*Comments*
–4.03	–1.05	7	Recent river bottom sediments, leafy peats, and sands
–4.79	–1.81	6	Upper surface erosionally truncated, erosional surface dipping approximately 15° east
–5.71	–2.73	5	So-called Bolen surface, thickness varies, 0.05–0.3 m, dip varies, southeast to south 0°–11°
–6.00	–3.02	4	Sandy silts
–8.65	–5.67	3	Sands and silty sands with thick accumulations of digesta
–9.63	–6.65	2	Red peat. Minimum thickness 0.20 m

[1] Measured from western edge of central meter of south wall profile.

long) wood fragments comprises the lowermost horizon. Vertebrate fossil remains, dominated by American Mastodon (*Mammut americanum*), are present in this horizon and penetrate into the overlying strata. A thin (0.06 m max.) peat lens (3b), centered in the southeast corner of the test, immediately overlies sandy horizon 3a.

A second thin (0.06 m max.) sand horizon (3c), similar to 3a but with fewer large pebbles, immediately overlies the peat. Contacts above and below 3b are sharp. Horizons 3b and 3c pinch out 1 m west of the southeast corner of Test C. Here, 3a is directly overlain by 3d, a thick (1.05–1.15 m) horizon of digesta in a sandy matrix. The sand content throughout the horizon is high, but variable. Sands in the lower 0.20–0.40 m of 3d comprise less than 10% of the sediments by volume. Sand volume increases in the middle 0.31–0.55 m of 3d. Sands decrease again in the upper 0.30–0.41 m. A 0.20 m thick tabular, sandy lens (3e), similar in content to the sands of 3a and 3c, is evident in the east wall profile, centered within the area of increased sands in horizon 3d. The lens dips southeast, subparallel to Unit 2 and horizons 3a–3c in Unit 3. The edges of other sand lenses appear in the northeast corner of the pit, within the middle and lower levels of horizon 3d. The upper surface of 3d registers the same gentle southeastward dip evident in the units below. An undulatory, transitional contact marks the break between Units 3 and 4. We interpret these digesta-rich horizons as representing still-water pond or sinkhole accumulation. Coarse clastic material is locally derived and colluvial in nature.

Four thin, sandy silt horizons mark the lowermost 0.15–0.29 m of Unit 4. They represent a transition from the coarse, digesta-rich sand characteristic of Unit 3 to the sandy silts prevalent through most of the rest of the section in Test C. The four horizons, from lowest to highest, are a gray sandy silt with intermixed digesta, 0.5–0.11 m thick (4a), a medium-gray sandy silt, 0.03 m thick (max.) (4b), a light-gray sandy silt, 0.02–0.17 m thick (4c), and a second medium-gray sandy silt, 0.05–0.12 m thick (4d). They are separated by sharp, undulatory contacts demarked by thin (< 0.01 m) sandy layers of compressed digesta. The sand content decreases upward through these horizons. A walnut located at the 4c/4d contact in the center meter of the 3 m south wall profile at −8.43 m ARPP RG dated to 12.400 +/− 60 ^{14}C BP.

A thick (0.80–1.17 m), tan sandy silt (4e) contacts the underlying horizon 4d along an abrupt, undulatory contact. Horizon 4e contains occasional limestone pebbles and Oligocene echinoids weathered from the surrounding Suwannee Limestone, whole and fragmentary gastropods, insects, fish bones and scales, leaves, and concentrations of small and large fragments of wood. Horizons 4a through 4e also maintain the gentle southeastward dip expressed in the underlying strata. When first exposed, horizon 4e is a light tan. Minutes after exposure to the water column, however, the tan silts change to light gray. Wood fragments are concentrated in the lower half of horizon 4e. One large piece, approximately 0.30 m in diameter protrudes from the central section of the south wall profile. Between 0.95 and 1.35 m above the Unit 3/4 contact, a sharp, undulatory to irregular line marks an abrupt contact between horizon 4e and a thick (1.63–1.31 m) dark gray, sandy silt (4f). The sedimentological composition of 4e and 4f is similar. Like 4e, 4f contains occasional limestone pebbles and echinoids, whole and fragmentary gastropods, insects, fish bones and scales, leaves, and large and small fragments of wood, however, their colors are distinctive. Furthermore, horizon 4f does not change color on exposure to the water column during excavation. An abrupt, smooth to undulatory contact marks the break between horizon 4f and Unit 5 above. We interpret the shift to silt-dominated sediments in Unit 4 as a shift from quiet water deposition to a fluvial regime.

Unit 5, a thin (0.05–0.25 m), dark brown, sandy, smectitic silt, contains gastropod shells, fish bones and scales, limestone pebbles, and wood and charcoal. Unit 5 dips to the southeast in Test C, as do the underlying sediments. Cultural materials were found on and in the upper surface of Unit 5 in Test C. An abrupt, undulatory to smooth surface marks the contact between Units 5 and 6 in Test C. This quiet water deposit is unique to the Test C–Test F area.

A very thin veneer of shell-rich silt immediately overlies Unit 5. Unit 6 proper, a 1–2 m thick, massive, gray to tan sandy silt, contains gastropods, wood, leaves, and a few poorly rounded limestone pebbles to cobbles. In texture and content, Unit 6 resembles Units 4e and 4f and represents a similar fluvial environment. Gastropod shell fragments are found throughout the unit, but are concentrated in the first 0.10–0.20 m above Unit 5 in a light gray horizon (6a) with wood, limestone pebbles, and root filaments penetrating the upper surface. A gradual contact with horizon 6b, a dark gray sandy silt with shell fragments, wood, leaves, and root filaments is marked by horizontal wood fragments with oxidized roots. The upper surface of Unit 6 is a smooth, eastward-dipping (toward the center of the present-day river channel) erosional surface. This erosional surface truncates the easternmost exposures of Units 5 and 6 in Test C.

Above the erosional surface, Recent river bottom sediments (Unit 7) composed of couplets of leaf and twig rich organic peats and very dark fine sands, clothe the western bank. Thicker leaf and twig peats in Unit 7 have produced Archaic cultural materials.

3.3.1.4 Tests D and D′

The research project established Tests D, D′, E, and E′ in 1987, and Tests I and II in 1988, to identify the kinds and extents of sediments in the eastern and northern parts of Page-Ladson Site.

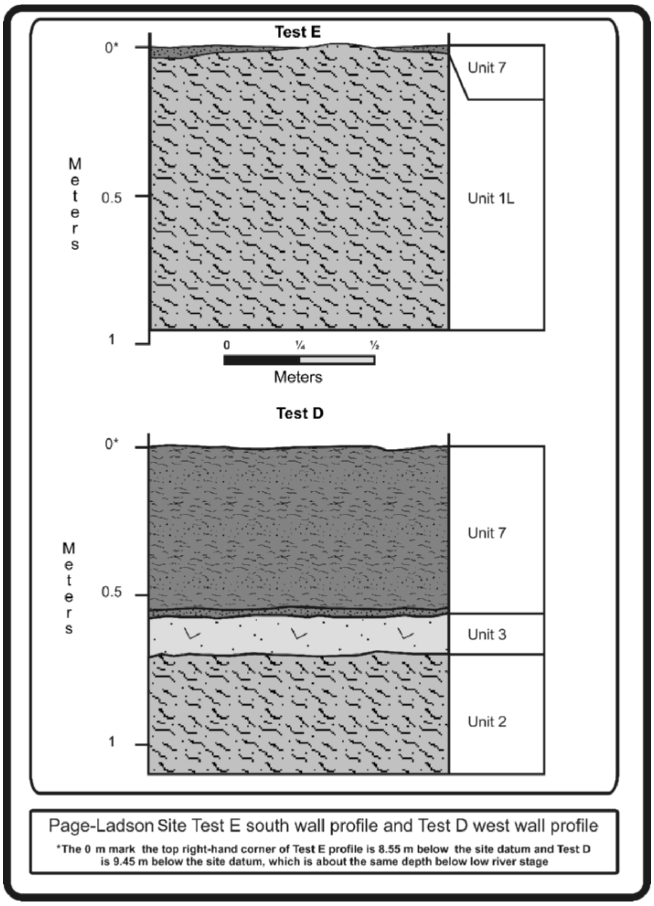


Figure 3.7 Stratigraphic profiles of Test D and Test E. Test D exposed the red peat of Unit 2 and an erosionally truncated Unit 3. Recent river sands and leaf mats lay on top.

3.3.1.4a Test D. (See Fig. 3.7.) Test D lies in the deepest part of the present river channel at Page-Ladson, almost −10 m ARPP RG. Excavation in Test D penetrated approximately 0.50 m below the present river bottom surface and revealed coarse sandy sediments similar to Unit 3 (Table 3.1), underlain by a compact, red to brown sandy, peaty silt. Vertebrate fossils were recovered from within and at the bottom of the sandy unit. Core 88.6 penetrated 1 m below the depth of excavation in Test D and recorded a continuing sequence of sandy silts and silty sands (Table 3.13).

3.3.1.4b Test D′. Excavation in D′, set north and west of Test D at −8.53 m ARPP RG, revealed two sedimentary layers similar to those recorded in D: a coarse, tan sand horizon underlain by a dense, organic-rich red to brown sandy silt. An abrupt, irregular contact marked the boundary between these two horizons. The surface of the silt featured a 1-m diameter depression; the overlying stratum followed and filled the contour. Excavation in the sandy unit yielded well-preserved vertebrate fossils, including a chlamythere (*Holmesina septentrionalis*) moveable scute.

3.3.1.5 Tests E and E′

3.3.1.5a Test E. Excavation in Test E (see Fig. 3.7), set −8.68 m ARPP RG and resting close to the eastern edge of Page-Ladson, revealed a single stratum of dense, red, woody peat. *Taxodium* wood from this bed dated to 18,400 +/− 220 ^{14}C BP, making this the oldest dated horizon at the site. Large pieces of *Taxodium* wood were common in this horizon, including a charred Cypress knee. Microstructural examination of the knee shows this individual to have been stressed. Test E also produced insect forewings or elytra (subsequently lost).

3.3.1.5b Test E′. Test E′ lies approximately −6.0 m ARPP RG and abuts the limestone scarp marking the eastern edge of preserved sediments at Page-Ladson. Excavation in Test E′ revealed a shell- and organic-rich sandy, peaty silt. Wood fragments were common, but not as common as limestone gravel, cobbles, and boulders.

3.3.1.6 Test I

Test I lies in the northern end of Page-Ladson, in the inundated segment of an abandoned surface channel entering the Aucilla (Fig. 3.1). Hand excavations in Test I encountered Recent silts and sands.

3.3.1.7 Test II

Test II also lies in the northern embayment at Page-Ladson (Fig. 3.1), at −4.13 m ARPP RG. Excavation in Test II penetrated approximately 1m into the sediment column and revealed four different horizons. These include a dense, woody peat at the bottom, a light gray silty sand with gastropod shells, burned wood, vertebrate fossils, including *Mammut*, and limestone pebbles and cobbles, grading to a light to medium brown sandy silt with crushed fine shells, and a gray to blue clayey silt that included Archaic age cultural materials.

3.3.1.8 Test F

Excavations in Test F encompass 6 years of fieldwork and approximately 40 m^2 of hard-won underwater exposure. Rigorous excavation methods resulted in a well-constrained sequence of sedimentological, palynological, paleontological, and archeological data (Latvis and Quitmeyer, this volume).

3.3.1.8a Test F-91. Cascading down the sloping contour of the Aucilla's western bank, Test F-91 slices through the sedimentary column at Page-Ladson (Fig. 3.8, Table 3.4).

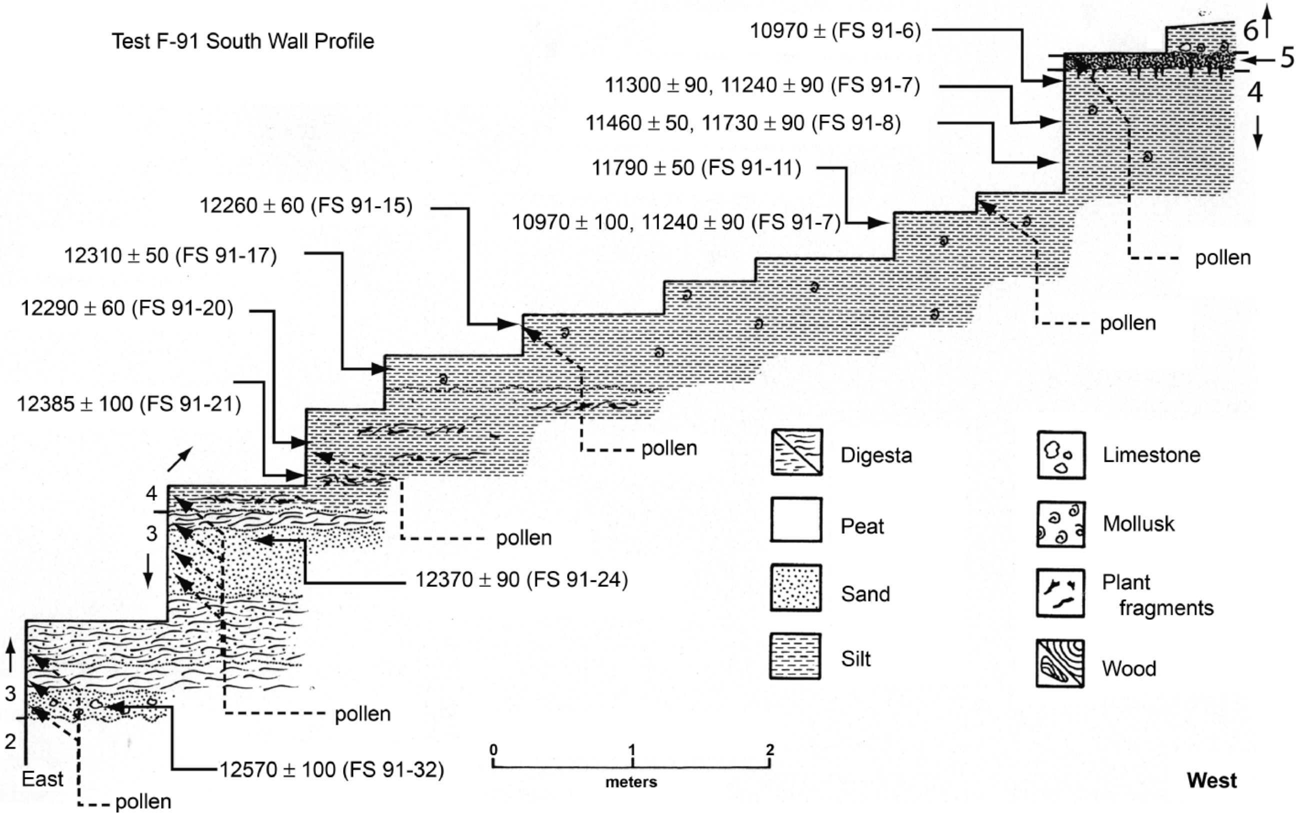


Figure 3.8 F-91 idealized south wall profile. This profile accurately reflects the changing lithology, but does not reflect original dips. Numbers on left and right are stratigraphic units and their boundaries. Selected carbon dated horizons are noted by solid arrows and identified by FS#. (See Table 4.2 in Webb and Dunbar, this volume.) Dashed arrows denote pollen samples. (See Hansen, this volume.)

Table 3.4 Test F-91 sediment column

AARP RG	*MSL*	*Unit*	*Comments*
–5.63	–2.65	6	Unit 6 only 0.20 m in Test F-91 and thickens westward into riverbank
–5.83	–2.85	5	Top of Unit 5 the is so-called Bolen surface
–5.93	–2.95	4	Sandy silts
–9.34	–6.36	3	Sands, sandy silts, and digesta
–10.56	–7.58	2	Red Peat. Maximum exposure in F-91 is 0.10 m

Dubbed "Stairway to the Past" because of its step-wise exposure of the sedimentary column (see inset in Fig. 3.2 for its geometry), the strata exposed in F-91 are laterally continuous with and similar to those detailed for Test C in Section 3.3.1.3. Because F-91 was a long, sloping trench, rather than a 5 m deep pit as Test C was, more of the strata were exposed for examination. This allowed for exploration of lateral variation in the strata. One notable feature uncovered in F-91 that was not present in the Test C strata bears examination. As in Test C, an abrupt, undulatory contact marks the boundary between Units 4 and 5 in F-91. The upper levels of Unit 4 in F-91, however, display 0.40–0.10 m long vertical cracks or shafts filled with sediments of Unit 5. These may represent infilled desiccation cracks. Polygonal cracks are not evident on the upper surface of Unit 4, so the interpretation is open. It is also possible that these are the result of human activity, as the surface of the overlying Unit 5 (in Test C) included cultural materials, but there is no other evidence to support this interpretation.

F-91's excavation protocols were specifically designed for rigorous, methodical sampling (Latvis and Quitmeyer, this volume); analyses of these samples provide some of the most tightly constrained and comprehensive results. Table 3.5 provides the key for interpreting the stratigraphic position of samples in the composite stratigraphic column and correlations between excavation/sampling levels (Table 3.5, column 4) and the stratigraphic units described in this chapter (Table 3.5, column 3). For example, chapters by Scudder (15) and McCarty and Schwandes (17) in this volume detail analyses of what the authors call Stratum 2A or sometimes Unit 2A. This use refers specifically to excavation level 2A of Test F-91, which corresponds with Unit 5 of the composite stratigraphic column used here.

3.3.1.8b F-92 and F-93. Test F-92 was located north of and adjacent to F-91 (Fig. 3.1, inset Fig. 3.2) at the deeper (eastern) end of the trench and eventually subsumed most of the "stairway". Test F-93 expanded to incorporate all of Test F-92. These test pits explored the lower strata (Units 2–4) in the Page/Ladson column (Fig. 3.9). The sediments exposed are laterally continuous with those in F-91 and in Test C and represent the same sedimentary environments. The western profile of F-93 (Fig. 3.9) clearly shows the southern aspect of the east and south-east dipping strata.

3.3.1.8c F.97. Research in 1997 focused on two adjacent 2 × 3 m excavation units, F.97-1 and F.97-2, approximately 4 m north of F-91, and located −5.58 m ARPP RG (Fig. 3.1). Excavation uncovered Pleistocene vertebrate fossils dominated by *Mammut*

Table 3.5 Test F-91 sediment column

ARPP RG	*MSL*	*Unit*	*Excavation level*	*Level thickness*	*Pollen*	*Comments*
0	–2.98	6	1	0.2		Unit 6 is only 0.20 m in Test F-91 and thickens westward into bank
0.20	–3.18	5	2a	0.1	X	So-called Bolen surface
0.30	–3.28	4	2b	0.11		Sandy silts
0.41	–3.39	4	3	0.21		
0.62	–3.6	4	4	0.19		
0.81	–3.79	4	5	0.17		
0.98	–3.96	4	6	0.22		
1.20	–4.18	4	7	0.14	X	
1.34	–4.32	4	8	0.15		
1.49	–4.47	4	9	0.19		
1.68	–4.66	4	10	0.2		
1.88	–4.86	4	11	0.24		
2.12	–5.1	4	12	0.16	X	
2.28	–5.26	4	13	0.2		
2.48	–5.46	4	14	0.23		
2.71	–5.69	4	15	0.17		
2.88	–5.86	4	16	0.2		
3.08	–6.06	4	17	0.18	X	
3.26	–6.24	4	18	0.18		
3.44	–6.42	4	19	0.18	X	
3.62	–6.6	4	20a	0.09		
3.71	–6.69	3	20b	0.1	X	Sands, sandy silts, and digesta
3.81	–6.79	3	21	0.19	X	
4.00	–6.98	3	22	0.19	X	
4.19	–7.17	3	23	0.18		
4.37	–7.35	3	24	0.16		
4.53	–7.51	3	25	0.2	X	
4.73	–7.71	3	26a	0.13	X	
4.86	–7.84	3	26b	0.07	X	
4.93	–7.91	2	27			Red Peat. Maximum exposure in F-91 is 0.10 m

americanum and several artifacts buried within this complex of eastward-dipping, interfingering strata. The sediments exposed included more than 12 horizons of peats, silts, sands, and proboscidean digesta. The lowermost strata represent the oldest sequence of rigorously excavated beds at Page-Ladson; radiometric dates from these strata span a range from 15,390 +/– 120 to 14,210 +/– 120. The upper units exposed in F.97 are lateral extensions of the strata encountered in the adjacent F-91 excavations and in Test C; radiometric dates from these beds demonstrate that they are time-equivalent to the lowermost sediments in F-91 and Test C.

3.3.1.8d F.97-1. The F.97-1 south wall profile (Fig. 3.10, Table 3.6) shows two southeast-dipping packages of sediment: a dense red peat overlain by a sequence of sand and digesta horizons.

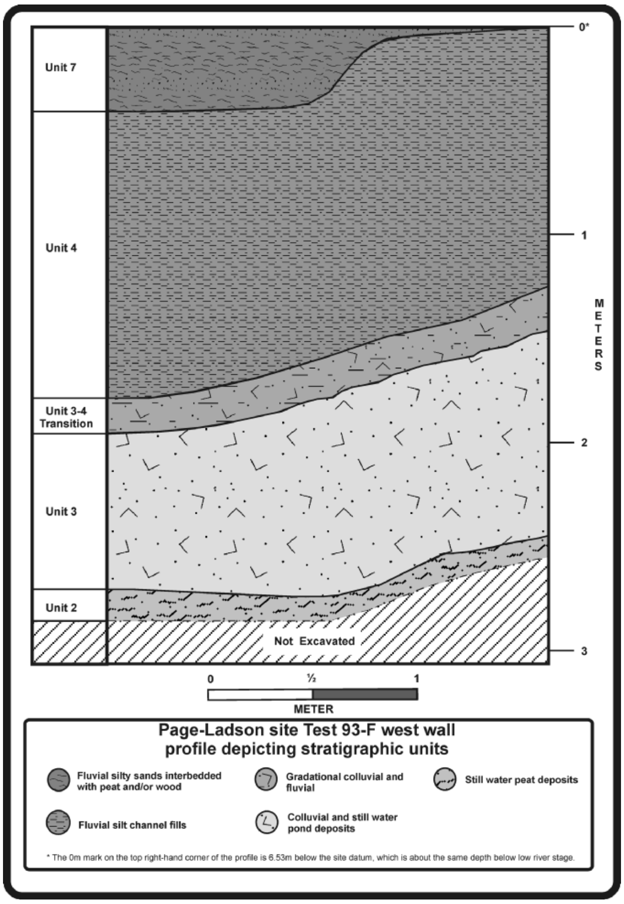


Figure 3.9 F-93 west wall profile. F-93 exposed Units 2, 3, and 4. Unit 4 was truncated by erosion of the modern Aucilla River. Recent river sediments overlay Unit 4.

The base of F.97-1 exposes Unit 2, the dense, red to brown, woody peat, to a thickness of 0.40 m on the upslope (west) end of the profile. Downslope (and downdip), the unit thins to <0.01 m of exposed sediment. The lower extent of Unit 2 was not penetrated in F.97-1; these thicknesses are therefore minimum estimates. Unit 2's lithology remains constant among its exposures across Page/Ladson. As in the base of Test C and F-91, wood and seeds, especially *Taxodium*, comprise a large fraction of its content. In addition, Unit 2's constituents display no evidence of current-mediated alignment. The upper surface of this stratum is highly irregular and may even appear cratered. An abrupt to diffuse contact marks the boundary between Unit 2 and the overlying Unit 3. Where diffuse, the contact appears as a variably thick (0.01–0.20 m) horizon (3a) of unevenly mixed red peat and digesta components. Where abrupt, a

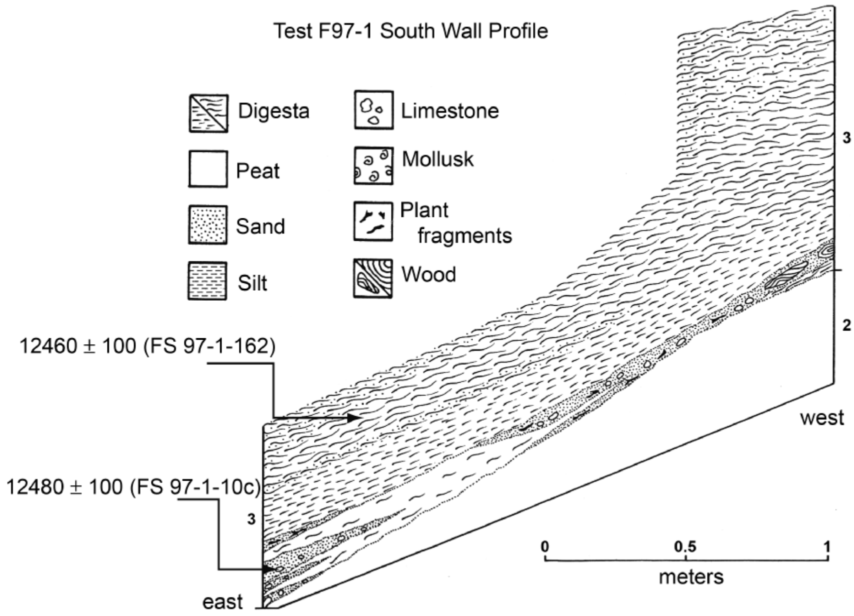


Figure 3.10 F.97-1 south wall profile showing strongly east dipping strata. Numbers on left and right are stratigraphic units and their boundaries. Selected carbon dated horizons are noted by arrows and identified by FS#. (See Table 4.2 in Webb and Dunbar, this volume.)

horizon (3b) of coarse quartz and shell sands with poorly rounded, low-sphericity limestone pebbles (common), gravels, and cobbles (uncommon) and short (0.01 m) to long (0.20 m) wood and twig fragments directly overlies Unit 2, concentrating in the irregular pockets in the surface of the unit. These abrupt and diffuse contact geometries are distributed unevenly across the surface of Unit 2. Crew speculation centered on interpreting the "cratered" surfaces as *Mammut* footprints; however, there is no definitive evidence for this.

Unit 3 in Test F.97-1 includes six different sedimentary horizons, identifiable by varying fractions of clastic sediments and digesta fragments. All are similar in appearance and content to the Unit 3 horizons described for Test C in Section 3.3.1.3, and most variations between horizons result from increased or decreased sand and fines

Table 3.6 Test F.97-1 sediment column

ARPP RG[1]	*MSL*	*Unit*	*Comments*
–5.49	–2.51	3	Upper surface dips 25°–35° southeast; subunits thicken downdip
–6.40	–3.42	2	Upper surface dips approximately 30° southeast

[1] Depths at center of 2 m wide profile.

content. A 0.15–0.20 m thick-horizon (3c) of digesta intermixed with silts and fine sands overlies horizons 3a and 3b. An increased sand to digesta ratio identifies the thin (0.04 m) horizon (3d) overlying 3c. Horizon 3d pinches out upslope, where 3c is immediately overlain by 3e, a 0.09–0.50 m thick horizon of dense, relatively pure digesta. Horizon 3f, overlying 3e in the west and east ends of the profile, records another increase in sand and silt content. Across the profile, contacts between horizons are undulatory and clearly defined. Although distinctions between horizons are based on relatively small differences in sand and silt content, rather than differences in constituent components, the boundaries are obvious. Several small, gravely sand lenses including wood, bone, and limestone gravel wedge into the down-slope margin of Unit 3 in the eastern margin of the profile.

3.3.1.8e F.97-2. Three sediment packages comprise the sediments in F.97-2: a lowermost sequence of sands and silts with interbedded digesta, a compact, red to brown woody peat, and a second sequence of coarse sands interbedded with digesta (Fig. 3.11, Table 3.7). The upper two strata (Units 2 and 3) are continuous with those exposed in F.97-1, however, because the strata are dipping south-east, excavation in the more northerly F.97-2 penetrated the oldest sediments tied to the sedimentary column in Test C.

A sequence of sandy silt horizons, bracketed by coarse quartz and shell sands with wood fragments, shells, and limestone pebbles comprise Unit 1. Horizon 1a, exposed in the western edge of the F.97-2 north wall profile, consists of brown to gray silty sand, with wood fragments and whole and fragmentary mollusks.

A clear, undulatory contact marks the boundary with the overlying horizon 1b, a 0.40-m thick (apparent) gray to brown sandy silt with localized concentrations of gastropods, thin sand laminae, and wood fragments. Half-way through the unit, beginning 0.33 m above the base of the western end of the profile, the sand, gastropod, and wood concentrations increase, appearing as stringers within the horizon. After 0.10 m, the concentrations decrease again. A thin (0.05 m) lens of digesta intermixed with gray silts and mollusk shells wedges in to the upper segment of 1b in the eastern half of the profile. An abrupt, undulatory contact separates horizon 1b from 1c, a 0.05–0.10 m thick bed of sand with coarse wood fragments, limestone pebbles, and mollusk shells.

A compact, red to brown woody peat (Unit 2) with localized concentrations of sand, silt, and limestone pebbles overlies Unit 1. The boundary is marked by an abrupt, smooth to undulatory contact. Larger wood fragments are concentrated in the

Table 3.7 Test F.97-2 sediment column

ARPP RG[1]	*MSL*	*Unit*	*Comments*
–6.50	–3.52	3	Horizons thicken to east
–6.62	–3.64	2	Dip relatively constant
–6.83	–3.85	1	Dips steepen within profile to approximately 30°

[1] Depths at center of 2 m wide profile.

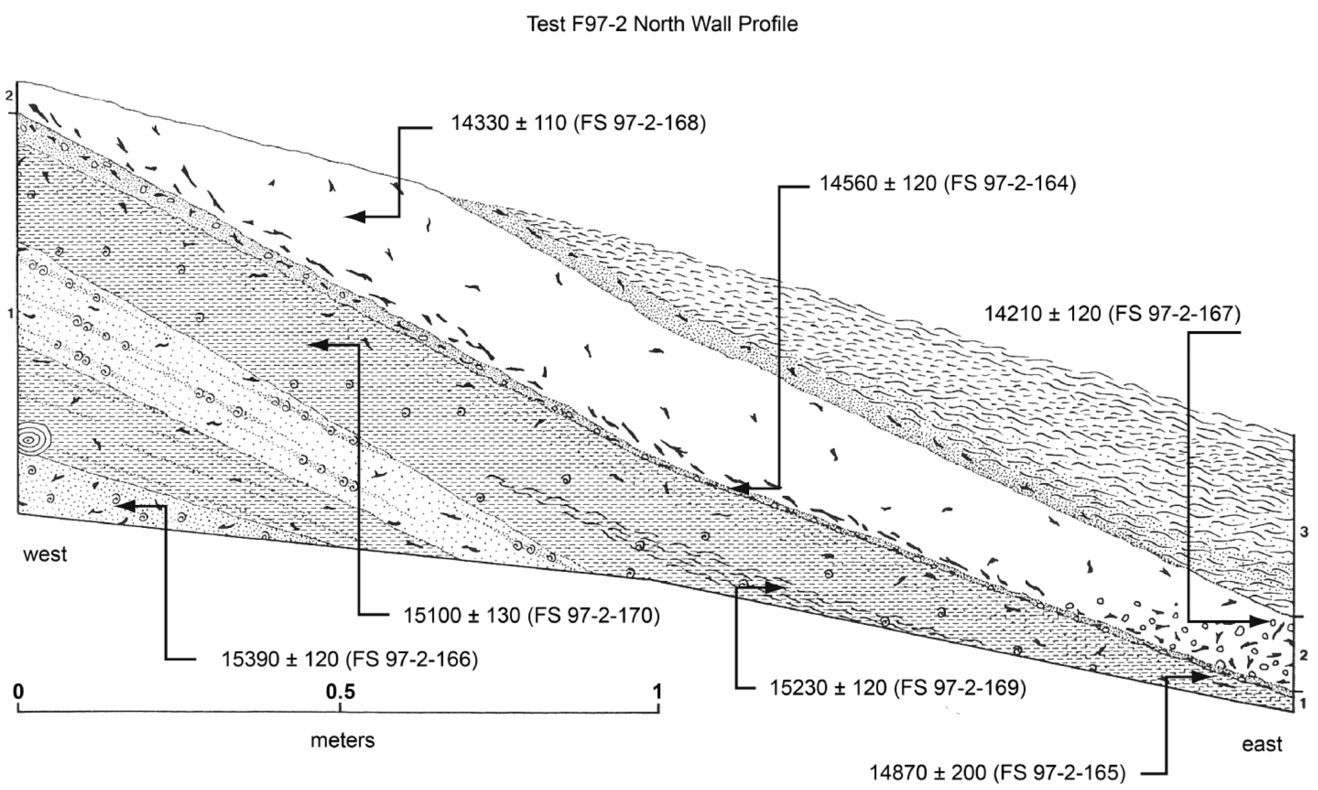


Figure 3.11 F.97-2 north wall profile showing strongly east and southeast dipping strata. Numbers on left and right are stratigraphic units and their boundaries. Selected carbon dated horizons are noted by arrows and identified by FS#. (See Table 4.2 in Webb and Dunbar, this volume.) See Figure 3.10 for legend.

lower 0.01–0.05 m of Unit 2; however, wood, especially *Taxodium*, is common throughout the unit. Silt and limestone granule and pebble concentrations increase in the toe of Unit 2 as exposed in the F.97-2 profile in Fig. 3.10. The upper surface of Unit 2, as elsewhere, is undulatory to irregular.

A thin (0.01 m) sand horizon (3a), grading to sands with intermixed digesta (3b), to pure digesta with some sand and silt matrix (3c) immediately overlies Unit 2. The lower digesta horizons may display a transition zone with digesta fragments intermixed with a red peaty matrix derived from the underlying Unit 2.

Excavations in F.97-2 recovered Pleistocene vertebrates, including a partial *Mammut americanum* maxilla, embedded in Unit 1 and penetrating up through Unit 2.

3.3.1.9 Test G

The letter G was used to identify two different excavations by two different people at Page-Ladson – Test G and Bolen G.

Test G lies against the western bank, a westward extension of Test D′ (Fig. 3.1), –8.66 m ARPP RG. Excavation 0.80 m deep revealed a single dark brown to gray sandy silt stratum, with well-preserved short (0.04 m) to long (0.45) charred and uncharred wood fragments throughout, locally abundant mollusks, and discontinuous lenses of pure sands or sandy silts. Limestone gravel, cobbles, and boulders were also present, increasing in frequency and size toward the western bank.

Bolen G and H represent excavation of Units 5 and 6 in a wide lateral expansion of Test C. Excavation and sample levels in Bolen G and H are correlated laterally with the lithologic units described in Tests C and F.

3.3.2 Cores

In 1988 we used portable vibracoring equipment, as described in Hoyt and Demarest (1981) and Lanesky *et al.* (1979), to place a series of cores around the Page-Ladson Site Complex (Fig. 3.1). Vibracoring underwater is a strenuous experience. Our efforts produced six useful sedimentary logs, varying from 1 to 6 m long and sampling most kinds of sediments at the site. In the following discussion, if horizons within a particular core are immediately referable to units listed in Table 1.1, they are listed in the appropriate core description as such. Otherwise, sedimentary horizons in core descriptions are numbered from bottom to top with a prefix listing the year and core number, e.g. 88.4.1 is the lowermost unit in core 88.4. Four cores (88.1, 88.2, 87.6, and 88.3) are briefly discussed here; descriptions of cores 88.4, 88.5, and 88.6 are provided in Tables 3.11–3.13 without comment.

3.3.2.1 Core 88.1

Immediately adjacent to Test C at –2.98 m ARPP RG, Core 88.1 mirrored the sediments we later encountered in the Test C excavations, from the uppermost Unit 7 at its top, to midway through Unit 4 at its maximum penetration (Table 3.8).

Table 3.8 Core 88-1

Unit	*Thickness (m)*	*Depth*[1]	*MSL (m)*	*Description*
7	2.0	0	0	Sand and leafy peat couplets: sands dark (10YR > 2/2), fine, well-sorted, unfrosted, no effervescence in dilute HCl; peats black to dark brown (5YR 2.5/1), approximately 90–95% organic, wood, twigs, and leaves; erosional unconformity between Units 6 and 7
6	1.06	2.0	–2.0	Sandy silt, upper 0.71 m gray (2.5Y 3/2), sands very fine, unfrosted, infrequent wood, limestone pebbles, frequent whole and fragmentary gastropod shells, strongly effervescent in dilute HCl, lower 0.37 m tan (2.5Y 4/2), darkening at bottom (10YR 2/2) rare wood, frequent gastropod shells and fish scales increasing to maximum immediately above contact with bed 5, strong effervescence in dilute HCl, sharp contact with Unit 5
5	0.10	3.06	–3.06	Sandy, clayey silt, dark brown (10YR 2/1), sands fine, unfrosted, charred wood, gastropod shells, fish scales, no effervescence in dilute HCl, sharp contact with Unit 4
4	1.54	3.16	–3.16	Sandy silt, gray (10YR 3/1) in upper 0.30 m to gray (10YR 3/3) below, sands fine to very fine, unfrosted, wood, increasing in frequency toward bottom, frequent shell fragments, charcoal, strong effervescence in dilute HCl

[1] Meters below sediment/water interface.

3.3.2.2 Core 88.2

Core 88.2 records 4.5 m of sediment (Table 3.9) in an embayment in the southwest corner of Page/Ladson, just north of a collapsed land bridge (Fig. 3.1). Two features of the core are particularly notable. First, the strata exposed in the core are unusual with respect to most areas of Page/Ladson, in that the column consists almost entirely of peats. The uppermost unit, 88.2.4, consists of the sandy Recent river bottom sediments: Unit 7 as exposed in the tops of Test C and Core 88.1, and certainly is continuous with them. Except for a 0.30 m thick sequence of interbedded peats and sands in Unit 88.2.2, the rest of the column consists of dark, rich peats composed of chopped woody organic material with a texture reminiscent of shredded tobacco and is consistent with the digesta deposits common in Unit 3; this core likely represents a thick accumulation of the digesta mats recognized in other parts of the site and other locations downriver. If so, digesta are distributed very widely along the western edge of the site.

The east and southeast-dipping beds within the lower strata of Core 88.2 are its second notable feature. Strata in Core Unit 88.2.2 consistently dip 15°–20° east and southeast. This core was taken just 2–3 m from the sheer limestone banks of the river; the vertical walls of the channel rise 3–5 m above the current average river level. The

Table 3.9 Core 88.2

Unit	*Thickness (m)*	*Depth*[1]	*MSL (m)*	*Description*
88.2.4	1.33	0	−0.02	Alternating sand and peat horizons, ~5 couplets, approximately 0.10 m thick with stringers of opposite lithology within. Sands 10YR 6/2–10YR 5/2, medium, moderately rounded, unfrosted. Peats leafy, 10YR 2/1. Compare Unit 7 in Table 3.1
88.2.3	0.47	1.33	−1.35	Fibrous peat, dark (2.5Y 2/0) or darker, wood fibers, twigs, seeds, leaves, 0.5–1 cm length, rare fine sands, no effervescence in dilute HCl
88.2.2	1.27	1.8	−2.0	Fibrous peat with sand horizons. Peat woody, dark (2.5Y 2/0 or darker, organic fibers short (0.5–1.0 cm); sands dark (2.5Y 3/2), medium to fine. 0.47 m thick sand horizon a −1.8 m ARPP RG, with thin peaty stringers. No effervescence in dilute HCl. Sandy horizons dipping variably south and east, between 5° and 20°. 0.08 m long wood fragment at −2.9 m ARPP RG
88.2.1	1.33	3.13	−3.15	Fibrous peat, woody, dark (2.5Y 2/0) or darker, organic fibers, shredded tobacco texture with occasional silt blebs, well-preserved, unstained wood, no effervescence in dilute HCl, single 0.01 m thick fine sand horizon

[1] Meters below sediment/water interface.

presence of dips close to the limestone walls of the channel is more evidence that the lower strata in the Page–Ladson Site are quiet water paleosinkhole fill, not foreset beds of channel deposits. These dipping digesta mats lie between 3 and 5 m below the current average river level. At the time of the "deposition" of the digesta, the height of the limestone walls would have been even higher because of the lower water levels.

3.3.2.3 Core 87.6

In 1987 we cored the bottom of the then-shallow Test C and recovered a 2.5 m long sedimentary column. Core 87.6 records the lower 2 m of Unit 4 and the upper 0.5 m of Unit 3. (See Test C description in Section 3.3.1.3 and Table 3.3.) Further excavation of Test C removed all the material through which the core penetrated.

3.3.2.4 Core 88.3

Core 88.3 (Table 3.10) records approximately 2 m of strata on the west side of the site near what later became Test F (see Fig. 3.1 and Section 3.3.1.8). The lower 1 m of this core records a sequence of steeply dipping fining-upward couplets of sand and silt. The dip of these beds progressively decreases from bottom to top, from a high of about 45° near the bottom to approximately 30° near the middle of the core. An abrupt erosional contact marks the top of this unit (88.3.3). The

Table 3.10 Core 88.3

Unit	*Thickness (m)*	*Depth*[1]	*MSL (m)*	*Description*
88.3.6	0.24	0	−5.19	Shelly, silty sand, light gray (2.5Y 4.5/2), medium to fine, whole and fragmentary mollusk shell, poorly rounded limestone pebbles, 0.1–0.2 cm diameter, 1–3 cm length wood fibers common, reactive in dilute HCl. Diffuse contact with unit below
88.3.5	0.16	0.24	−5.43	Sandy, shelly silt, gray to dark gray, (10YR 3/2–2.5YR 3/2), sands medium to fine, mollusk shell, woody fibers and fragments common, reactive in dilute HCl
88.3.4	0.23	0.40	−5.59	Shelly, gravely sand, light gray (2.5Y 3.5/2), sands medium, whole and fragmentary mollusk shell, limestone pebbles and gravel, 0.08 m long wood fragments, reactive in dilute HCl. Abrupt contact with unit below, marked by 0.03 m thick wooden plug filling core tube
88.3.3	0.28	0.63	−6.22	10–12 couplets of (1) loosely compacted peats and (2) dense, organic-rich silts. Peats brown (10YR 2/1.5–7.5YR 3/2), fibrous, unreactive in dilute HCl; silts dark gray (10YR 2/2), dense. Abrupt, erosional contact with unit below. Unit dipping horizontal to subhorizontal
88.3.2	0.94	0.91	−7.13	Alternating 0.02–0.22 m thick silty, shell-rich sands and sandy silts; sands light to medium gray to brown, (10YR 3.5/2–2.5Y4/2), medium to fine, abundant mollusk shell sand, wood fragments locally abundant, charcoal, one fragment undiagnostic bone; silts gray, (10YR 3/2) organic, frequent wood fragments, mollusk shell; horizons dipping 45° (near bottom) to 30° near top of unit, contacts between overlying sand horizons and underlying silts abrupt, contacts between overlying silts and underlying sands clear, gradational, coarse couplet between −1.26 and −1.24 m depth, marked by coarser sands, layered 0.05-m long wood fragments, and whole gastropod shells. Contact with underlying unit abrupt. Horizons
88.3.1	0.09	1.85	−8.98	Sandy, organic-rich silt, lower section mottled, 10YR 2/1, 10YR 3/1.5, upper section 10YR 2.5/2, sands medium to fine, mollusk shell fragments, wood and organics common, 0.02-m thick silty peat horizon midway through unit, upper section with thin (1 mm) stringers of wood, shell sand, and organics, horizons dipping approximately 45°

[1] Meters below sediment/water interface.

strata above are flat lying, loosely compacted peats and silts. The steeply dipping beds reflect steep paleobathymetry, while the lessening dip may represent infilling of the sinkhole. The peats and silts in the upper part of the core are typical of the seasonal deposits of the Aucilla today; the unconformable contact between Units 88.3.3 and 88.3.2 likely represents erosion and exposure of older sediments by flowing water.

3.3.3 Composite Section Sediment Analyses

Table 3.14 presents sediment analyses of a composite section from the Page-Ladson Site. See Scudder (this volume) for methods. The composite section includes analyses of samples taken from expanded Test C (labeled Bolen G and H) and Test F-91 excavations. Data include pH, phosphorus, and percent weight fractions of organic carbon, sand, silt, and clay, as well as a breakdown of sand size fractions.

Sand dominates the lower levels of the section, peaking near 98% at the bottom of Unit 3. The sand fraction remains high through Unit 3, ranging between 70% and 90%, but then drops precipitously in the transition to Unit 4. The silt size fraction mirrors this pattern, remaining less than 20% within Unit 3, then increasing to over 60% in Unit 4. Sand and silt oscillate within Unit 4, mirroring each other. Ultimately the % sand size fraction diminishes while the silt size fraction increases through Units 5 and 6. Sand spikes again at the top of the section in Unit 7, the modern river sediments. A statistical test of the hypothesis that sand size fraction decreases with cumulative thickness shows a significant correlation with $R = 0.85$ and $R^2 = 0.72$ at $p < 0.001$. The calculated relationship is % sand fraction = $-0.10\ ^{*}$ (cumulative thickness) + 0.81. This analysis excludes the sample from Unit 7 at 6.3 m cumulative thickness because Unit 7 represents transient, unconsolidated modern river sediments (see Fig. 3.12).

The graph can be misleading, as at first glance it appears that the data show a decrease in flow rates over time, based on the size fraction; however, the bulk of the sediment volume, the sand-rich lower levels, is made up of digesta. The sands collect in the interstices and irregular layers. It is unlikely that the digesta were washed in by flowing water, rather, they represent *in situ* "deposition".

Table 3.11 Core 88.4

Unit	*Thickness (m)*	*Depth*[1]	*MSL (m)*	*Description*[2]
88.4.3	0.31	0	−2.52	Silty sand, 10YR 6/2, medium, moderately-sorted with sand-sized shell fragments + whole shells, uncommon wood fibers, wood increases toward top of unit, reactive in dilute HCl
88.4.2	0.25	0.31	−2.83	Sandy peat, 5Y 2.5/1 where pure organic, 5Y 6/1 in horizons with increased sand, sands fine, primarily mollusk shell, peat dense, woody, unreactive in dilute HCl, except in shell sands, abrupt contact with unit below
88.4.1	0.59	0.56	−3.39	Sandy silt to clay, 10YR 6/2, uncommon 0.03 m long woody fragments, wood or twig fibers, whole and fragmentary mollusk shell, uncommon to common limestone pebbles and cobbles, strongly reactive to dilute HCl, very plastic and moderately sticky when fresh, dries to a rock-like consistency

[1] Meters below the sediment/water interface.

[2] All descriptions under fluorescent lights. Unit 88.4.1 dried to a concrete-like consistency, requiring vigorous sawing to open the core tube. As a result, any structure present in 88.4.2 and 88.4.3 was destroyed.

Table 3.12 Core 88.5

Unit	*Thickness (m)*	*Depth*[1]	*MSL (m)*	*Description*[2]
88.5.4	0.29	0	–0.52	Peaty sand, 2.5Y 3/2, medium, moderately-sorted, wood fragments, fibers, and leaves very common, weakly reactive in dilute HCl. Abrupt contact with underlying unit. Recent river bottom sediments
88.5.3	1.33	0.29	–0.81	Dense, calcareous, shelly silt to clay, 10YR 3/1, mollusks common and larger above lower contact, teleost spines, reactive in dilute HCl, very similar to Unit 88.5.1 below, clear contact with underlying unit
88.5.2	0.25	1.62	–2.43	Woody, peaty silt, 10YR 3/1 (dry) to 10YR 2/1 (wet), sands fine to very fine, uncommon mollusk shells, and 0.05 m wood fragments, weak reaction in dilute HCl, diffuse 0.12 m contact with underlying unit
88.5.1	0.37	1.72	–4.15	Dense, calcareous silt to clay, 10YR 3/1, medium to fine mollusk shell, <0.03 m wood fragments, strongly reactive with dilute HCl, very plastic when fresh, dries rock-hard, limestone cobbles, 8 × 4 cm, recovered from bottom of core

[1] Meters below sediment/water interface.
[2] All descriptions under fluorescent lights, after desiccation.

3.4 Conclusions

Most of the fine-grained, organic-rich peats, clays, fine sands and silts found at the Page-Ladson Site represent the gradual infilling of a sinkhole or sinkholes with locally derived clastic sediments and organic detritus. Thick, irregularly shaped lenses of proboscidean digesta attest to the repeated presence of mastodon (*Mammut americanum*) (see Newsom and Mihlbachler, this volume). Couplets of peat and sand in the upper

Table 3.13 Core 88.6

Unit	*Thickness (m)*	*Depth*[1]	*MSL (m)*	*Description*
88.6.3	0.12	0	–6.75	Shelly, silty sand, 2.5Y 5/2, sands medium to fine, mollusk shell and shell fragments common, wood common, limestone granules and pebbles, reactive in dilute HCl, gradational contact with underlying unit
88.6.2	0.80	0.12	–6.87	Silts and sandy silts, 10YR 3/2–2.5Y 3/2, sands fine, sand to granular sized mollusk shell fragments common, wood common, reactive in dilute HCl; unit consists of repeated coarsening-upward sequences grading from silt to sandy silt with increased shell and wood content and size; abrupt contact with underlying unit
88.6.1	0.10	0.80	–7.67	Dense, sandy silt, 10YR 3/2, sands fine, uncommon woody fibers, reactive in dilute HCl

[1] Meters below sediment/water interface.

Table 3.14 Page/Ladson sediment analyses

Excavation	*Unit*	*ARPP RG (m)*	*MSL (m)*	*Cumulative thickness (m)*	*pH*	*% O.C.*	*P (PPM)*	*% VC*	*% C*	*% M*	*% F*	*% VF*	*% Sand*	*% Silt*	*% Clay*
Bolen G w-14	7	–4.53	–1.55	6.30	ND[1]	0.0	230	0	0	5.2	64.8	10	80	12	8
Bolen H w-22	6	–4.88	–1.9	5.95	ND	4.2	1340	0	0.4	0.8	7.2	17.2	25.6	60.2	14.2
Bolen H w-21	6	–5.1	–2.12	5.73	ND	0.0	1150	0.4	0.4	1.6	10	19.6	32	60.6	7.4
Bolen G w-13	6	–5.28	–2.3	5.55	ND	5.2	1200		0.8	2	8.8	17.2	29.2	55.4	15.4
Bolen G w-12	6	–5.5	–2.52	5.33	ND	3.7	1060	0	0	0.8	6	15.2	22	62.5	15.5
Bolen G w-11	6	–5.68	–2.7	5.15	ND	4.6	1520	0.2	0.8	1.8	7.8	14.8	25.4	52	22.5
Bolen G w-10	5	–5.88	–2.9	4.95	ND	10.8	461	3.6	1.6	4.4	13.2	9.2	32	37.6	30.4
Bolen G w-9	4	–6.1	–3.12	4.73	ND	5.9	1520	0	0	0.8	4.4	12.4	17.6	77.8	4.6
Bolen G n-1	4	–6.33	–3.35	4.50	ND	5.0	1860	0.4	1.2	4.8	15.6	16	38	45	17
F-91, level 5[2]	4	–6.53	–3.55	4.30	7.2	8.2	1076	ND	ND	ND	ND	ND	ND	ND	ND
F-91, level 7	4	–6.93	–3.95	3.90	7.5	9.3	1142	0.4	1.6	5.2	19.6	19.2	46	43.4	10.6
F-91, level 8	4	–7.13	–4.15	3.70	7.2	9.8	3475	ND	ND	ND	ND	ND	65	23.4	11.6
F-91, level 12	4	–7.93	–4.95	2.90	7.1	9.2	993	ND	ND	ND	ND	ND	54.5	31.9	13.6
F-91, level 17	4	–8.93	–5.95	1.90	7.8	8.3	914	0.0	0.8	1.6	9.2	17.2	28.8	61.8	9.4
F-91, level 19	4	–9.33	–6.35	1.50	7.9	6.0	723	1.4	2.8	8.6	24.4	19.6	56.8	39.1	4.1
F-91, level 20b	3	–9.58	–6.6	1.25	8	3.0	457	2.0	6.6	19.6	48.8	12.4	89.4	7	3.6
F-91, level 21	3	–9.73	–6.75	1.10	7.7	3.0	533	4.0	9.6	21.2	40	10	84.8	9.3	5.9
F-91, level 22	3	–9.93	–6.95	0.90	7.9	5.3	761	3.2	6	17.6	44.4	16.4	87.6	7.4	5
F-91, level 23	3	–10.13	–7.15	0.70	7.5	2.2	761	2.8	8	21	46.6	9.2	87.6	8.8	3.6
F-91, level 25	3	–10.53	–7.55	0.30	7.6	12.3	1142	0.0	1.2	7.2	44	18	70.4	20.5	9.1
F-91, level 26a	3	–10.68	–7.7	0.15	7.5	15.4	1713	1.2	2.8	10.4	46.8	13.2	74.4	17.8	7.8
F-91, level 26b	3	–10.78	–7.8	0.05	8.3	0.6	1409	8.4	17.2	41.4	29	1.6	97.6	1.2	1.2

[1] No data.

[2] See Table 3.5 for F-91 tie-ins.

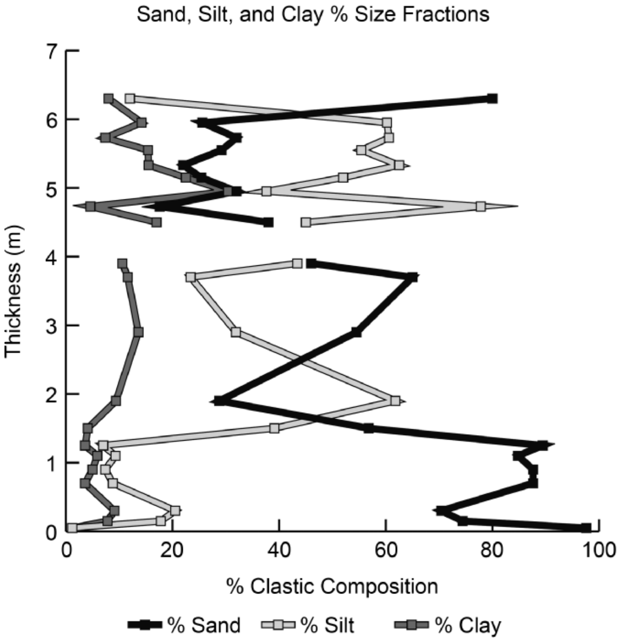


Figure 3.12 Sand, silt, and clay % size fractions. Percent clastic composition is plotted on the x axis. Position within the section is plotted on the vertical axis. Sand dominates the lower levels (Unit 3 here), oscillates within Unit 4 but ultimately diminishes while the silt size fraction mirrors this pattern. Sand spikes again at the top of the section – this represents Unit 7, modern river sediments.

strata represent the transition from quiet-water sinkhole deposition to the seasonally variable stream flow of the Aucilla River.

Several major processes have governed the dynamic geologic and fluvial history of this part of the Aucilla River during the late Quaternary. First are the transitions between surface and subterranean drainage. A second major influence has been formation of sinks and their consolidation into subaerial watercourses within the WKP. Both of these processes are ultimately governed by vertical migration of the water table in response both to rainfall and to sea-level changes. During each interglacial cycle of the Quaternary Era, the surface drainage in this region has probably changed its exact course. The abandoned channels near the Half Mile Rise section of the Aucilla River give evidence of such variations. Another example of shifting surface drainage is the capture of one branch of the Wacissa River by the Aucilla River, presumably during the most recent deglacial hemicycle. Such processes have strongly influenced the depositional history of the Page-Ladson Site Complex.

In the region of the Page-Ladson Site, the prevailing pattern of rising water tables and the widespread presence of backfilling sinkholes combined to yield nearly continuous accumulations of fine-grained, organic sediments up to more than 8 m thick. Such sediments, as demonstrated in the ARPP excavations, span more than 10,000 years during the Late Pleistocene and Early Holocene.

3.5 Acknowledgements

Jim Dunbar, Dave Webb, Irv Quitmeyer, and Joe Donoghue all improved this paper with discussion, comments, memories, and suggestions at one time or another. Jim Dunbar gave immeasurable help with the production of figures and retrieving long-filed data. Mark Muniz' sketches clarified some of the stratigraphy. Sylvia Scudder and others graciously provided the sediment analysis data. Mike Faught and Brinnen Carter were great sounding boards over the years. Finally, many thanks to all the workers on the ARPP from the beginning to the end, but especially to Bill Gifford and, most of all, Joe Latvis.

References

Cooke, C. W., and Mansfield, W. C., 1936, Suwannee Limestone of Florida, Geological Society of America Proceedings, 1935, pp. 71–72.

Dunbar, J. S., Webb, S. D., and Cring, D., 1989, Culturally and naturally modified bones from a Paleoindian site in the Aucilla River, North Florida, in: *Bone Modification* (R. Bonnichsen and M. H. Sorg, eds.), pp. 473–497, Center for the Study of the First Americans, Orono, Maine.

Healy, H. S., 1975, Terraces and shorelines of Florida, Florida Bureau of Geology Map Series No. 71.

Hoyt, W. H., and Demarest, J. M., IV, 1981, Vibracoring in coastal environments: a description of equipment and procedures, DEL-SG-01-81, Sea Grant College Program, University of Delaware, Newark, Delaware, pp. 20–31.

Lane, E., 1986, Karst in Florida, Florida Geological Survey Special Publication No. 29, 100 pp.

Lanesky, D. B., Logan, B. W., Brown, R. G., and Hine, A. C., 1979, A new approach to portable vibracoring under water and on land, *Journal of Sedimentary Petrology*, 49, 654–657.

Puri, H. S., 1957, Stratigraphy and zonation of the Ocala Group, Florida Geological Survey Bulletin No. 38, 248 pp.

Puri, H. S., and Vernon, R. O., 1964, Summary of the geology of Florida and a guidebook to the classic exposures, Florida Geological Survey Special Publication No. 5 (revised), 312 pp.

Rupert, F. R., 1996, The geomorphology and geology of Taylor County, Florida, Florida Geological Survey Open File Report No. 70.

Rupert, F. R., 2000, Regional and local geologic setting of the Woodville Karst Plain, in: *The Wakulla Springs Woodville Karst Plain Symposium – Transactions October 9, 1998* (W. Schmidt, J. M. Lloyd, and C. Collier, eds.), Florida Geological Survey Special Publication No. 46, pp. 4–10.

Schmidt, W., 1997, Geomorphology and physiography of Florida, in: *The Geology of Florida* (A. F. Randazzo and D. S. Jones, eds.), pp. 112, University of Florida Press, Gainesville, Florida.

Scott, T. M., 1988, The lithostratigraphy of the Hawthorn Group (Miocene) of Florida, Florida Geological Survey Bulletin No. 59, 147 pp.

Scott, T. M., 1991, A geological overview of Florida, in: *Florida's Ground Water Quality Monitoring Program: Hydrogeological Framework*, Florida Geological Survey Special Publication No. 32, pp. 5–14.

White, W. A., 1970, The geomorphology of the Florida peninsula, Florida Geological Survey Bulletin No. 51.

Yon, J. W., Jr., 1966, Geology of Jefferson County, Florida, Florida Geological Survey Bulletin No. 48.

Chapter 4

Carbon Dates

S. DAVID WEBB[1] and JAMES S. DUNBAR[2]
[1]Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.
[2]Department of Historical Resources, Gray Bldg., Tallahassee, FL 32399 USA.

4.1 Introduction

The primary goal of the ARPP excavations at the Page-Ladson Site complex was to establish a long nearly continuous stratigraphic record of environmental history during the late Pleistocene and early Holocene. Once the sedimentary sequence and the diversity of organic preservation had been established, it became evident that a refined series of multiple carbon dates was essential to assure sound correlation with virtually any other set of prehistoric events from local to regional and even to a global perspective.

In the half century since the radiocarbon method was established it has become the primary standard for communication about chronology within the many interrelated disciplines dealing with the Quaternary. During the past 20 years the application of accelerator mass spectrometry (AMS) to dating radioactive carbon reduced the required sample size from many grams to a few milligrams (Taylor, 1992). Where previously a bone date might require the whole bone of an ungulate, now a tooth of a rodent provides an ample sample. An additional practical advantage of AMS dates is that use of a pinpoint sample goes far toward eliminating potential contaminants that were often incorporated into old-style bulk samples.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 83–101

Throughout this book diverse specialists turn to the carbon-dated framework to integrate and correlate their discussions which range from climatic events and environmental patterns to aquatic and terrestrial flora and fauna and finally to human cultures. Therefore the validity of the carbon dates and their placement within the site profiles become fundamental.

In this chapter we describe the field methods by which we acquired carbon samples and the lab procedures by which we submitted them to three major labs. We also discuss various issues regarding sample biases and consider current issues concerning calibration curves and calendar corrections. Finally, we present the essential results by which the Page-Ladson Site complex can claim century-scale chronology for a critical interval of ten millenia. This framework of dates, tied directly to the physical stratigraphy, extends from the time of the last glacial maximum, ca. 18,500 ^{14}C BP, to a time just after the final retreat of the Laurentide Ice Sheet, ca. 8200 ^{14}C BP.

4.2 Methods

4.2.1 Field Sampling

The first samples for carbon dating came from 4-in. aluminum vibracore tubes taken at a number of sites along the course of the Aucilla River. These cores provided the preliminary framework upon which subsequent analyses of stratigraphy and geochronology were erected. The Page-Ladson Site complex was represented by six cores ranging in length from one to six meters, as described in Chapter 3 by Kendrick. When the cores were cut, key organic strata were sampled and a few dates were acquired. On the other hand, we recognized that more reliable (less potentially disturbed) carbon samples would be acquired directly from hand excavations that would come later.

The majority of datable samples were acquired during vertically controlled SCUBA excavations, as described in Chapter 1 by Latvis and Quitmyer. The most important samples were taken in Test Pit F during the 1991 and 1993 seasons. This enterprise was appropriately dubbed “The Stairway into the Past”. In subsequently developed test pits we often redated familiar strata a few meters laterally. Such redundancy is generally favored in the sciences, and for several reasons demonstrated below, that principle applies very well to carbon dating. We also sought to acquire several dates immediately above and just below stratigraphic unit boundaries as set forth by Kendrick in Chapter 3.

During the excavations bulk sediments were bagged according to specific field protocols. Upon returning to the laboratory, the samples were more carefully picked and prepared for submission to appropriate carbon-dating labs.

4.2.2 Selection of Datable Materials

In general we sought to acquire dates on two or three different materials from the same stratigraphic unit. When wood was selected we sought compact pieces that represented one or only a few growing seasons. The context was carefully scrutinized to be sure the wood was not an intrusive growth but was germane to the sediments. Much preferred to wood were compact single-year products such as nuts and seeds. A number of dates were based on hickory nuts and on gourd seeds. These had the virtues of being dense cellulose and of being the product of a single season of growth. In a few instances we were required to select bulk organic material such as digesta (chewed fibers), a small plug of peat, or even a small amount of organic clay, but these were used only as a last resort.

Toward the end of our 20-year project, we selected a few specimens of bone and ivory for dating. In the early years we avoided bone dates for two reasons: the cost was prohibitive and collagen dates were still providing anomalous results, primarily because of contamination by humates. Several important methodological advancements in bone dating, following the advent of AMS dating, made that approach more desirable in the later phases of ARPP work.

4.2.3 Laboratory Submissions

We sent samples to three radiocarbon labs. The majority went to Beta Analytic Inc in Miami, Florida, the world's largest radiocarbon laboratory. They offered us moderate prices for multiple dates and excellent service in terms of turnaround time and response to questions. We attempted to balance the number of AMS dates as compared with conventional radiometric dates. The only advantage of conventional dates was that our budget could support more of them. With relatively large samples such as wood pieces there was no major disadvantage methodologically. We felt that there was some advantage to employing multiple labs, and so we also enjoyed the excellent reputation and good results from the University of Arizona, AMS facility supported by the National Science Foundation. Dates from this latter source are listed as AA, followed by a sample number, in the table of radiocarbon dates below.

Thirdly we submitted some culturally modified bone and ivory specimens from various Aucilla River sites to Stafford Research Laboratories, Inc in Boulder, Colorado and to Beta Analytic. Our first AMS collagen sample, submitted to Beta in December 1997, was an extremely well-preserved fragment of the cheekbone of an extinct camelid (*Palaeolama mirifica*). It was backed up by a datable gourd seed against which the collagen date could be checked. The excellent results from that llama bone, derived from 15 gm sample drilled from the squamosal, helped convince us that we should overcome our initial caution about the variable results traditionally coming from collagen samples.

The ultimate value of directly dating a bone or ivory object is that there can be no doubt about the association of the object with the date. We urgently wished to have a direct date on the extremely rare worked ivory shafts that are more frequently encountered in Florida rivers than anywhere else in the New World. We therefore submitted a very well preserved ivory shaft from Sloth Hole Site on the Aucilla River to the Stafford Lab. They proceeded very cautiously. They first conducted a quantitative analysis of individual amino acids to determine if the composition of the mastodon ivory resembled the collagen found in modern dentine. The most important amino acid characteristics of collagen are proline, hydroxyproline, glycine and aspartic and glutamic acids. Although the proportions were somewhat skewed relative to a modern dentine control, the amino acid profile of the fossil ivory was "collagen derived" (Thomas W. Stafford, Jr. pers. com. in letter, June 7, 2000).

The second phase of this ivory processing was a quantitative assessment of the original protein. The ivory contained only 7 nm of amino acids per milligram of sample. This meant that only 0.3% of the original protein remained. Although these results were somewhat discouraging, the Stafford Lab consulted with ARPP to consider whether it was feasible to proceed. At least 1 g, perhaps 1.5 g, of the 3.7 g submitted would be required for such a faint sample. And the low amino acid content might cause the resulting date to be younger than expected. An important consideration at this point was the fact that in the field the ivory shaft had the color of fresh ivory and appeared pristine. A further favorable observation was that when the shaft was cut, to provide a sample for submission, it smelled strongly of "burning protein". Such a smell gave more hope for adequate collagen preservation than the more rigorous analysis at Stafford Lab. Thus it was determined that the analysis should proceed. This was another example of the careful procedure and remarkably improved results that now come from bone collagen dates (Stafford *et al.*, 1999).

4.2.4 Problems and Caveats

Before each field season, the Aucilla River Prehistory Project attempted to specify radiocarbon sampling protocols in its research plan. And every effort was made to secure and sequester carbon datable samples from each stratigraphic level the moment they were collected. On several occasions, however, bags inadvertently were kept in too warm a place for too long and algal growth contaminated the samples.

Every project collecting samples for radiocarbon dates must consider various natural contaminants that might systematically interfere with true radiocarbon values. In the Aucilla River the primary concerns were the possible hardwater effect of Oligocene carbonates that outcropped widely in the region and the possibility of contamination by adventitious tree roots that penetrated deeply into the banks and bottoms of the river course. A major advantage of AMS dates was that by pinpointing the material dated they avoided possible introduction of a few adventitious pieces of carbonates that were too old or modern vegetation that was too young. And by consistency of bulk dates with some of these more secure dates most concerns about contaminants were alleviated.

We were fairly consistent in avoiding use of peat samples for dates. This was based on cautionary reports in the literature, for example Shore *et al.* (1995), in which a mixture of unreliable carbon sources including humates and dissolved carbonates often contaminate the samples. In the lowermost stratigraphic levels of Unit 1 and Unit 2 we had no choice but to date peat samples. In such cases we carefully picked the samples apart and submitted the more substantial individual fragments for AMS dates.

Larger concerns for the regional affects of old carbon reservoirs were not adequately worked out in the course of this project. We are reasonably certain that marine carbonate reservoir effects did not apply to our region, simply because during the glacial maximum sea levels had regressed far out into the Gulf of Mexico. Outflow from the Floridan Aquifer produced the major source of freshwater in the sinkhole complex sampled in this study. If the Floridan Aquifer of the latest Pleistocene required an old carbon reservoir correction, that issue will have to be recognized in future studies in the region.

4.2.5 Calibration Concerns and Calendar Years

The vast majority of global and local age determinations for late Quaternary history are expressed in radiocarbon years, and this volume adheres to that tradition (Dasovich, 1996; Lowe *et al*., 2001). On the other hand, some critical data sets depend on quite different methods of age determination, for example tree rings, annual layered ice-cores, and ^{230}Th dating. This raises the problem of whether to attempt correlation between different chronologies derived through different methods. Some researchers have opted to avoid correlation between dating methods (e.g. Dyke *et al*., 2002). Most others attempt to do so (e.g. Hughen *et al*., 2000a,b), simply because most disciplines benefit by participating in a fully integrated record of Quaternary events. A clear example of this quest is presented by Lowe *et al*. (2001:1182–1183):

> All radiocarbon age measurements for events and materials of late glacial-interglacial transition age should be calibrated using INTCAL98 ... in order to standardize data and facilitate comparison. ... More attention should be paid to the detailed probability structures in the original radiocarbon measurements and in the INTCAL98 calibration data set. The uncertainties of calibration can be reduced for a series of radiocarbon dates using, for example, a Bayesian approach to probability assessments, which incorporates prior information about stratigraphic context and succession of the series of dates into the analysis. ...

In the past decade numerous studies have attempted to refine the radiocarbon record by recalibrating it to exact solar years. The reason for attempting such calibrations is the discovery that the true age given by the annual rings in an ancient bristlecone pine, for example, differed from the radiocarbon determination (Taylor *et al*., 1996). Many researchers recognized the onset of both the Younger Dryas and subsequent Preboreal as major episodes of ^{14}C disruptions (Marchal *et al*., 2001). A particularly long flat spot in the radiocarbon curve occurs in the terminal Pleistocene just when many exciting Quaternary events occur, including peopling of the Americas, megafaunal extinctions, and rapid climate change (Taylor *et al*., 1996; Fiedel, 1999).

In general, cool phases of the last glacial recession have resulted in episodes of atmospheric ^{14}C supercharging (Lowe *et al*., 2001), most notably during Heinrich ice-rafting events in the North Atlantic. Heinrich events chilled and freshened the sea surface thereby disrupting the North Atlantic Deepwater Conveyor Current. This disruption evidently unbalanced the exchange of carbon between the atmosphere and ocean (Beck *et al*., 2001), preventing ^{14}C from entering the deep ocean and overstocking this daughter product in the atmosphere. Such atmospheric fluctuations in ^{14}C represent episodes of departure from the modern ^{14}C to ^{12}C radioactive decay constant, and thus require *ad hoc* corrections to the standard.

When radiocarbon assays on terrestrial samples yield dates that are too young compared to samples dated by tree rings, varves or other calendric methods (Björck *et al*., 1996), it may be desirable to use radiocarbon calibration programs. To complicate matters further, radiocarbon dating of marine samples requires still other correction protocols (Reimer, 2001).

To calibrate late Pleistocene radiocarbon years to calendar years, computer programs such as CALIB (Stuiver and Reimer, 1993) or OxCal (Bronk, 1995) have been developed to run INTCAL98 calibration data sets such as Intcal.14c for terrestrial and Marine.14c for marine corrections (Stuiver *et al*., 1998).

Several research programs suggest that revisions in the INTCAL98 radiocarbon correction dataset will eventually take place. An important example is the recent work by Beck *et al*. (2001), dating the annual layers of a speleothem both by ^{230}Th and by ^{14}C. Another program compares ^{14}C dates to a sequence of lake varves (Kitagawa and van der Plicht, 1998). Recent research conducted on deep ocean core 58PC (820 m depth) from the Cariaco Basin off the Venezuelan coast provides marine radiocarbon dates from annually deposited varves. And a new dendrochronology for Central and Southern Europe uses late Pleistocene Scotch pines (*Pinus sylvestris*) (Friedrich *et al*., 2001).

None of these older data sets is directly tethered to the present. The Cariaco Basin varve chronology has been anchored to the European pine dendrochronology and the European pine dendrochronology to the Older Dryas chronozone by a method known as “wiggle-matching” (Hughen *et al*., 2000a,b; Friedrich *et al*., 2001). Although all of these advances promise to refine calendric control of radiocarbon dating, none has been incorporated into the radiocarbon conversion programs as of this writing.

Recently an expert panel of International Quaternary Union (INQUA) reviewed the integration of ice-core, marine, and terrestrial methods of placing late glacial climatic episodes in time. The results were published as a set of recommendations, guidelines, and methodologies (Lowe *et al*., 2001). We make special note here of the fact that one of the panel members was William A. Watts of the University of Dublin, Trinity College, Ireland. We do so because much of Watts’ research has been conducted in the Southeastern US, and thus asssues that the INQUA working group considered issues and data from this region along with the rest of the North Atlantic, the Nordic seas, and Europe.

While the INTIMATE group recognizes existing evidence for near synchronous global climatic changes during the late glacial, they are concerned with improving the correlations between marine, terrestrial, and ice-core records so that the “leads” and “lags” in timing between them may be more fully understood. They are also interested in how global climatic shifts were expressed in different regions of the world. While they do not object to calibrating radiocarbon dates using INTCAL98 Lowe *et al*. (2001:1182) add the following:

> Whereas correction factors and calibration methods may change in the future, the original radiocarbon measurements will retain their validity, assuming that certain quality assurance criteria are satisfied. It is the original data, therefore, that will be used for recalculations and re-calibrations, and which it is therefore vital to capture within appropriate databases.

These authors also make the following observation (Lowe *et al*., 2001:1187):

> In only a few limited sectors of the [present] calibration curve do plots of radiocarbon ages give a limited range of possible calendar ages, which explains why, for samples of LGIT [Last Glacial – Interglacial Transition] age, calibration to INTCAL98 often significantly reduces, rather than improves, age precision.

The Event Stratigraphy and Walker *et al*. (1999) constitutes perhaps the most satisfactory basis for effective inter-regional comparison. The INTIMATE group recommends that stratigraphic sequences be described using local terms initially, and dated independently whenever possible. The climatostratigraphy and chronology of each sequence should then be compared with the GRIP [ice-core] stratotype in order to establish the degree of compatibility or otherwise with regional stratigraphic schemes (Lowe *et al*., 2001:1184). Such broader correlations are considered in Chapter 5 by Dunbar.

Given this background, one question that emerges is whether it would be better in the future to channel resources towards the generation of high-resolution radiocarbon data sets from carefully selected, key regional sequences, rather than dilute them by supporting a larger number of more limited investigations (Lowe *et al*., 2001:1187). Clearly the Page-Ladson Site complex represents the former strategy, and now provides the most complete chronostratigraphic framework for Latest Quaternary environmental history in north Florida.

4.3 Results

Table 4.1 presents the master list of averaged carbon dates for all dated stratigraphic intervals in the Page-Ladson Site complex. This is an excellent series of ^{14}C dates, many with multiple corroboratory dates. The earliest dates exceed 18,000 years and represent full glacial times. They are separated by a chronologically significant unconformity from the more continuous series above. Thereafter the site offers a more closely spaced series of well-dated strata proceeding upwards from the upper part of Unit 1 to the upper part of Unit 6. The 20 dated levels within this section span nearly 6,000 years with an average interval of 296 ^{14}C years. Of the dates listed in Table 4.1 four are supported by three concordant dates each, including the very productive Bolen cultural level (Level 2 of Test F) at the base of Unit 6. Seven dates depend on a single dated sample each. The very productive levels embodied in Unit 3 (including Level 23 of Test F) are covered by seven dates. It is important to note that the dates presented in Table 4.1 are completely concordant in the sense that none fall out of sequence.

Table 4.1 Master list of radiocarbon dates from Page-Ladson Site calibrated with CALIB 4.4.2

Stratigraphic unit and number of ^{14}C dates, if more than one the dates were averaged	*Maximum–minimum range of ^{14}C dates in the sample*	*Averaged ^{14}C age*	*Calendar BP age ranges (2 sigma, 95.4% area enclosed)*	*Relative area under probability distribution*	*Context and/or suspected inter-site association*
Unit 1 L (n = 3)[1]	18,580 ± 110	18,441 ± 88	22,631–21,210	1.00	Je591, Ta98, and IF71 1L
	18,090 ± 200[3]				
Unit 1 U base (n = 1)[2]	15,910 ± 160	15,910 ± 160	19,695–18,323	1.00	Aucilla 3E Mammoth in shell marl
Unit 1 U mid (n = 1)	15,390 ± 120	15,390 ± 120	18,737–17,584	1.00	Assumed middle shell marl date
Unit 1 U top (n = 2)	15,230 ± 120	15,170 ± 88	18,638–17,475	1.00	Top of U1U shell marl
	15,100 ± 130				
Unit 1U top (n = 3)[1]	15,230 ± 120	15,142 ± 77	18,694–17,562	1.00	Top of U1U shell marl and Aucilla 3E Mammoth in shell marl
	15,050 ± 160				
Unit 2 base (n = 1)	14,870 ± 200	14,870 ± 200	18,508–17,118	1.00	Lowest level of U2
Unit 2 mid (n = 2)	14,600 ± 115	14,580 ± 83	18,013–16,942	1.00	Middle of column U2
	14,560 ± 120				
Unit 2 top (n = 2)	14,330 ± 110	14,275 ± 81	17,641–16,606	1.00	Top two levels U2
	14,210 ± 120				
Unit 3 (n = 7)	12,570 ± 100	12,425 ± 32	15,405–14,146	1.00	3L and 3U together
	12,370 ± 90				
Unit 3—4 transition (n = 3)	12,400 ± 60	12,351 ± 39	15,428–14,531	0.575	U3–4 transition zone
	12,290 ± 60		14,450–14,113	0.425	
Unit 4L (n = 3)	12,310 ± 50	12,289 ± 30	15,408–14,568	0.516	Tests C–F, Unit 4L
	12,260 ± 60		14,412–14,096	0.476	
			13,895–13,865	0.009	
Unit 4L-U contact (n = 3)	12,160 ± 50	12,107 ± 37	15,332–14,640	0.335	
	12,030 ± 60[3]		14,351–14,024	0.506	Tests C and B 4U bottom
			13,969–13,824	0.155	
			13,710–13,693	0.004	
Unit 4U below L5 (n = 2)	11,790 ± 50	11,735 ± 41	14,983–14,932	0.006	Tests C-F below L5 mid 4U
	11,649 ± 70		13,306–13,990	0.984	
			13,235–13,181	0.010	
Unit 4U, L5 (n = 2)[NR]	11,730 ± 90	11,523 ± 44	13,833–13,621	0.335	Test 91-F, Level 5
	11,460 ± 50		13,543–13,163	0.665	
Unit 4U, L4 (n = 2)	11,300 ± 90	11,270 ± 64	13,757–13,704	0.030	Test 91-F, Level 4
	11,240 ± 90		13,463–13,013	0.970	

Unit 4U upper ($n = 2$)[NR]	10,970 ± 100	10,721 ± 57	12,983–12,618	0.946	Upper levels
	10,600 ± 70		12,474–12,407	0.054	
Unit 5 ($n = 2$)[NR]	10,360 ± 115	10,200 ± 84	12,359–11,546	0.944	In upper most part of Unit 5
	10,016 ± 124[3]		11,509–11,406	0.040	
			11,390–11,342	0.016	
Unit 5–6L surface ($n = 3$)	10,000 ± 80	9,953 ± 40	11,558–11,465	0.247	Primary Bolen level on contact of U5–U6L and bottom most U6L, shelly silt
	9,930 ± 60		11,443–11,224	0.753	
Unit 6L ($n = 1$)	9,697 ± 129[3]	9,697 ± 129[3]	11,536–11,522	0.004	Test B, U6L, the upper-most Bolen level that accumulated in a still water deposited peat in the deep-water component.
			11,303–10,667	0.008	
			10,660–10,639	0.977	
			10,610–10,597	0.008	
			10,585–10,584	0.004	
Unit 6U ($n = 1$)	9,466 ± 105[3]	9,466 ± 105[3]	11,157–11,147	0.004	Test BU6, 2nd level from top
			11,138–10,480	0.986	
			10,443–10,427	0.010	
Unit 7 ($n = 1$)	4,150 ± 68[3]	4,150 ± 68[3]	4,836–4,518	0.980	Test B, Unit 7, Level 6
			4,467–4,449	0.020	
Unit 7 ($n = 1$)	3,407 ± 85[3]	3,407 ± 85[3]	3,871–3,465	1.000	Test B, Unit 7, Level 5

---

[1] Includes radiocarbon dates from Page-Ladson as well as other sites in the range, pooled averaged ^{14}C, and calendar age.

[2] Radiocarbon date from a Aucilla or Wacissa River site other than Page-Ladson.

[3] Includes one or more recalibrated Beta Analytic.

[NR] Averaged dates determined not to be statistically related at a 95% confidence level.

In this book we have generally preferred to consider uncalibrated radiocarbon dates. In the long run these are the least vulnerable to misunderstandings and miscalculations. However, there are some occasions where the urge to compare radiocarbon estimates with true calendric perspectives seems important. Clearly calendric dates are relevant to early Holocene cultural levels and this practice is evident in Chapter 21. When we do make correlations between calendric and radiocarbon evaluations we designate them as years *^{14}C BP* for radiocarbon and as years *cal BP* for calendar years.

In acknowledgment of the advances in the realm of calendar-year calibrations, we list them in the fourth column in Table 4.1. We used the CALIB version 4.4.2 to convert radiocarbon years to GRIP ice-core calendar years (Stuiver *et al*., 1998). This software program, in conjunction with the INTCAL98 calibration data set, provides a means to compare proxy evidence for global and regional environmental shifts from the last glacial maximum, ca. 18,500 ^{14}C BP, to a time just after the end of the last glacial meltdown of the Laurentide ice sheet, ca. 8,500 ^{14}C BP.

These calibration methods are explained by Lowe *et al*. (2001:1182–3) as follows:

> All radiocarbon age measurements for events and materials of late glacial–interglacial transition age should be calibrated using INTCAL98 ... in order to standardize data and facilitate comparison. ... More attention should be paid to the detailed probability structures in the original radiocarbon measurements and in the INTCAL98 calibration data set. The uncertainties of calibration can be reduced for a series of radiocarbon dates using ... a Bayesian approach to probability assessments, which incorporates prior information about stratigraphic context and succession of the series of dates into the analysis. ...

The Page-Ladson Site complex yielded 60 radiocarbon dates. Table 4.2 lists the results of 48 of these dates. Many of the dates cluster as replicates, either in the sense that they are based on different materials from the same stratigraphic level, or in the sense that they were sampled from laterally equivalent sediments in adjacent test pits. For example, as discussed above, the AMS collagen date from the jugal bone of *Palaeolama mirifica* was corroborated by a gourd seed hand picked from the same horizon. These dates span about 10,000 years with ages ranging from 18,430 to 8,905 years BP.

We have removed 12 dates from the research data set. They are presented, just for the record, in Table 4.3, with our reasons for disallowing them. Still other relevant carbon dates from the Aucilla River and other Florida sites, including the collagen date from the Sloth Hole ivory shaft discussed above, are presented in Table 4.4. Many of these are discussed in Chapter 5 by Dunbar.

4.4 Conclusions

The Page-Ladson Site complex offers a long stratigraphic column spanning the time interval from full glacial to the final retreat of the Laurentide Ice Sheet. It is now placed in an excellent chronostratigraphic framework by interpolation of the richest set of carbon dates from any single site in north Florida. Essentially this record

Table 4.2 Forty-eight radiocarbon dates used in the Page-Ladson chronology

Unit ID	*C-14 age*	*Stan. dev.*	*Test unit*	*Level*	*Lab code*	*Type date*	*Material dated*	*Other sample data*	*FS #*	*Comments*
1L	18,446[1]	222	87-E	1	Beta-021751	RM-U	Charcoal	^{13}C-24 ± 2[2]	87-9-88	Sample taken from burned cypress log
1U	15,390	120	97-F-2	H	Beta-116503	AMS	Plant material	^{13}C = –24.7	97-2-166	Bottom of test 97-2-NC at north end of pit, sand pebble stringers, gastropods with silt.
1U	15,230	120	97-F-2	Q	Beta-116506	AMS	Plant material	^{13}C = –30.0	97-2-169	Sample of lowest horizon having digesta at the Page-Ladson Site
1U	15,100	130	97-F-2	En	Beta-116507	AMS	Plant material	^{13}C = –31.2	97-2-170	Upper part Unit 1b
2	14,870	200	97-F-2	D	Beta-116502	AMS	Wood	^{13}C = –25.9	97-2-165	Lower part of Unit 2 at contact of Unit 1
2	14,600	115	88-F	N/A	AA-007455	AMS	Wood	0.1624 ± 0.0023[3]	88-104	East end of Trench F-88 where Unit 2 is exposed, this sample taken from Unit 2
2	14,560	120	97-F-2	B	Beta-116501	AMS	Plant seed	^{13}C = –21.4	97-2-164	Lower part of Unit 2, brown peat
2	14,330	110	97-F-2	P	Beta-116505	AMS	Peat	^{13}C = –24.7	97-2-168	Upper part of Unit 2
2	14,210	120	97-F-2	P	Beta-116504	AMS	Peat	^{13}C = –23.8	97-2-167	Unit 2 brown peat at contact with Unit 3 from NE end of North wall profile
2–3	13,820	190	97-F-1	Es	Beta-116498	AMS	Wood	^{13}C = –24.0	97-1-85c	97–1-NC a charred wood sample from level of *Mammut americanum* pelvis
2–3	13,120	50	95-C	Upper	Beta-118908	AMS	Plant material	^{13}C = –27.9	95-C14-5	Sample from the bottom of Test C about ~10 cm below top of Unit 2
2–3	12,940	70	F-93	23	Beta-118586	AMS	Plant material	^{13}C = –29.0	9316	Digesta and sediment fill taken from *Mammut americanum* tusk cavity
3	12,570	100	91-F	26b	AA-008759	AMS	Plant seed	0.2091 ± 0.0026[3]	91-32	F Trench, 1991, Lv. 26b, a *Cucurbita* seed on *Mammut americanum* skull fragment.
3	12,480	100	97-F-1	Upper	Beta-116493	AMS	Plant seed	^{13}C = –28.5	97-1-10c	Lower part of Unit 3b, an acorn adjacent to the *Palaeolama mirifica* jugal
3	12,460	100	97-F-1	Es	Beta-116499	AMS	Wood	^{13}C = –26.0	97-1-162	From a lower digesta level
3	12,420	130	97-F-1	Es	Beta-116500	AMS	Wood	^{13}C = –28.0	97-1-163	North, north wall of end 97–1-SC
3	12,400	110	97-F-1	Es	Beta-116497	AMS	Plant seed	^{13}C = –26.8	97-1-51c	Acorn collected at base level of the *Mammut americanum* pelvis
3	12,390	50	97-F-1	B	Beta-112236	AMS	Bone collagen		97-1-11c	*Palaeolama mirifica* jugal

(*Continued*)

Table 4.2 *Forty-eight radiocarbon dates used in the Page-Ladson chronology*—(*continued*)

Unit ID	*C-14 age*	*Stan. dev.*	*Test unit*	*Level*	*Lab code*	*Type date*	*Material dated*	*Other sample data*	*FS #*	*Comments*
3	12,370	90	91-F	20b	AA-011048	AMS	Plant seed		9124	F Trench, 1991, Lv. 20b. (arranged by Michael Faught at Univ. of Arizona)
3–4 trans	12,400	60	95-C	15	Beta-093653	AMS	Plant seed		95-C14-1	~2.40 m below Unit 5
3–4 trans	12,385	100	91-F	18	AA-008760	AMS	Plant seed	0.2140 ± 0.0026^{3}	9121	F Trench, 1991, Lv. 18, this level is tan silt with pockets of sand and digesta
3–4 trans	12,290	60	91-F	17	Beta-116282	AMS	Wood	^{13}C = −26.2	9120	F Trench, 1991, Lv. 17
4L	12,310	50	91-F	14	Beta-116280	AMS	Wood	^{13}C = −29.1	91-17	F Trench, 1991, Lv. 14
4L	12,290	50	97-C	9	Beta-116494	AMS	Plant material	^{13}C = −25.5	97-1-41c	~1.35 m below Unit 5
4L	12,260	60	91-F	12	Beta-116281	AMS	Wood	^{13}C = −27.7	91-15	F Trench, 1991, Lv. 12
4L 4U	12,160	50	97-C	8	Beta-116495	AMS	Plant material	13C = −26.2	97-1-42c	~1.10 m below Unit 5
4L 4U	12,200^{1}	124	84-B	15a–b	Beta-015090	RM-U	Wood	^{13}C = −20 ±2^{2}	84-572-49	Bottom of Test B at 4.10 m depth in pit, a wood sample from a log
4L 4U	12,030	60	95-C	9	Beta-093654	AMS	Wood		95-C14-2	~1.30 m below Unit 5 at contact of 4U and 4L
4U, below Lv. 5	11,790	50	91-F	8	Beta-118907	AMS	Plant material	^{13}C = −28.3	9111	F Trench, 1991, Lv. 8
4U, below Lv. 5	11,630	70	97-C	7	Beta-116496	AMS	Wood	^{13}C = −27.5	97-1-43c	~90 cm below Unit 5
4U, Lv. 5	11,730	90	91-F	5	Beta-129550	AMS	Wood	^{13}C = −20.7	918	F Trench, 1991, Lv. 5
4U, Lv. 5	11,460	50	91-F	5	Beta-118906	AMS	Plant material	^{13}C = −28.2	918	F Trench, 1991, Lv. 5
4U, Lv. 4	11,300	90	91-F	4	Beta-129554	AMS	Wood	^{13}C = −22.9	917	F Trench, 1991, Lv. 4
4U, Lv. 4	11,240	90	91-F	4	Beta-129553	AMS	Wood	^{13}C = −28.8	917	F Trench, 1991, Lv. 4
4U, upper	10,970	100	91-F	3	Beta-129552	AMS	Wood	^{13}C = −24.4	916	F Trench, 1991, Lv. 3
4U, upper	10,600	70	88-C	6	Beta-023753	RM	Wood	^{13}C = −27.1	88-11-89	~75 cm below Unit 5
4–5	13,780	100	91-F	7	Beta-129551	AMS	Plant material	^{13}C = −21.4	9110	Sediment filled crack in F Trench, 1991, Lv. 7
5	10,360^{1}	115	87-C	2b	Beta-021752	RM-U	Wood	^{13}C = −20 ± 2^{2}	87-09-66	Desiccated wood in Unit 5 with upper face in Unit 6
5	10016^{1}	124	87-C	1a–2b	Beta-021750	RM-U	Charcoal	^{13}C = −24 ± 2^{2}	87-09-65	Charred wood in Unit 5 with upper face in Unit 6

5–6L Surface	10,300	120	95-C	1a	Beta-103889	RM	Organic sediment		95-E-29	Sample from pedestal under Bolen point taken 5 cm to 10 cm above Unit 5 (B. Carter PC)
5–6L Surface	10,000	80	92-C	1a	Beta-058857	AMS	Wood	?^{4}	9213	Wooden stake in Unit 6 and driven through Unit 5 and Unit 4 (B. Carter PC)
5–6L Surface	9,950	70	95-C	1a–2b	Beta-103888	AMS	Plant seed		95-E-27	Hickory nut on contact of Unit 5 with Unit 6
5–6L Surface	9,930	60	92-C	1a	Beta-058858	RM	Wood		9226	Sample taken from cypress log
5–6L	12,297^{1}	115	85-B	12a	Beta-015088	RM-U	Plant material	^{13}C = –27 ± 2^{2}	85-59-42	Redeposited mix of Unit 3, 4, 5, and 6 sediments
6L	9,697^{1}	130	84-B	10	Beta-011905	RM-U	Peat	^{13}C = –27 ± 3^{2}	84-527-13	Bolen point and peat sample surrounding it recovered from western profile wall
6U	9,466^{1}	105	85-B	9	Beta-015089	RM-U	Charcoal	^{13}C = –24 ± 2^{2}	85-59-44	Sample from Level 9
7	4,150^{1}	68	84-B	6	Beta-011558	RM-U	Wood	^{13}C = –20 ± 2^{2}	84-527-5L	Land Bridge collapse Level 6 of Test B
7	3,407^{1}	85	84-B	5	Beta-011559	RM-U	Peat	^{13}C = –27 ± 3^{2}	84-527-5U	Peat capping Level 5 of Test B

---

[1] Radiocarbon samples that were not originally adjusted for ^{13}C and were subsequently adjusted using CALIB98 and the ^{13}C values.

[2] ^{13}C values as given in the CALIB radiocarbon calibration program manual in Table 1 (*http://depts.washington. edu/qil/calib/manual/table1.html*).

[3] Fraction modern – NSF-Arizona AMS Facility assumed a delta ^{13}C of –25.0 per mil.

[4] AMS measurements were made by the Lawrence Livermore National Laboratory in California, not by Beta and the C13/12 values were not indicated.

[RM-U] Radiometric date *not* originally adjusted for C13/12 by Beta.

[RM] Radiometric date adjusted for C13/12 by Beta.

Table 4.3 Twelve radiocarbon dates not used in the Page-Ladson chronology

Unit ID	*C-14 age*	*Stan. dev.*	*Test unit*	*Level ID*	*Lab code*	*Type date*	*Material dated*	*Other sample data*	*FS #*	*Comments*
3	13,130	200	83-A	1	I-013591[1]	RM-U	Wood	Delta C14 = 805 ± 5	84-106-3	Sample from wood sandy, shelly sediments
3	12,570	200	83-A	2	I-013590[1]	RM-U	Plant material	Delta C14 = 791 ± 5	84-106-2	Sample of "Straw mat" (digesta), the upper unit of the test
3	12,545	80	88-C-S[2]	N/A	AA-007452	AMS	Plant seed	0.2098 ± 0.0021	88-11-131	Sample collection questionable, diver head first in 1 m × 1 m sondage 4 m deep
3	12,375	75	88-C-S[2]	N/A	AA-007453	AMS	Plant material	0.2143 ± 0.0020	88-11-131	Sample collection questionable, diver head first in 1 m × 1 m sondage 4 m deep
3	12,240	90	87–6-Core	21	Beta-022268	RM-U	Plant material		87-C6-2	Sample taken from bottom 10 cm of core in Unit 3 sediment
3	11,770	90	83-A	2	Beta-008365	RM-U	Plant material		84-106-1	Digesta sample
3	10,800	130	88-C-S[2]	N/A	Beta-026722	RM-U	Wood		88-11-131	Sample collection questionable, diver head first in 1 m × 1 m sondage 4 m deep
3	10,520	130	83-A	1–2	Beta-008360	RM-U	Bone collagen		84-106-1	Proboscidean bone from Test A in digesta
4	11,790	90	87–6-Core	20a	Beta-022267	RM-U	Plant material		87-C6-1	Bottom 10 cm of Unit 4
4	11,570	210	88-C-S[2]	N/A	Beta-026721	RM-U	Wood		88-11-130	Sample collection questionable, diver head first in 1 m × 1 m sondage 4 m deep
6L	8,905[3]	65	88-C	1a	AA-007454	AMS	Wood	0.3300 ± 0.0020	88-60	Date may be too young due to 3 to 4 years wet storage and possible bacteria

[1] Teledyne Isotopes samples treated for removal carbonates and humic acids. Based on libby half-life of 5568 years and no corrections for atmospheric C14.

[2] Deep exploratory sondage placed in the bottom of Test C. This was not a controlled unit excavation, rather it was to confirm the position of stratigraphic units.

[3] Wood sample from stake, artifact of hickory wood. Specimen recovered in 1987, stored wet in a light proof container then, in 1991, a sampled was taken and submitted for dating.

Table 4.4 List of radiocarbon dates from other Florida sites calibrated with CALIB 4.4.2

Stratigraphic unit and number of ^{14}C dates statistically the same at 95% level of confidence	*Maximum and minimum of ^{14}C dates in sample*	*Averaged ^{14}C age*	*Calendar BP age ranges (2 sigma 95.4% area enclosed)*	*Relative area under probability distribution*	*Context and/or suspected inter-site association*
Aucilla 3B (*n* = 1)	15,910 ± 160	N/A	19,695–18,323	1.00	Aucilla 3B Oldest 1U
Sloth Hole (*n* = 1)	12,300 ± 50	N/A	13,894–13,866	0.008	Je121, Test 22, Lv. 7 this component is below Clovis
			14,424–14,094	0.464	
			15,418–14,556	0.528	
Sloth Hole (*n* = 1)	11,050 ± 50	N/A	12,714–12,670	0.023	Ivory shaft (dated by Tom Stafford) from Clovis level (Hemmings, 2004)
			13,185–12,872	0.977	
Little River Rapids (*n* = 2)[1]	12,130 ± 140	11,930 ± 99	14,305–13,525	0.851	Je603, Test 2, Zone 4, Lv. 3
	11,730 ± 140		15,205–14,724	0.149	
Little River Rapids (*n* = 2)	11,770 ± 160	11,628 ± 120	14,054–13,163	0.990	Je603, Test 2, Zone 4, Lv. 2
	11,450 ± 180		14,997–14,915	0.010	
Little River Rapids (*n* = 1)	10,910 ± 200	N/A	12,520–12,333	0.068	Je603, Test 2, Zone 3, Lv. 2
			13,430–12,585	0.932	
Little River Rapids (*n* = 1)	8,860 ± 220	N/A	10,431–9,472	0.984	Je603, Test 2, Zone 2, Lv. 2
			10,495–10,438	0.016	
Alexon Bison Site (*n* = 1)	11,170 ± 130	N/A	13,466–12,882	0.976	Je570, Test 1, Level 2
			13,759–13,700	0.024	
Le2105	10,090 ± 70	9,948 ± 40	11,224–11,440	0.770	Le2105, Bolen fire hearth feature
	9,850 ± 80		11,467–11,553	0.230	
Wakulla Springs Lodge (*n* = 2)	9,310 ± 40	9,285 ± 28	10,300–10,288	0.023	Wa329, Bolen pit feature
	9,285 ± 40		10,319–10,307	0.021	
			10,340–10,330	0.015	
			10,363–10,368	0.006	
			10,380–10,562	0.921	
			10,567–10,577	0.014	
Warm Mineral Springs (*n* = 5)	10,310 ± 145	10,271 ± 67	11,644–11,673	0.007	8So19, Burial 1, samples under and beside burial
	10,225 ± 145		11,687–12,383	0.935	
			12,479–12,644	0.058	

(*Continued*)

Table 4.4 List of radiocarbon dates from other Florida sites calibrated with CALIB 4.4.2—(continued)

Stratigraphic unit and number of ^{14}C dates statistically the same at 95% level of confidence	*Maximum and minimum of ^{14}C dates in sample*	*Averaged ^{14}C age*	*Calendar BP age ranges (2 sigma 95.4% area enclosed)*	*Relative area under probability distribution*	*Context and/or suspected inter-site association*
Warm Mineral Springs (*n* = 5)	10,085 ± 145	9,967 ± 58	11,204–11,644	0.983	8So19, Burial 1, samples associated with burial
	9,860 ± 140		11,675–11,688	0.007	
			11,871–11,896	0.011	
Warm Mineral Springs (*n* = 2)	9,700 ± 190	9,621 ± 122	10,588–10,583	0.003	8So19, Burial 1, samples younger than burial
	9,565 ± 160		10,611–10,596	0.009	
			10,661–10,638	0.016	
			10,666–11,225	0.972	
Little Salt Springs (*n* = 1)	12,840 ± 90	N/A	15,877–14,408	1.000	8So18, Plastron fragment from giant tortoise feature in sinkhole
Little Salt Springs (*n* = 1)	12,030 ± 200	N/A	14,385–13,483	0.731	8So18, Burned wooden stake-like object from giant tortoise feature in sinkhole
			15,333–14,623	0.269	
Windover (*n* = 1)	10,750 ± 190	N/A	11,997–11,980	0.003	8Br246, Water lily peat old end
			12,253–12,097	0.047	
			13,160–12,275	0.949	
Windover (*n* = 1)	10,160 ± 120	N/A	12,354–11,257	0.998	8Br246, Water lily peat young end
			12,556–12,546	0.002	
Windover (*n* = 2)	9,590 ± 110	9,560 ± 78	10,606–10,602	0.002	8Br246, sand stringers, an organic hiatus between water lily peat and rubber peat levels
	9,530 ± 110		10,653–10,642	0.010	
			10,679–10,673	0.005	
			11,162–10,685	0.983	

[1] Set of dates is not statistically related at a 95% confidence level.

provides continuous century-scale chronological control for ten millenia of the latest Pleistocene and early Holocene. The largest gap, amounting to about three millenia, is that between the cypress beds (Test E) representing full glacial time and the main sequence that begins with Unit 1 (Level 26b of Test F). The nearly continuous chronostratigraphic column spans about six millenia with an average time interval of about 300 years between 20 sets of averaged radiocarbon dates (Table 4.1). The Page-Ladson chronostratigraphic foundation makes it possible to develop realistic hypotheses regarding correlations between environmental as well as floral, faunal, and cultural changes during the time of the first Floridians and the last mastodons.

As Taylor (2000, p. 64) states "... Investigators now have a good handle on the 'wiggles' in the calibration for the last twelve millenia." Such calibrated dates are especially useful in correlating cultural and faunal changes with more regional or even global environmental changes. Such examples will be evident in the following chapter by Dunbar (Chapter 5).

4.5 Acknowledgments

We are most grateful to the staffs of Beta Analytic, Inc. in Miami and the AMS dating facility at the University of Arizona for their helpful advice and timely cooperation in securing high-quality carbon dates. We thank Tom Stafford for helping us acquire critical bone and ivory dates.

We are indebted to Vance Haynes, Bill Watts, and Joe Donoghue for their expert advice on Quaternary chronostratigraphy in general and the Aucilla River Project in particular.

References

Beck, J. W., D. A. Richards, R. L. Edwards, B. W. Silverman, P. L. Smart, D. J. Donahue, S. Hererra-Osterheld, G. S. Burr, Leal Calsoyas, A. J. T. Jull, and D. Biddulph. 2001. Extremely Large Variations of Atmospheric ^{14}C Concentration During the Last Glacial Period. *Science*, 292 (5526):2453–2458.

Björck, S., B. Kromer, S. Johnsen, O. Bennike, D. Hammarlund, G. Lemdahl, T. L. R. G. Possnert, B. Wohlfarth, C. Uffe Hammer, and M. Spurk. 1996. Synchronized Terrestrial-Atmospheric Deglacial Records Around the North Atlantic. *Science*, 274:1155–1160.

Bronk, R. C. 1995. Radiocarbon Calibration and Analysis of Stratigraphy: the OxCal Program. *Radiocarbon*, 37:425–430.

Dasovich, S. J. 1996. *A Compilation and Analysis of Florida's Prehistoric Radiocarbon Database*, Masters Thesis, Department of Anthropology, Florida State University, Tallahassee, FL.

Dyke, A. S., J. T. Andrews, P. U. Clark, J. H. England, G. H. Miller, J. Shaw, and J. J. Veillette. 2002. The Laurentide and Innuitian Ice Sheets During the Last Glacial Maximum. *Quaternary Science Reviews*, 21 (1–3):9–31.

Fiedel, S. J. 1999. Older Than We Thought: Implications of Corrected Dates for Paleoindians. *American Antiquity*, 64 (1):95–115.

Friedrich, M., B. Kromer, K. F. Kaiser, M. Spurk, K. A. Hughen, and S. J. Johnsen. 2001. High-Resolution Climate Signals in the Bølling-Allerød Interstadial (Greenland Interstadial 1) as Reflected in European Tree-Ring Chronologies Compared to Marine Varves and Ice-Core Records. *Quaternary Science Reviews*, 20 (11):1223–1232.

Hughen, K. A., J. R. Southon, S. J. Lehman, and J. T. Overpeck. 2000a. Synchronous Radiocarbon and Climate Shifts During the Last Deglaciation. *Science*, 290 (5498):1951–1954.

Hughen, K. A., J. R. Southon, S. J. Lehman, and J. T. Overpeck. 2000b. Cariaco Basin 2000 Deglacial ^{14}C and Grey Scale Data, *NOAA/NGDC Paleoclimatology Program, IGBP Pages/World Data Center A for Paleoclimatology, Data Contribution Series #2000-069*, Boulder, CO.

Kaufman, D. S., G. H. Miller, J. A. Stravers, and J. T. Andrews. 1993. Abrupt Early Holocene (9.9–9.6 ka) Ice-Stream Advance at the Mouth of Hudson Strait, Arctic Canada. *Geology*, 21:1063–1066.

Kitagawa, H., and J. van der Plicht. 1998. Atmospheric Radiocarbon Calibration to 45,000 Yr B.P.: Late Glacial Fluctuations and Cosmogenic Isotope Production. *Science*, 279 (5354):1187–1190.

Lowe, J. J., W. Z. Hoek, and the INTIMATE Group. 2001. Inter-Regional Correlation of Paleoclimate Records for the Last Glacial–Interglacial Transition: A Protocol for Improved Precision Recommended by the INTIMATE Project Group. *Quaternary Science Reviews*, 20:1175–1187.

Marchal, O., T. F. Stocker, and R. Muscheler. 2001. Atmospheric Radiocarbon During the Younger Drays: Production, Ventilation, or Both. *Earth and Planetary Sciences Letters*, 185:383–395.

Reimer, P. J., Compiler. 2001. Marine Reservoir Correction Database. At Web Page, http://depts.washington.edu/qil/marine/, University of Washington, Quaternary Isotope Lab, date accessed December 2001.

Shore, J. S., D. D. Bartley, and D. D. Harkness. 1995. Problems Encountered with the ^{14}C Dating of Peat. *Quaternary Science Reviews*, 14 (4):373–383.

Southon, J. 2002. A First Step to Reconciling the GRIP and GISP2 Ice-Core Chronologies, 0–4,500 Yr B.P. *Quaternary Research*, 57:32–37.

Stafford, T. W., Jr., P. E. Hare, L. Currie, A. J. Jull, and D. J. Donahue. 1991. Accelerator Radiocarbon Dating at the Molecular Level. *Journal of Archaeological Science*, 18:35–72.

Stafford, T. W., Jr., H. A. Semken, Jr., R. W. Graham, W. F. Klipperl, A. Markova, N. G. Smirnov, and J. Southon. 1999. First Accelerator Mass Spectrometry ^{14}C Dates Documenting Contemporaneity of Nonanalog Species in Late Pleistocene Mammal Communities. *Geology*, 27:903–906.

Stuiver, M., and P. J. Reimer. 1993. *CALIB 4.1 Manual*. Quaternary Isotope Lab., University of Washington, Seattle, WA.

Stuiver, M., P. J. Reimer, E. Bard, J. W. Beck, G. S. Burr, K. A. Hughen, B. Kromer, G. McCormac, J. van der Plicht, and M. Spurk. 1998. INTCAL98 Radiocarbon Age Calibration, 24,000-0 Cal BP. *Radiocarbon*, 40 (3):1041–1083.

Taylor, R. E. 1992. Radiocarbon dating of Bone: To Collagen and Beyond, pp. 375–402, *in* R. E. Taylor, A. Long, and R. A. Kra (eds), *Radiocarbon After Four Decades: An Interdisciplinary Perspective*, Springer-Verlag, New York.

Taylor, R. E. 2000. The Contribution of Radiocarbon Dating to New World Archaeology. *Radiocarbon*, 42:1–21.

Taylor, R. E., C. V. Haynes, and M. Stuiver. 1996. Clovis and Folsom Age Estimates: Stratigraphic Context and Radiocarbon Calibration. *Antiquity*, 70:515–525.

Walker, M. J. C., S. Björck, J. J. Lowe, L. C. Cwynar, S. J. Johnsen, K. L. Knudsen, B. Wolfarth, and INTIMATE Group. 1999. Isotopic “Events” in the GRIP Ice Core: A Stratotype for the Late Pleistocene. *Quaternary Science Reviews*, 18:1143–1150.

Chapter 5

Pleistocene–Early Holocene Climate Change: Chronostratigraphy and Geoclimate of the Southeast US

JAMES S. DUNBAR
Senior Archaeologist, Public Lands Archaeology, Florida Bureau of Archaeological Research
Mailing Address: R. A. Gray Bldg, 500 South Bronough Street, Tallahassee, FL 32399-0250, USA.
Street address: B. Calvin Jones Center for Archaeology, 1001 DeSoto Park Drive, Tallahassee, FL 32301, USA.
E-Mail: jsdunbar@dos.state.fl.us, Phone: (850) 245-6307, Fax: (850) 245-6463

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 103–155

5.1 Introduction

5.1.1 Objectives

The purpose of this chapter is to relate the paleo-water table proxy derived from the radiometrically dated stratigraphic units at the Page-Ladson site with late glacial environmental subphases. This study of time, stratigraphy, and paleoclimate includes consideration of:

(1) Aspects of the geology and geomorphology of the lower, karst section of the Aucilla River basin, including its tributary, the Wacissa River.
(2) Documented evidence of global and regional late Pleistocene climate change through time.
(3) Chronostratigraphy and paleoclimate of the Southeast US as determined by the well-dated stratigraphic sequence from the Page-Ladson site.
(4) Correlate the global and regional records with those of the paleoclimate data from the Page-Ladson site as a means of developing a geoclimatic record for the Southeastern US.

The Page-Ladson site provides a highly stratified sediment column over 6 m deep that spans the period of the late glacial recession. Because many of the sediment levels were originally deposited in a wetland or underwater setting and much of the geologic history of that sediment column remained wet despite two episodes of subaerial exposure, the organic material necessary for obtaining high-quality radiocarbon dates survived and provided the means to establish chronology. A total of 48 radiocarbon dates have been run on samples collected from seven stratigraphic units. In many, but not all cases, each stratigraphic unit consists of several distinct levels. The levels within a unit are associated by their similar composition (e.g. calcareous silt matrix) compared to the level or levels in the units directly above and below them (silt versus peat versus colluvium). Units are numbered inversely to their age with Unit 1a and 1b being the oldest and Unit 7 the youngest. The upper and lower age range of each stratigraphic unit is noted as are its total number of radiometric dates from each unit. Where appropriate, suites of statically related radiocarbon dates were averaged (see Tables 5.3–5.5). The geologic interpretation of each unit as compiled by Kendrick (Chapter 3) of the Aucilla River Research Project will be reviewed to provide additional information (e.g. where there are conformable and non-conformable contacts and information related to depositional history).

5.1.2 The Aucilla–Wacissa River Basins and the Page-Ladson Site

The Aucilla River is a relatively small drainage area encompassing about 2590 sq. km^2 (USGS, 2002). However, only the low karst section of the Aucilla River and the Wacissa River that occupy the coastal lowlands, where organic preservation is often excellent, is considered here. It is also important to contrast the Aucilla River with its tributary, the Wacissa River. The lower Aucilla River is highly karstified where it runs through the coastal lowland as a narrow, but deep, slot encompassing a total of about 3.0 km^2. The Aucilla has numerous isolated surface channels connected to one another by underground passages. The bottoms of the surface channels are interrupted many times by sinkhole depressions that serve as sedimentary basins. The sinkholes in the river channels appear to have originated as egress or ingress points connecting the surface to the subterranean channel system. Caused largely by the processes of karstification, headward erosion has gradually extended the length of the surface channels, but in doing so, has left behind numerous, deep sediment-filled depressions. The Page-Ladson site occupies one of these sediment-filled sinkhole depressions at a location that was once a river siphon (ingress point).

The Wacissa River is also karstified but differs greatly from the Aucilla River. The Wacissa River is primarily a surface drainage that originates from headsprings. The clear water springs are located just below the Cody escarpment in the coastal plain. From the headspring southward, the Wacissa River forms a relatively short, but wide, drainage basin encompassing about 170 km^2. The Wacissa River has two types of surface channel systems: (1) ones that flow in numerous, low energy, braided channels through swamp forest, or (2) ones that flow in one or two wide channels located in sections dominated by savannah swamps (Yon, 1966). The Wacissa River runs through an elongate, wide swampland and not one of its channels is entrenched. The Wacissa River discharges into the Aucilla in at least two different places. Where the channel of the Wacissa River joins the Half Mile Rise section, the Wacissa is slightly elevated above the Aucilla River. As a result the Wacissa cascades over a rocky race (Wacissa Race) during times of low water conditions. The Page-Ladson site lies in a sinkhole just below the Wacissa Race in the channel of the Aucilla River.

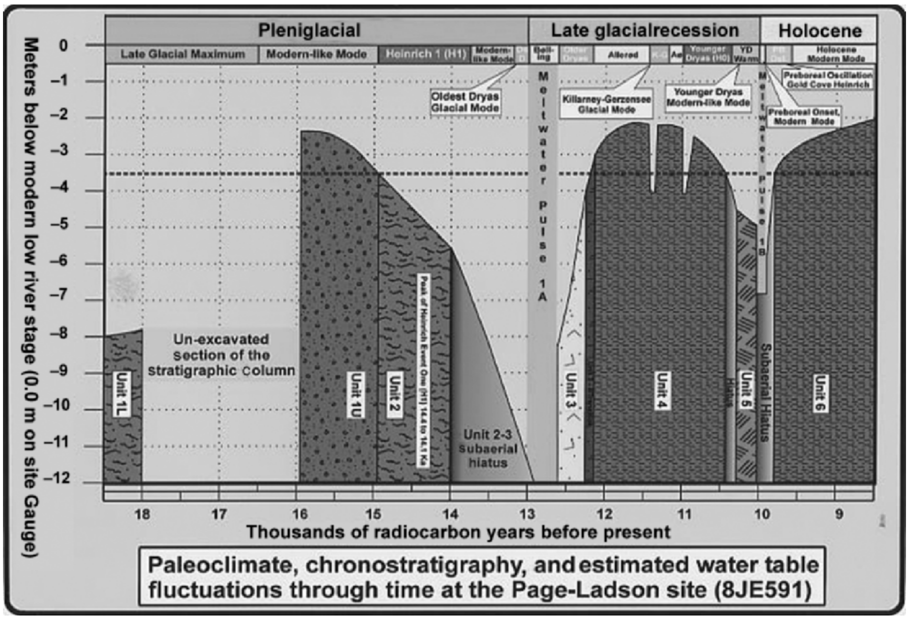


Figure 5.1 Proposed correlations between stratigraphic units at Page-Ladson site and climatic events of the last deglacial hemicycle at global, northern hemispheric, and regional scales. This graph spans about 10,000 radiocarbon years from left to right. The Y axis represents local changes in water table. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

The Page-Ladson site, at latitude 30° 10′ 13″ North and longitude 83° 57′ 29″ West, provides one of the most extensive (6 m plus), detailed, and well-dated stratigraphic sections of late glacial age east of the Mississippi River. The stratigraphy from the Page-Ladson site is discussed in chronological comparison to other local evidence as well as global and regional proxies. Figure 5.1 indicates several of the regional sites of late Pleistocene and early Holocene age with which the Page-Ladson site will be correlated.

The lower Aucilla River is formed by a series of disconnected surface channels cut by chemical weathering and water flow through the limestone bedrock. The surface channels are connected to other downstream surface channels by subterranean river segments. Surface channels, such as the Half Mile Rise section, have very irregular bottom topography consisting of rocky shallows interrupted by deep, sediment filled sinkholes. Cavernous openings to the subterranean conduits are mostly located at active river rises and sinks where the river water is either expelled to the surface or siphoned back into the subterranean channel network.

The inundated sinkhole at the Page-Ladson site is located in a land-locked segment of the Half Mile Rise section in the center of the river channel. Half Mile Rise and other karst sections of the Aucilla River have non-meandering, entrenched channels with no natural levees or flood plain terraces. Today the lower, karst section of the Aucilla River carries little or no particulate sediment load, but does carry a load high in dissolved chemicals including humic acids from decomposing organic material and calcium carbonate dissolved from the surrounding Oligocene, Suwannee Limestone (Yon, 1966:15–18). Thus the modern environment of the Aucilla River is one of a dark-water river continually undergoing chemical processes, striving but never reaching stability; it is the process of active karst erosion.

Where the lower, karst section of the Aucilla River crosses the coastal plain its channel is entrenched in the limestone. Entrenchment occurred by emergence and once a former underground channel segment surfaced, its position stayed fixed, becoming confined by limestone walls. The river channel's stability is reflected in its preserved sediment sequences that have accumulated in sinkhole depressions and date from ~40,000 ^{14}C BP to ~9,500 ^{14}C BP. One undated river channel site upriver from the Half Mile Rise section has produced the remains of the mastodon-like *Cuvieronius* spp., which suggests at least one mid-river sinkhole formed during the Sangamonian interglacial ~130,000 years ago. The occurrence of brackish water and marine shell beds in the Wacissa River is also likely to date to the Sangamonian interstadial. The karst section of the Aucilla River holds an extraordinary diversity of late Pleistocene sediments. The age range of these sediments varies from sinkhole to sinkhole.

The depositional history of the sinkhole at the Page-Ladson site was relatively uninterrupted after the last glacial maximum when a sediment column of more than 7 m accumulated. Excavations of the site have not encountered bedrock at the bottom of the most important stratigraphic sections. The oldest stratigraphic unit encountered dates to the time of the late glacial maximum ~18,500 ^{14}C BP. Thus the Page-Ladson site provides a mostly uninterrupted column of sediments containing generally well-preserved botanical remains and, as such, the means to temporally place sedimentary episodes by means of radiocarbon dating. The Page-Ladson chronology dates from the late glacial maximum of late Pleistocene to early Holocene age: ~18,500 ^{14}C BP to ~9,400 ^{14}C BP.

During the middle Holocene and thereafter, both sea level and climate lead to the establishment of modern current flow regimes in the Aucilla River. Consequently, the period of mid-Holocene to present fluvial action has reduced some areas of the original sediment column, most strikingly in the north and east-central bowl-shaped depression of the sinkhole (See Kendrick, Ch 3). This depression represents a blowout where lightweight sediment fraction was removed by current action and the heavier, less transportable fraction was left behind as channel lag deposits. About four decades ago, the first river divers (SCUBA divers) discovered substantial Paleoindian and Early Archaic artifact concentrations in the blowout area of the Page-Ladson sinkhole. The Aucilla Research Project's investigation of the site was aimed at locating uneroded sediment sequences and determining which levels of the site produced archaeological and paleontological remains.

5.2 Methods

5.2.1 Glacial Phase Terminology

Most North American archaeologists utilize terms for late Pleistocene time intervals based on established glacial climatic events: for example, the term Younger Dryas.

The terminology to identify these events originates in northern Europe and may then be extended around the earth insofar as they can be correlated. I begin with an introduction to those glacial terms and their evolving meaning.

This is followed by a discussion of the nature of proxy data as indicators of environment. It is through different interpretations of the proxy data that different conclusions can and have been made regarding late glacial environments. Just because proxy data might be interpreted in different ways does not mean that the data are not important, rather, it is an indication that a particular proxy's true significance is not yet determined. As Bloom (1998:395–396) characterized it, "proxy records are subject to multiple interpretations."

Radiocarbon dating has been the mainstay of archaeological research in the Southeastern US since its introduction in the mid-20th century. Eventually other means of dating may vie for a place next to the radiocarbon method as a means for determining age evaluations on samples recovered from archaeological context, but that remains for the future. Researchers in the Southeastern US have been heavily dependent on the radiocarbon method for age evaluations from archaeological sites.

In 1974 terminology for a Pleistocene stratotype was proposed for northwest Europe. Terms such as Younger Dryas and Allerød were used to place glacial phases into chronozones delineated in radiocarbon years before present. Conventional radiometric dates were obtained on organic samples extracted from bulk sediments in order to develop the chronology (Mangerud *et al*., 1974). The late glacial chronology was divided into Oldest Dryas, Bølling (including Oldest Dryas), Older Dryas, Allerød, and Younger Dryas chronozones and the first phase of the early Holocene, the Preboreal. "This chronostratigraphy has subsequently been widely adopted and the terminology has been applied to records based on a variety of climatic proxies from terrestrial, ice-core and marine realms" (Walker *et al*., 1999). Today, some North American archaeologists use the European terminology (e.g. Haynes, 1991; Fiedel, 1999; Richerson *et al*., 2001) but there is a problem with how these terms were originally applied and their shifting interpretation into the present century.

As Björck *et al*. (1998) point out, terms such as "Younger Dryas" and "Allerød" have a much longer and varied history of use. Their origins date to the turn of the 20th century when they were used as geologic biozones based on pollen and botanical evidence. The proposed usage of Mangerud *et al*. (1974) altered the meanings by placing the terms into chronostratigraphic divisions or chronozones based on lithostratigraphy, but climatic shifts during the late glacial recession sometimes occurred on a decadal timescale, which is below the resolution of the radiometric dating used. In addition, biozones are frequently time-transgressive of chronozones in the sense that climatic change occurs followed by biotic response to that change. To complicate matters further, this terminology has more recently been transformed into geologic-climate units of global inference (Walker *et al*., 1999).

> The problem, of course, is that formal stratigraphical procedures are being applied to a part of the geologic record for which they were never originally intended. In older strata, lithostratigraphic boundaries, although usually time-transgressive, *appear* to be synchronous

> when set against the vast span of geologic time. By contrast, ultra-rapid climatic shifts over time-scales of half a century or less can now be detected in many palaeoenvironmental records from the Last Termination [glacial recession]. Furthermore, detailed analysis of the GISP2 core (Taylor *et al*., 1997 [another of the Greenland ice-cores]) shows that the time-lag, between low and high latitudes, for major climate events is less than a few decades (Björck *et al*., 1998). [**NOTE** -block inserts, for example [another of the Greenland ice-cores], represent this author's comments and are intended to clarify quotations and terms of usage in this chapter]

Another problem with the European terminology, therefore, is not simply related to the meaning of terms, but the correlation of geographically separated sites dated by different means. The problem of chronological correlation includes concern about the detectability of leads or lags in time for the different climatic proxies. Yet another factor is the detectability of climate shifts due to the resolution of the dating method being employed. All of these concerns represent a relatively recent topic of scientific consideration. Because the European terminology was already in widespread use, one of the first debates about revisions was whether the terms Allerød, Younger Dryas, etc. should be used as informal terms for regional and inter-regional correlations or whether they should be completely abandoned altogether as chronostratigraphic nomenclature (Wohlfarth, 1996). As a result, researchers formed the INTegration of Ice-core, MArine and TErrestrial records (INTIMATE) Group to address these problems. Among the results of the INTIMATE Group deliberations are proposals to standardize terminology along with methodological guidelines for the interpretation of late Pleistocene proxy data (Björck *et al*., 1998; Walker *et al*., 1999; Lowe *et al*., 2001; Walker *et al*., 2001).

The INTIMATE Group recognizes the isotope record derived from the GRIP ss08c ice-core as the most fine-grained indicator of late glacial climatic change. As such, this Greenland ice-core record has been identified as a benchmark stratotype. Within the GRIP stratotype, several short-term duration climatic episodes are recognized and collectively represent an event stratigraphy. The event stratigraphy follows the GRIP ice-core isotope nomenclature using the prefix GS to indicate Greenland Stadials (glacial-like cool modes) versus the prefix GI to indicate Greenland Interstadials (modern-like warmer modes). Designators such as GS-2 and GS-1 further subdivide these prefixes in order to identify unique modes of the same kind through time. Finally, one further subdivision of modes (stadial or interstadial) separates them into fine-grained events such as GS-2a and GS-2c colder episodes versus GS-2b, a warmer episode within that stadial. The chronology in the GRIP ice-core is based on counted annual ice layers back to 14,500 cal BP. Beyond that age, a formula is used that assumes a steady-state ice-flow in order to calculate older annual events. The Greenland ice-core chronology is expressed in calendar years before present (cal BP) (Björck *et al*., 1998).

Adoption of the GRIP ice-core terminology has been mixed, with some researchers continuing to prefer the established European terminology. In other instances, researchers have either fully embraced the GRIP terms or have used both European and GRIP terms interchangeably. However, terms like Younger Dryas appear to be entrenched in the modern literature, possibly because they are more suited for unmistaken recognition. It is probably for this reason that the recent methodological guidelines published by the INTIMATE Group include both the "formal" GRIP and "informal" European terminology for the event stratigraphy (Lowe *et al*., 2001).

This study uses the European terminology in the text and relates it to the GRIP terminology in Tables 5.1 through 5.5. Because the North Florida chronology is based on radiometric dating (both conventional and AMS) which, by present standards, is incapable of resolving to a decadal scale, the data at this juncture cannot settle issues related to possible leads or lags in the timing of the Florida climatic events compared to the GRIP event stratigraphy. This chapter deals with the coarse-grained radiocarbon timescale, both near synchronous and asynchronous events are detectable in the Page-Ladson stratigraphy and are comparable to GRIP. For that reason the North Florida data are compared to GRIP and other data sets using the European terminology.

5.2.2 Proxy Data as Indicators of Late Glacial Climate

Whether or not samples originated from the Greenland ice-cores, lake or deep-ocean varves or from tree-rings in the Americas or Europe, the evidence collected represents proxy data about late glacial environments and climatic change. Although it is possible that a fundamental assumption about a particular proxy is incorrect, the proxy is usually meaningful in another way. For instance, there are two notable examples of differing hypothesis about proxy interpretations; one regional to the Southwestern US and the other regional to the Southeastern US. Both deal directly with paleoclimate and represent important background information.

In the Desert Southwest there were two interpretations of the available proxy data. One suggested that there was a late Allerød (11,500 ^{14}C BP to 11,000 ^{14}C BP) drought in the Desert Southwest (Haynes, 1991; Humphrey and Ferring, 1994; Haynes *et al*., 1999); the other suggested that the drought took place during the Younger Dryas

Table 5.1 INTIMATE Group radiocarbon chronology of GRIP ice-core events stratigraphy (Lowe et al., 2001; Lowe, 2002[1])

GRIP isotope stage: Informal European name	*Early Holocene: Preboreal*	*Mid-GS-1: mid-Younger Dryas Vedde*	*GI-1a/GS-1: Allerød/Younger Dryas boundary Ash (tephra)*	*Mid-GI-1c: mid-Allerød*	*GI-1d: older Dryas onset*
Steep Point ^{14}C Age	9,800	10,310 ± 50	10,800	11,200	12,100
Termination of ^{14}C Age Plateau Effect	9,600	N/A	10,600	11,100	12,300
Onset of ^{14}C Plateau Effect	10,000	N/A	11,000	11,300	12,500[1]
INTCAL98 Calendar Age BP	11,200	12,000–12,300	12,800	13,200	14,100
GRIP ice-core Age BP	11,570	12,000	12,650	N/A	N/A 12,500

(10,900 ^{14}C BP to 10,200 ^{14}C BP) (Holliday, 1997; Holliday, 2000). Subsequent studies have favored Haynes' (1991) interpretation (Weng and Jackson, 1999; Liu *et al.*, 2000; Bentacourt *et al.*, 2001; Jahren *et al.*, 2001), with the most convincing from the Sunshine locality in north-central Nevada (Huckleberry *et al.*, 2001). Because computer models of the late glacial ocean–atmospheric circulation incorporate Haynes' data with other proxy data from the Gulf of Mexico and Caribbean (Leyden *et al.*, 1994; Manabe and Stouffer, 1997) it became important to accurately place the Southwestern wet and dry episodes in time. Confirmation came from the well-dated speleothem proxy that chronologically demonstrates the Desert Southwest shifted from dry to wet around the Allerød–Younger Dryas boundary (Polyak *et al.*, 2004).

In Florida, one of the most notable proxies for late Pleistocene climate studies has been palynological. Pollen studies have required the compilation of profiles from cores extracted from lake-bottom sediment throughout Florida and South Georgia (Watts, 1975; Watts and Stuiver, 1980; Watts, 1983; Watts and Hansen, 1988; Watts *et al.*, 1992; Watts and Hansen, 1994; Watts *et al.*, 1996). Pollen counts from different levels within the cores are correlated chronologically using the radiocarbon method to develop evidence about paleoecological evolution through time. In turn, different plant assemblages that existed during different time intervals are used as proxy evidence indicative of one type of paleoclimate or another. Recently, the interpretation of Late Pleistocene *Pinus* (pine) pollen from Florida has been revised. Once considered to be indicative of arid conditions and xeric habitats (Watts *et al.*, 1996), intervals of late Pleistocene *Pinus* dominance are now viewed as a shift toward climatic moderation and more humid conditions. Episodes of more arid conditions are now believed to have occurred when scrub *Quercus* (oak), *Carya* (hickory), and *Ambrosia* (ragweed) pollen dominated the plant assemblage. The reinterpretation of the pine proxy came about as a result of using a comparative approach that identified a correlation between Heinrich ice-rafting events, H1 through H5, in the North Atlantic (between latitudes 40°North and 55°North) with that of marked increases in the pine record from Lake Tulane in south-central Florida (at latitude 27° 35′North). The Florida climate during major Heinrich events such as H1 is now considered to represent cooler episodes with an increase in atmospheric moisture and to have supported a non-fire adapted *Pinus* regime (Grimm *et al.*, 1993; Watts and Hansen, 1994; Watts *et al.*, 1996).

The interpretation of proxy data is an evolving process. Differences of opinion are often resolved in the long run and eventually provide additional clues about climate and environment. It is important for archaeologists to understand late glacial climate change due to the dramatic, often globally expressed climatic shifts that were occurring. The greatest challenge stems from the fact that some climate shifts were truly global whereas others were manifested locally. The impacts of global climatic shifts were manifested in different ways in the Southeast compared to other regions in North America.

Within the past few decades, numerous proxies have been investigated that provide a striking record of late glacial climatic change. Figure 5.2 places several key examples on a global map. Volumes of research have been published suggesting that many late glacial climate shifts occurred in near synchrony on a global scale (e.g. Edwards *et al.*, 1993; Grimm *et al.*, 1993; Hughen *et al.*, 2000a,b). However, it is

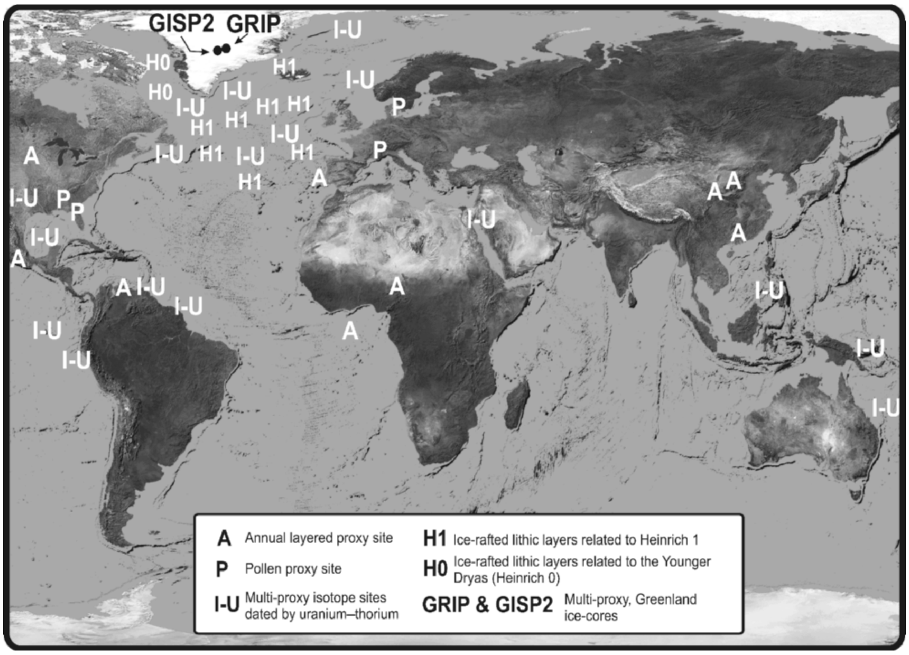


Figure 5.2 Global map showing selected locations of proxy data from terrestrial, lacustrine, and marine environments.

becoming apparent that regional factors also came into play. Evidence of regional shifts and steady-state conditions in the proxy records was not always in phase with global shifts. For example, the difference between the Southeastern and Southwestern US appears, in part at least, to be one of seesawing climatic opposites. When the Eastern Gulf Coast was wet the Western Gulf Coast was dry. These climatic shifts did not simply occur because of warm–cold mode shifts, they seesawed independently due to factors such as the timing, volume, and presence or absence of meltwater in the Gulf of Mexico (Heine, 1994; Leyden *et al.*, 1994). It is therefore important to understand what is known and hypothesized about the nature and timing of climate-altering forces both globally and regionally.

5.2.3 Establishing the Elevations of Late Pleistocene Water Table Stands in North Florida

One of the uniquely important aspects of the Page-Ladson site is the opportunity to establish water table position (elevation) through time as proxy for paleoclimates. This approach depends upon the fact that it occurs within a regional karst system of considerable breath and depth. The Page-Ladson site lies in a sinkhole that is part of the karst region known as the Gulf Coastal Lowlands. Its deposition or nondeposition reflected regional water level and was closely linked to eustatic sea level. The sediment being deposited in the sinkhole represented one of four possible environmental conditions: fluvial (lotic), still water (lentic), colluvial (slopewash), or terrestrial (non-depositional). Evidence of ancient water tables is indicated by the nature of the sedimentary beds being deposited. The deposition of silt, shell-rich silt, and channel lag represents fluvial origin. The deposition of peat and small animal bone assemblages indicates a still pond origin. The deposition of iron-rich smectite and small animal bone assemblages is of still or slow flowing, mostly lotic water deposition. The deposition of colluvium is from terrestrial slope reduction from higher to lower grades. The occurrence of hiatuses in the stratigraphic column is either from erosional fluvial conditions or from subaerial oxidizing conditions.

The reconstruction of the Aucilla–Wacissa basin paleohydrology is primarily based on data collected from the Page-Ladson site but also includes data collected from sites in the basin as well as other wetland and submerged locations.

The reconstruction of paleo-water tables is based on the assumption that the elevation of the shallow, limestone channel upstream from the Page-Ladson sinkhole represents the vertical bench that acted as a dam. When the water table was above the bench, flowing water could pass over it; however, when the water table was below the bench it became impounded and prevented downstream flow. The shallow limestone bench lies 3.5 m below the site's vertical datum river gauge. Thus, estimates of the paleo-water table stands are expressed as meters below the site's river gauge datum and any water table stand 3.5 m below present therefore represents an episode of non-flowing conditions (Fig. 5.3). An estimate of 3–5 m, however, implies an episode of intermittent flowing conditions.

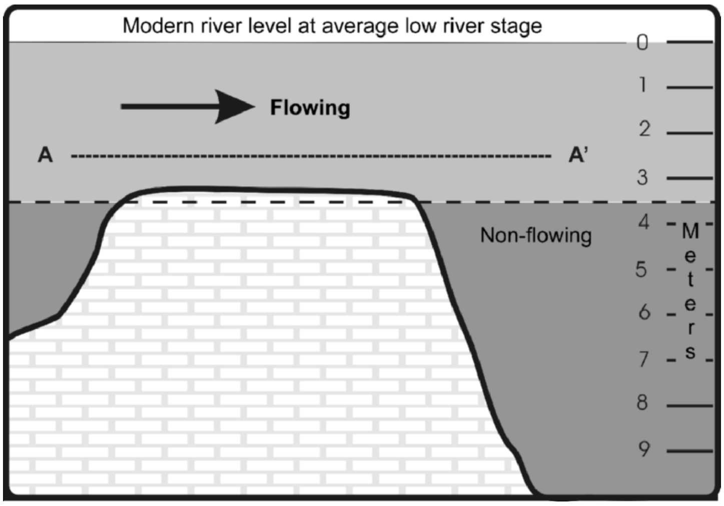


Figure 5.3 Elevation cross section of the limestone bench at the Page-Ladson site in the Aucilla River.

Finally sea level is not considered important to this chapter because the sites being considered were well inland from the coast during Paleoindian times. Nevertheless, this reconstruction may eventually provide data useful in the attempt to understand the larger and more complex question about the relationship between inland water tables and eustatic sea level fluctuation.

5.2.4 Radiometric Chronological Control

Among the chief concerns of the INTIMATE Group is the need to improve quality control for radiocarbon chronologies. Stratigraphic precision in the selection of material for dating is a fundamental need (Lowe *et al.*, 2001:1182). For the Page-Ladson site, only the radiocarbon samples collected in stratigraphic context during the controlled excavation are considered here. These samples (48 of the 59 dated samples from the Page-Ladson site) are included because they represent samples collected under controlled conditions. Each of the 48 samples was removed by hand from profile walls or from an established stratigraphic position in a test unit. In addition, several other radiocarbon dates from other Aucilla–Wacissa River sites are considered.

5.2.4.1 Radiocarbon Dates Included in the Page-Ladson Chronology

Of the 48 radiocarbon dates being considered in the Page-Ladson chronology, 36 are AMS dates, 3 standard radiometric dates adjusted for carbon 13/12, and 9 standard radiometric dates not originally adjusted for $d^{13}C$ by Beta Analytic. The radiometric dates not originally adjusted for $d^{13}C$ were recalculated by the CALIB98 software program and using the suggested mean values for $d^{13}C$ given in the CALIB 4.1 software manual (Stuiver and Reimer, 1993:28). Recalculated dates from the Page-Ladson site are listed. Seven different types of materials were sampled for dating: bone collagen ($n = 1$), organic sediment ($n = 1$), charcoal ($n = 3$), peat ($n = 4$), plant seeds ($n = 8$), plant material such as grape vine tendrils ($n = 11$), and wood ($n = 20$). With one exception, processing of the samples included freezing and/or desiccation of the samples prior to submission for dating. Preparation of the samples was done either at the Vertebrate Paleontology Lab at the Florida Museum of Natural History in Gainesville, Florida or at the Bureau of Archaeological Research, Conservation Lab in Tallahassee, Florida. When radiometric dates were found to be statistically related using the CALIB98 version 4.4.2 software, the group of dates was averaged using a routine of the software program for averaging related dates.

5.3 Climatic Cycles

5.3.1 Introduction to Global Climatic Cycles

Three aspects of climate change, which took place during the late Pleistocene and early Holocene, are considered here: (1) recurrent oscillations, (2) global climate modes, and (3) regional climatic influences. The ocean's role with the interplay of oceanic–atmospheric change is also considered, albeit briefly.

The Pleistocene epoch is marked by the growth and demise of numerous continental glaciers that are theorized to have waxed and waned as a result of the earth's orbital eccentricities over intervals known as Milankovitch cycles. The glacial episodes over the last ~1.2 million years have had an average periodicity of about 100,000 years (Suarez and Held, 1976; Liu, 1995). Glacial episodes are not the only cyclic events leading to climatic change. On smaller timescales, there are millennial, centennial, decadal, inter-annual, and, of course, annual rhythms of climate change (Bond *et al*., 1997; Appenzeller *et al*., 1998; Kahl *et al*., 1999; Tudhope *et al*., 2001). Of importance here are two climatic oscillations that have clearly imprinted on late Pleistocene proxy records: (1) the millennial-scale Dansgaard–Oeschger oscillation of the North Atlantic (Bond *et al*., 1997) and (2) the inter-annual, El Niño Southern Oscillation (ENSO) of the tropical southern Pacific (Zhou *et al*., 2001).

The second aspect of climate includes the different types of climate modes during the late Pleistocene. Two of these climate modes are familiar in concept; modern mode and glacial mode. A third, less familiar aspect of climate, Heinrich mode, is a North Atlantic phenomenon that occurs during the glacial phase of Milankovitch cycles. Heinrich events were episodes of glacial ice-rafting, sea surface chilling, salinity dilution, and deposition of ice-rafted lithic debris on the ocean floor (Vidal *et al*., 1997). Heinrich events took place irregularly through time both in advance of, and subsequent to, Pleistocene glacial maxima (Clark *et al*., 1999). Heinrich events are considered an independent mode of climatic change due to the extreme chilling of the northern North Atlantic and its seaboard (Alley and Clark, 1999).

Finally, a third aspect of climate change are regional influences that took place as a result of the direction and volume of meltwater being discharged from the Laurentide ice-sheet to the ocean.

5.3.2 The Oceanic Side of Climatic Change: North Atlantic Thermohaline Circulation and Southern Pacific El Niño Southern Oscillations

In 1798 Thompson Count Rumford proposed a dynamic ocean model, which emphasized large scale, interacting current mechanisms now recognized as the north–south, thermohaline, oceanic circulation (Weaver *et al*., 1999). The three-dimensional configuration of the North Atlantic and, to a lesser extent, the adjoining Arctic Ocean forms a natural pump that generates convectional, thermohaline circulation. Today, the warm surface current known as the Gulf Stream flows to the northeastern European coastline then circulates further north until it is substantially cooled. Once cold, the water becomes dense and begins to sink to the ocean floor. Here it begins re-circulation and forms the North Atlantic Deep Water (NADW) conveyor off the coasts of Greenland. The NADW current flows southward to the tropics where it up-wells, is again warmed, and rejoins the Gulf Stream. During the Pleistocene, Atlantic conveyor currents impacted climate depending on their volume flow, the degree of latitudinal repositioning during

Dansgaard–Oeschger oscillations, or the cessation of flow during Heinrich events (Boyle, 2000). The Pacific Ocean does not have a counter part to this type of thermohaline circulation.

Another type of oceanic circulation phenomenon resulting in climate change is the west to east ENSO of the southern Pacific. A 130,000-year record of El Niño oscillations is recorded in the Pleistocene corals of Papua, New Guinea (Tudhope *et al*., 2001). ENSO couplets have a warm ocean phase, El Niño, and a cold ocean phase, La Niña, that occur about once every three to seven years. Oceanic proxy data suggest that the end result of some ENSOs has resulted in noticeable climatic downturns about once every 2,000 years (Weaver *et al*., 1999:267–276). This is about the same periodicity as the Dansgaard–Oeschger cycles (Peterson *et al*., 2000:1947–1951) discussed below.

Thus any consideration of terrestrial climate change during the late Pleistocene is incomplete without recognition that there are corresponding changes of the oceanic components. From a much broader view, it is the paleoclimatic evidence of increased atmospheric CO_2 that is suspected to be the “Achilles heel” that has triggered past climate change. “The changes in climate associated with these jumps have now been shown to be large, abrupt, and global” (Broecker, 1997; Broecker, 2000).

5.3.3 The Terrestrial–Atmospheric Side of Climate Change

5.3.3.1 Dansgaard–Oeschger Oscillations

Millennial-scale Dansgaard–Oeschger oscillations have taken place throughout the Quaternary with the most recent Holocene event, the Little Ice-Age, taking place between A.D. 1600 and A.D. 1860 (Hendy *et al*., 2002). Dansgaard–Oeschger cycles occur at intervals about 1470 years apart. Even though the Dansgaard–Oeschger cycles of the Pleistocene and Holocene share a related periodicity, the Pleistocene events averaged 1536 ± 563 years apart compared to the Holocene events that averaged 1374 ± 502 years apart. Thus Dansgaard–Oeschger cycles are considered quasi-periodic (Bond *et al*., 1997). Dansgaard–Oeschger oscillations are considered to be ocean circulation processes triggered by meltwater changes that may vary randomly around this periodicity or that may follow in response to an ENSO-type mechanism. Dansgaard–Oeschger cycles are cool phase minima promoting glacial advance and are centered in the northern North Atlantic. They affect climate change in regions with strong atmospheric response to changes in the North Atlantic. In contrast, Heinrich events, which are also centered in the North Atlantic, transferred their climatic effects more globally (Clark *et al*., 1999). Because Heinrich events are restricted to glacial expression of Milankovitch cycles they do not appear to be true cyclic events. Heinrich events co-occur with and appear to represent particularly severe Dansgaard–Oeschger cycles.

Both proxy data and computer modeling of cool phase Dansgaard–Oeschger cycles indicate their occurrence did not result in the shutdown of the NADW conveyor current. During the Pleistocene, Dansgaard–Oeschger cycles resulted in Atlantic conveyor currents shifting southward to the middle North Atlantic but the rate of oceanic current overturn remained only slightly less than modern conditions. The Dansgaard–Oeschger cycles represent less intense cool phase minima when sea-ice, while present, was essentially non-existent compared to the volumes of icebergs that fill the North Atlantic during Heinrich events (Chappell, 2002). The sea-ice that existed during Dansgaard–Oeschger cycles originated from the eastern coast of Greenland (Bond *et al*., 1997) whereas Heinrich event sea-ice originated mostly from the Laurentide ice-sheet of northeastern Canadian coastline (Hemming *et al*., 1998 a&b). Pleistocene glacial-like conveyor circulation during Dansgaard–Oeschger cycles is believed to have resulted in cool oceanic conditions in the tropical western North Atlantic. Dansgaard–Oeschger cycles differed from cool phase Heinrich events in that Heinrich events disrupted the North Atlantic conveyor currents. This is an important distinction because Heinrich events, such as the Younger Dryas, are believed to have resulted in warmer oceanic conditions in the tropical western North Atlantic (Rühlemann *et al*., 1999; Seidov and Maslin, 2001), a factor that directly affected the Southeastern US.

5.3.3.2 El Niño Southern Oscillation

Inter-annual ENSOs are short duration, ~3–7 year events (Tudhope *et al*., 2001:1511) that fall below the resolution of the radiocarbon method. The global impact of ENSO cycles, that include both an El Niño and a La Niña phase, has been experienced in Florida in sometimes dreadful ways. For example, during La Niña phase droughts, forest fires and dramatic inland water table declines have taken place after the excessive rains, flooding and mosquito infestations of El Niño wet phases. The shifts in water table are especially pronounced in the Tertiary karst regions of Florida (Fig. 5.4). More important to this consideration is evidence suggesting that long-term

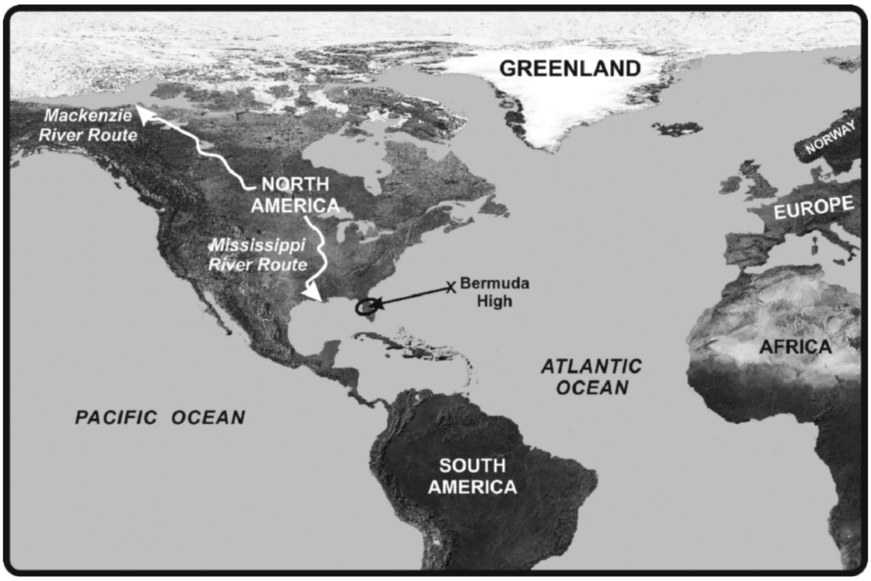


Figure 5.4 Map depicting the Mississippi River meltwater discharge route, a discharge route active during Meltwater Pulses 1A and 1B. The northern Mackenzie River route was active only during MWP-1B and was an early Holocene event. The Bermuda high pressure area over Florida resulted in extended arid conditions.

environmental change might be triggered by an ENSO event. Here I emphasize the terrestrial–atmospheric aspects of ENSO not the oceanic impacts.

ENSOs took place throughout the last glacial even though the intensity of the cycles appears to have been less than during Holocene cycles (Tudhope *et al.*, 2001:1514–1516). The remains of the coastal Quebrada Tacahuay Paleoindian site in Peru have yielded dates of 10,770 ±150 ^{14}C BP (Beta-958669 charcoal/hearth), 10,750 ±80 ^{14}C BP (Beta-108692A charcoal/hearth), and 10,530 ± 140 ^{14}C BP (Beta-108860C charcoal pieces interspersed with lithic flakes) sandwiched between probable El Niño phase flood deposits. The Paleoindian component of the Quebrada Tacahuay site shows that the occupants exploited shellfish, fish, and sea birds. Quebrada Tacahuay is located along a hyper-arid coastline that is only affected by rains during El Niño phase events. Fishing is disrupted during the El Niño phase events and, no doubt, played an important factor in subsistence decisions (Keefer *et al.*, 1998:1833–1835). On the other side of the Pacific the ENSO cycles are believed to have been linked to monsoonal activity during the Younger Dryas. Stratigraphic proxies from three locations located along the arid–semiarid transition zone of northern China show an initial cold, dry onset followed by a middle Younger Dryas interval of more humid conditions and increased organic preservation. This climatic shift to moderate conditions is attributed to a spatial shift in ENSO position that established a tropical-polar interconnection (Zhou *et al.*, 2001). This shift coincides with a decline in sea surface temperature of about 4–6°C in the tropical southwest Pacific where the ENSO cycles are spawned (Gagan *et al.*, 2000).

The effects of modern ENSO events have been mapped with most affected locations showing a seesaw impact of wet–dry or conversely dry–wet phases. The first phase of ENSO is El Niño followed by the second phase, La Niña. In North and Central Florida the effects are bimodal with a wet El Niño and a dry La Niña. The effect in South Florida is sometimes one of continued dry conditions through both phases (Holmgren *et al.*, 2001) making the impact particularly severe. However, if Zhou *et al.* (2001) are correct, the belt of ENSO effects may have also shifted to an undetermined configuration in the Gulf of Mexico-Caribbean region during one or more of the climate modes in the Pleistocene.

Perhaps the most interesting effects that ENSO cycles may cause are changes from one steady-state ecosystem to another (Holmgren *et al.*, 2001) or that a particularly strong and/or well-timed ENSO may trigger a longer term Dansgaard–Oeschger cycle (Peterson *et al.*, 2000).

5.3.3.3 Climatic Modes of the Last Glacial Recession

During the last glacial recession, environments variously shifted into one of three different modes: (1) glacial, (2) modern, or (3) Heinrich (Alley and Clark, 1999). Glacial mode includes those intervals of the glacial recessions during which climatic conditions in the northern latitudes returned to glacial-like, cold temperatures and the continental glaciers on both sides of the North Atlantic stabilized from retreat and often began re-advancing. Modern mode occurred during intervals of modern-like warm conditions. Generally modern mode intervals triggered glacial recession and meltwater discharge. Here the term mode denotes the state of atmospheric–oceanic conditions whereas the term event is used to denote when the various mode shifts occurred and how long they endured. In North America, meltwater discharged in the Gulf of Mexico versus the North Atlantic or Arctic Ocean served to affect open ocean regimes in different ways. As cold, non-saline meltwater and icebergs built up in the North Atlantic they sometimes reached threshold volumes that greatly reduced or halted the flow of the North Atlantic conveyor currents. These threshold events are believed to have triggered the sudden return to cold conditions; the Heinrich events enhanced by icebergs, being more severe than the relatively iceberg-free Dansgaard–Oeschger cycles. Thus the shifts from modern to glacial or Heinrich mode represented pulsed climatic shifts that seesawed for the duration of the last glacial recession (Alley and Clark, 1999).

Modern Mode During the periods of modern mode the Laurentide ice-sheet of North America, the Fenno-Scandinavian ice-sheet of northern Europe and most glaciers in other regions of the world were in recession due to global warming (Alley and Clark, 1999). Meltwater from the glaciers drained to the oceans. Across the northern latitudes in Europe and North America, mega-floods sometimes occurred when pro-glacial lake margins were breached by excessive meltwater discharge, events which resulted in catastrophic floods rushing toward base-level, the sea (Brown and Kennett, 1998:599–602).

Radiocarbon evaluations of both atmospheric (terrestrial) and marine sources indicate that the late glacial recession began in North America around ~17,000 ^{14}C BP along the southeastern front of the Laurentide ice-sheet and by ~16,500 ^{14}C BP along the front of the southern Laurentide (Jackson *et al.*, 2000; Clark *et al.*, 2001; Dyke *et al.*, 2002). The initiation of glacial recession took place under subdued modern mode conditions during the Pleniglacial. Meltwater from the Laurentide ice-sheet drained to the northeast via the Hudson and St. Lawrence Rivers to the Atlantic Ocean during the first Pleniglacial modern mode event. The onset of this meltwater event began ~17,000 ^{14}C BP and endured until ~15,100 ^{14}C BP in the North Atlantic (Clark *et al.*, 2001). This meltwater episode appears to coincide with the GRIP isotope warming phase GS-2b, the onset of which is placed at 19,500 GRIP cal BP (Walker *et al.*, 1999). Evidence from glacial moraines indicates that the initial phase of recession resulted in glacial ice mass thinning more than marginal retreat (Lambeck *et al.*, 2000). During this interval, between ~16,500 ^{14}C BP and ~16,000 ^{14}C BP, sea level rose 15 m or more (Clark *et al.*, 2001). It was the meltwater event that preceded the Heinrich, H1 ice-rafting cold phase (Sarnthein *et al.*, 1995).

Heinrich H1 occurred between ~15,100 ^{14}C BP and ~13,500 ^{14}C BP and took place between meltwater events (Clarke *et al.*, 2001). After ~14,000 ^{14}C BP the cooling effects of H1 began to abate in the northwestern Atlantic. After that, meltwater discharged to the Gulf of Mexico as well as the North Atlantic (Vidal *et al.*, 1997; Bard *et al.*, 2000; Chapman *et al.*, 2000). The second meltwater event during the Pleniglacial began ~13,400 ^{14}C BP and endured until the Oldest Dryas (a Dansgaard–Oeschger cycle) ~13,200 ^{14}C BP. Renewed meltwater discharge after H1 is the first evidence of major global warming. This event took place after the Pleniglacial during the Bølling (Clark *et al*., 2001). The climatic warming was preceded by the initiation of the first post-glacial maximum return of conveyor currents as far north as the Norwegian Trench in the eastern North Atlantic ~13,500 ^{14}C BP (Lehman and Keigwin, 1992).

The end of the Pleniglacial and the onset of the next modern-mode event, the Bølling, are varied in the radiocarbon record. Estimates for the onset range from ~13,000 ^{14}C BP (Mangerud *et al*., 1974; Sarnthein *et al*., 1995) to ~12,800 ^{14}C BP (Clark *et al*., 2001), and ~12,700 ^{14}C BP (Renssen and Isarin, 2001; Renssen *et al*., 2001). At ~13,000 ^{14}C BP, sedimentation regimes in the Gulf of St. Lawrence changed abruptly from low to high diatom concentrations with some species indicative of temperature moderation of cold conditions in the upper water column (Lapointe, 2000). The late Bølling coincides with major meltwater buildup in the Gulf of Mexico from ~12,700 ^{14}C BP to ~12,600 ^{14}C BP that was a result of the largest mega-flood down the Mississippi River (Brown and Kennett, 1998). Large volumes of meltwater in the Gulf of Mexico resulted in the Bermuda high-pressure area shifting west over Florida (Leyden *et al*., 1994). Following this meltwater event, there was another Dansgaard–Oeschger glacial mode cycle known as the Older Dryas that took place from ~12,500 ^{14}C to ~12,300 ^{14}C (Lowe, 2001, 2002). See Fig. 5.5.

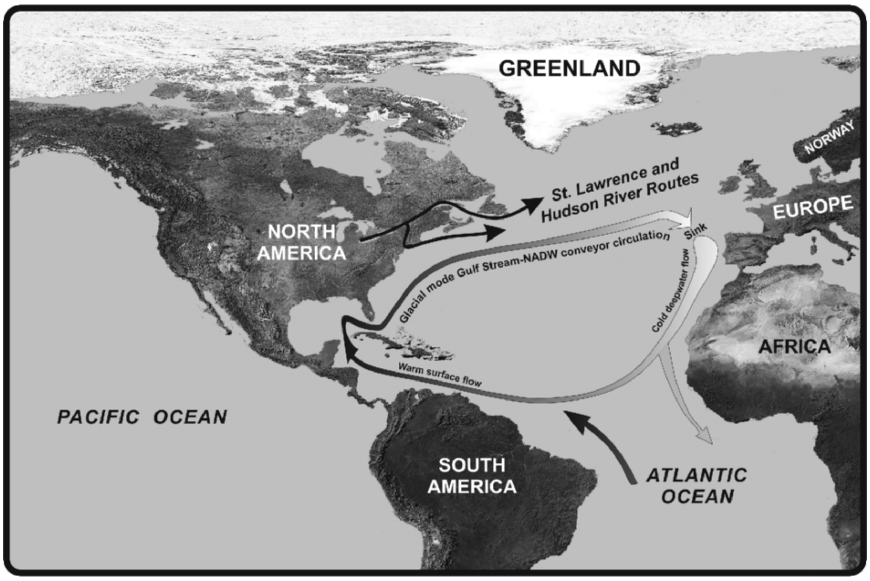


Figure 5.5 Map depicting the Hudson and St. Lawrence River meltwater discharge routes to the northern North Atlantic Ocean. These routes were active at various times, but the interval of discharge during the middle to late Allerød reversed the trend in arid conditions from the Southeastern to the Southwestern US. Cold meltwater in the Atlantic tended to attenuate the Gulf Stream to a lower latitude after the shift from modern to glacial mode.

After the Younger Dryas came the Allerød, a major modern mode episode. During the beginning of the Allerød the Laurentide ice-sheet began to retreat northward rapidly. As a result the northern meltwater routes captured ever-increasing volumes of discharge. By ~12,000 ^{14}C BP, the Mississippi River was carrying substantially less meltwater to the Gulf of Mexico and by ~11,700 ^{14}C BP to ~11,600 ^{14}C BP the northern routes had virtually captured all of the meltwater discharge (Wright, 1989; Heine, 1994). The absence of meltwater in the Gulf of Mexico during the middle to late Allerød resulted in the Bermuda High pressure area shifting easterly, away from Florida. And this shift produced a wet cycle in the Southeastern US and eastern Caribbean (Leyden *et al*., 1994).

Another brief episode of meltwater in the Gulf of Mexico (Broecker *et al*., 1989) occurred at the Younger Dryas-Preboreal transition between ~10,000 ^{14}C BP and ~9,900 ^{14}C BP (Wright, 1989; Lehman and Keigwin, 1992; Flower and Kennett, 1995; Jiang and Klingberg, 1996; Clark *et al*., 2000). This took place after the re-advance of the Laurentide ice-sheet that blocked meltwater from discharging through North Atlantic routes (Wright, 1989). See Fig. 5.5. The Florida climate again became dry.

During modern mode, routing of major meltwater to either the North Atlantic or the Gulf of Mexico is believed to have had regional climatic implications. In part or in whole, the discharge of cold, freshwater to the North Atlantic is believed to have shifted the Gulf Stream and NADW conveyor currents south upon the buildup to and during the onset of Dansgaard–Oeschger oscillations, or to have helped trigger the shutdown of the conveyor currents altogether during Heinrich events (Broecker *et al*., 1989). With the return of modern mode after the Pleniglacial, Atlantic conveyor currents returned in the northeastern North Atlantic. The post-Pleniglacial, modern mode surface expression of the Atlantic conveyor current, the Gulf Stream, served to warm the European coastline. However, during post-Pleniglacial glacial and Heinrich modes the conveyor current shifted south or was interrupted and Europe became a much colder place (Weaver *et al*., 1999).

An atmospheric–oceanic computer model of late Pleistocene climate change supports the hypothesis that meltwater via the St. Lawrence–Hudson River routes to the North Atlantic had a greater disruptive effect on the conveyor currents than southerly discharge via the Mississippi River to the Gulf of Mexico (Manabe and Stouffer, 1997). However, another computer model suggests that a Bølling-age mega-flood, sometimes referred to as Meltwater Pulse-1A (MWP-1A), which discharged to the Gulf of Mexico, served as a necessary precondition for the eventual onset of Heinrich event H0 (the Younger Dryas). It is worth restating that the Bølling mega-flood was the largest Mississippi River flood of geologic record (Flower and Kennett, 1995; Marchitto and Wei, 1995). Proxy evidence of the flood is dated from ~12,700 ^{14}C BP (Marchitto and Wei, 1995) to around ~12,600 ^{14}C BP (Brown and Kennett, 1998), just prior to the onset of the Older Dryas at ~12,500 ^{14}C BP (Flower and Kennett, 1995; Björck *et al*., 1996; Hughen *et al*., 1996).

Recent investigations have shown that modern mode episodes were the periods of active meltwater discharge, not the glacial mode episodes (Kaufman *et al*., 1993; de

Vernal *et al.*, 1996). Thus, the late glacial recession consisted of a series of warm, modern versus cold, glacial, or Heinrich mode episodes.

Several researchers have pointed to the seesaw nature of late glacial climate in the Eastern versus Western Gulf Coasts. During episodes of modern mode, when meltwater discharge occupied the Gulf of Mexico, the Southeastern Gulf Coast and eastern Caribbean experienced dry to arid climatic conditions because the Bermuda High moved west over Florida. Today, the most devastating droughts have been linked to the westerly expansion of the Bermuda High over Florida in the late spring and summer months during strong La Niña phase events. The Bermuda High repositioning over Florida results in the absence of summer convectional thunderstorm activity (Chen and Gerber, 1991). Cold meltwater in the Gulf of Mexico is another climatic condition that directed the Bermuda High over Florida, but had a much longer duration and devastating impact (Grimm *et al.*, 1993).

Conversely, Western and Central America was wetter when meltwater was in the Gulf of Mexico (Maasch and Oglesby, 1990) during the Bølling and early Allerød from ~13,000 ^{14}C BP to ~11,700 ^{14}C BP (Leyden *et al.*, 1994). A possible reflection of wet conditions in the Southwest US was the advance of Mexican mountain glaciers around the time of the Mississippi River mega-flood. The advance of glaciers in Central America was totally out of synchrony with the climate in modern mode and is believed to be a factor resulting from glacial meltwater in the Gulf of Mexico (Heine, 1994).

The presence or absence of glacial meltwater in the Gulf of Mexico during modern mode intervals directed the Bermuda High pressure area toward or away from the Southeastern US. In seesaw-like manner, meltwater in the Gulf of Mexico shifted the Bermuda High over Florida and led to prolonged dry conditions in the Southeast, but moderate to wet conditions in the Southwest US. Conversely, the absence of meltwater in the Gulf of Mexico led to moderate to wet conditions in the Southeastern US, but dry conditions in the Southwest US. Therefore, the presence or absence of meltwater in the Gulf of Mexico differentially affected climate on a regional scale independent from global, modern mode influences.

Glacial Mode The recession of the Laurentide ice-sheet began during the Pleniglacial ~17,000 ^{14}C BP to ~16,500 ^{14}C BP (Jackson *et al.*, 2000; Lambeck *et al.*, 2000; Clark *et al.*, 2001) and lasted until ~9,500 ^{14}C BP (Kaufman *et al.*, 1993). During the 7,500–7,000 radiocarbon-year duration of the meltdown, there were episodes of return to glacial mode cooling conditions. During Pleistocene glacial mode conditions, the Laurentide and Fenno-Scandinavian ice-sheets advanced or were stable (Lehman and Keigwin, 1992; Björck *et al.*, 1996; Lambeck *et al.*, 2000; Clark *et al.*, 2001). The Pleistocene Oldest Dryas, Older Dryas, Killarney-Gerzensee, and the Holocene 8.2 ka event were Dansgaard–Oeschger glacial mode events.

It should be noted that the terminology of Mangerud et al. (1974) included the Oldest Dryas as part of the Bølling during the post-Pleniglacial. Subsequent usage, however, separates the two with the Oldest Dryas representing a non-Heinrich glacial mode event and the Bølling a modern mode event. In this chapter, the Oldest Dryas is considered to be the last phase of the Pleniglacial because both H1 and the Oldest Dryas cool phases delayed the climatic amelioration experienced afterward, during the post-glacial recession of the Pleistocene (Sarnthein *et al*., 1995).

Radiocarbon dates for the onset of the Oldest Dryas vary from ~13,500 ^{14}C BP (Alley and Clark, 1999) to ~13,200 ^{14}C BP (Sarnthein *et al*., 1995; Björck *et al*., 1996). German lake varve chronology indicates the Oldest Dryas took place over an interval of 130 calendar years (Brauer *et al*., 1999).

Heinrich Mode Heinrich events (H1), the Younger Dryas (H0), and the Preboreal oscillation (HGC) represent Dansgaard–Oeschger events amplified by Heinrich ice-rafting. Heinrich events represent ocean–land–atmospheric events that impacted climates globally (Rühlemann *et al*., 1999; Bard *et al*., 2000). Over the last 100,000 years, there have been seven major Heinrich mode events that represent especially cold times in the North Atlantic (Alley and Clark, 1999). Heinrich events H1, H2, H4, and H5 were well-defined episodes primarily influenced by the Laurentide ice-sheet. Heinrich events H3 and H6 were less distinct episodes influenced by the European, Fenno-Scandinavian ice-sheet (Cortijo *et al*., 2000). Heinrich event H0, the Younger Dryas, is ignored or not recognized by many researchers because it has not been detectable as an ice-rafting event in the middle North Atlantic (Vidal *et al*., 1997; Chapman *et al*., 2000; Cortijo *et al*., 2000). The Gold Cove advance, which occurred during the Preboreal oscillation, represents a diminutive Heinrich event, not numbered and also ignored, that coincided with the last major advance of the Laurentide ice-sheet in the early Holocene (Kaufman *et al*., 1993; Clark *et al*., 2000).

Heinrich mode events are only documented during the buildup and decline of glacial episodes and occurred before or after glacial maxima. They did not occur during interglacials. Heinrich events are considered by some researchers to be part of so-called "Bond cycles". Bond cycles include several Dansgaard–Oeschger oscillations within a 6000–7000 year period that culminates in a Heinrich event. It is unclear, however, if the term Bond cycles should be used for sequences of Dansgaard–Oeschger cycles followed by a Heinrich event because the duration between H1 and H0 was only 4250 calendar years GRIP and between H0 and an unnamed Heinrich event in the Preboreal only 1300 calendar years GRIP (Björck *et al*., 1998; Walker *et al*., 1999; Walker, 2001). The short duration between the last two Heinrich events is clearly in disagreement with the proposed 6000–7000 year Bond cycle periodicity. On the other hand, H0 and the Preboreal HGC events were not as intense as those before them, thus the identification of Bond cycles may be related to the degree of Heinrich event intensity rather than their evidence of occurrence.

Heinrich cooling conditions resulted from voluminous ice-rafting, ocean surface chilling, and salinity dilution due to inordinate volumes of fresh meltwater (Clark *et al*., 2001). A possible cause of Heinrich ice breakouts may be related to sea level transgressions of ~10–15 m or more. In this model, sea level rose sufficiently to flood glaciated land and in doing so lifted large sections of continental glacier from dry-dock and set large sections of ice-sheet to sea (Chappell, 2002). The direction of iceberg drift is believed to have been determined by the position of the Polar front. When the polar front shifted southward to about ~37–40° North latitude as it did during H1 and H0, sea-ice drifted easterly toward Greenland and the European coastline. In contrast, when the polar front remained in near-modern position during the Preboreal oscillation, sea-ice drifted southerly from the Hudson Strait along the Newfoundland coast (Kaufman *et al*., 1993; Calvo *et al*., 2001). Figure 5.6 depicts some of the climatic effects imposed by Heinrich events.

Both H1 and H0 occurred as a result of and mostly subsequent to meltwater pulses discharged in the North Atlantic via the Hudson and St. Lawrence Rivers (de Vernal *et al*., 1996; Clark *et al*., 2001). The Preboreal HGC event occurred subsequent to and during Meltwater Pulse-1B (MWP-1B) that initiated as discharge from glacial Lake Agassiz southward via the Mississippi River to the Gulf of Mexico before shifting to a northern route via the Mackenzie River to the Arctic Ocean (Broecker *et al*., 1989; Fisher *et al*., 2002).

Digressing for a moment, it is of interest that there was no Heinrich event during the largest mega-flood down the Mississippi River to the Gulf of Mexico possibly because meltwater was discharged to a subtropical latitude (Brown and Kennett, 1998; Clark *et al*., 2001). Nonetheless, the culmination of the Mississippi River mega-flood

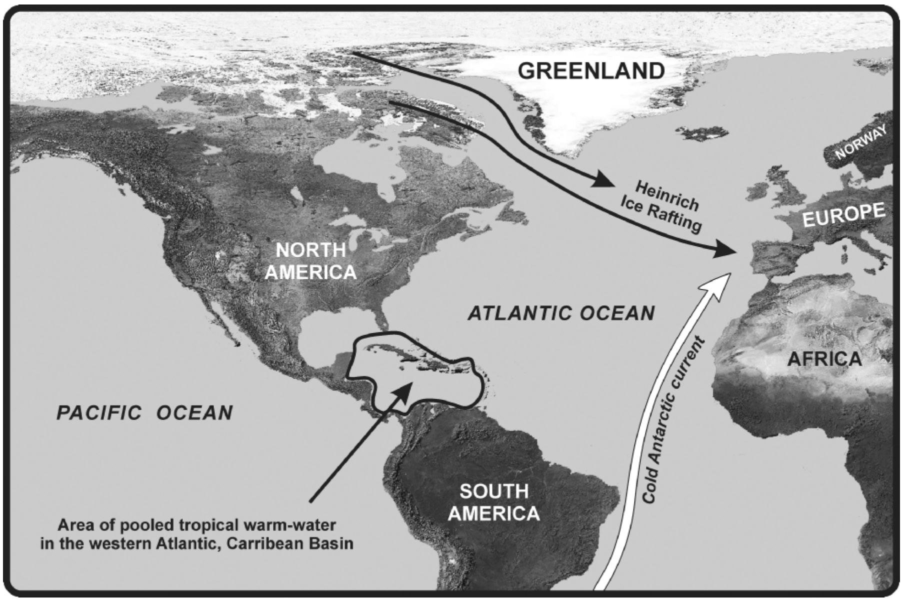


Figure 5.6 Map depicting the oceanic and atmospheric climatic conditions imposed by Heinrich ice-rafting events in the northern North Atlantic Ocean. Heinrich H1 and H0 caused a cessation of the Gulf Stream and deepwater conveyor currents in the North Atlantic, which resulted in the northward invasion of cold Antarctic current along the Eastern Atlantic. Conversely, in the tropical southeastern Atlantic and Caribbean the water was static and warm, particularly during the Younger Dryas (Heinrich H0).

may have led to the Older Dryas cool phase from ~12,500 ^{14}C BP to ~12,300 ^{14}C BP (Lowe *et al*., 2001; Lowe, 2002). The Mississippi River mega-flood was originally correlated with MWP-1A, however, a 19-m sea level rise is now also referred to as MWP-1A. It took place between ~12,200 ^{14}C BP and ~11,700 ^{14}C BP subsequent to the Mississippi mega-flood. Some researchers now think the cause of sea level rise attributed to MWP-1A to be related to an episode of Antarctic ice-sheet reduction of the later time frame (Clark *et al*., 1996). Nevertheless there was a mega-flood of all time record often referred to as MWP-1A that drained from Mississippi River to the Gulf of Mexico prior to the Older Dryas from ~12,700 ^{14}C BP to ~12,600 ^{14}C BP. Confirmation of the timing and direction of discharge to the Gulf of Mexico of MWP-1A as well as MWP-1B are further supported by the recent optical age chronology (OSL dating) established for the late Pleistocene braided channel belts of the Lower Mississippi River basin (Rittenour *et al*., 2003).

Rafted glacial ice during H1 and H0 (Younger Dryas) originated from the Hudson Strait or Cumberland Sound in the Baffin Island area of the Nunavut Province, Canada above 60° North latitude (Bond *et al*., 1992; Kaufman *et al*., 1993; Hemming *et al*., 1998 a,b). Thus, the sources of glacial ice during H1 and H0 came from a location more than 1400 km north of the point where meltwater was being discharged.

During the Younger Dryas-Preboreal transition and prior to the onset of the Preboreal oscillation (at ~9900 ^{14}C BP), meltwater discharged from Lake Agassiz not only went south down the Mississippi River but also north to the Arctic Ocean, a location well north of the Hudson Strait-Baffin Island launch point of glacial ice-rafting from the Labrador Sea (Spero and Williams, 1990; Alley and Clark, 1999; Fisher *et al*., 2002). The Arctic Ocean point of meltwater discharge is located above the Arctic Circle near 70° North latitude. Thus, the addition of substantial meltwater volumes in the Northern latitudes tended to affect the Atlantic conveyor currents in a more substantial way than discharge to the south (Fanning and Weaver, 1997; Manabe and Stouffer, 1997).

In every respect, H1 was the most severe late glacial Heinrich event. Studies of glacial sea-ice cover in the northwestern North Atlantic suggest that H1 summertime sea surface temperatures were much colder than those of the late glacial maximum (de Vernal *et al*., 1996). H1 sea-ice spread throughout the North Atlantic as the eastern Laurentide ice-sheet expelled massive amounts of ice into the ocean. Like other Heinrich events, H1 ice-rafting left its imprint on the ocean floor. As lobes of the Laurentide ice-sheet pushed over bedrock in the Hudson Strait and Cumberland Sound areas of northeast Canada it incorporated some of the bedrock in the ice. As glacial-born icebergs drifted in the open ocean they melted and eventually lost their lithic debris. It is the ice-rafted lithic debris that provides the means of determining the port of origin of both the lithic debris and the icebergs (Bond *et al*., 1992; Hemming *et al*., 1998 a,b; Thouveny *et al*., 2000; Andrews and Barber, 2002). In addition, proxy evidence indicates that H1 endured about 500 radiocarbon years longer along the European coast compared to the North American coastline. Thus the severe effects of H1 had terminated in the west by ~14,000 ^{14}C BP but endured until ~13,500 ^{14}C BP off the Portuguese coast (Chapman *et al*., 2000).

The 500 ^{14}C year lag in timing, as well as proxy evidence from the subtropical western Atlantic, indicates that sea surface temperatures became warm in the western low latitudes of the North Atlantic but remained cool along the European coastline as far south as the Iberian peninsula (Bard *et al*., 2000:1321–1324). Unlike the Dansgaard–Oeschger cycle glacial mode events (Fig. 5.7), Heinrich events are believed to have resulted in a bipolar climatic seesaw effect between the northern and southern hemispheres due to the disruption of the NADW conveyor current versus an uninterrupted Antarctic Bottom Water conveyor current (Seidov and Maslin, 2001). See Fig. 5.8. The effects of the Antarctic current negated the potential for warm water buildup in the tropical eastern North Atlantic. However, in the west, the potential for

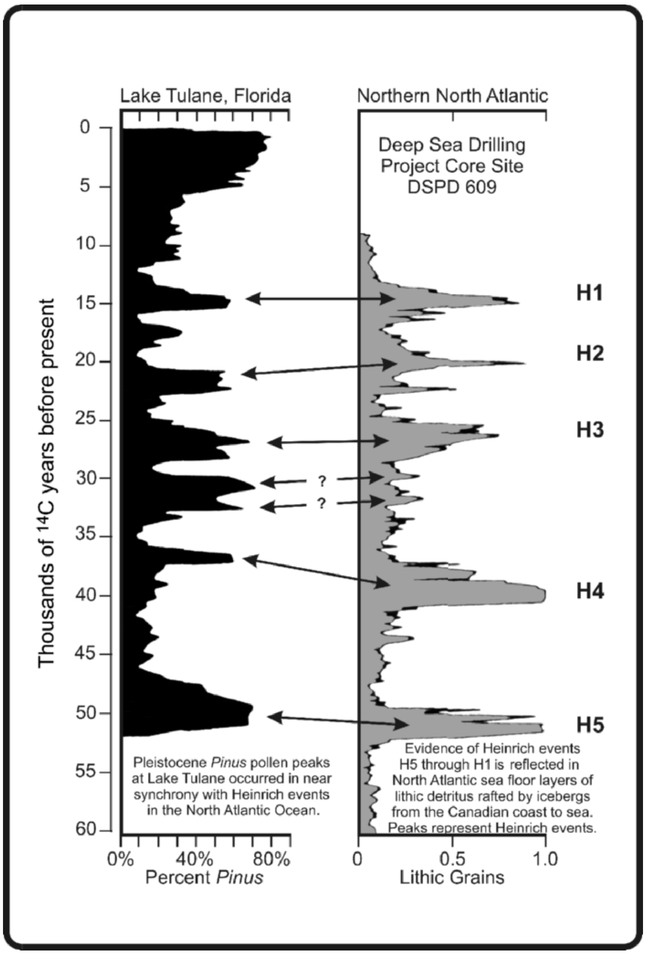


Figure 5.7 Fifty thousand-year record of *Pinus* pollen from Lake Tulane, Florida, compared with the occurrence of Heinrich events in the North Atlantic (after Grimm et al., 1993:199).

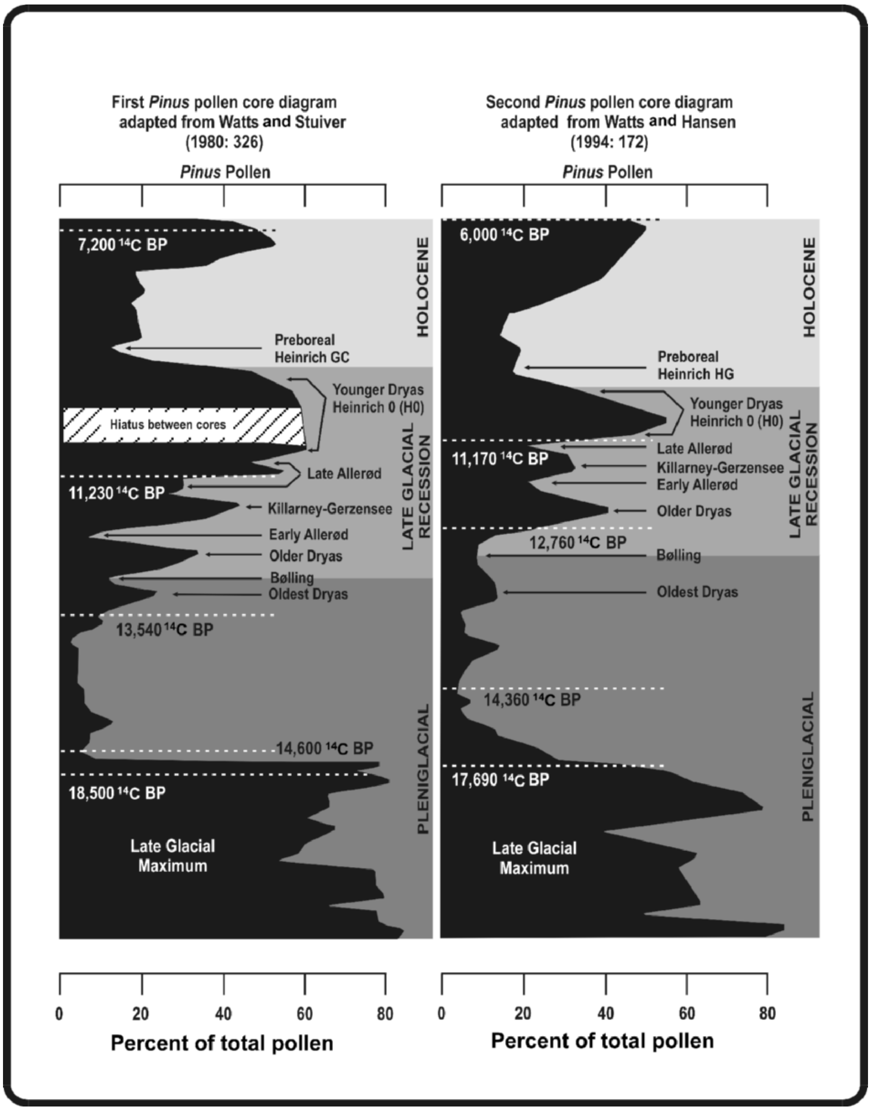


Figure 5.8 Global climatic mode shifts and Sheelar Lake, Florida, *Pinus* pollen oscillations from the Pleistocene Late Glacial Maximum to the mid-Holocene.

warm water buildup appears to have been magnified under pooling conditions unaffected by the southern hemisphere heat sink (Bard *et al.*, 2000:1321–1324). Thus, after ~14,000 ^{14}C BP the attenuating effects of a warm tropical western Atlantic ended the cooling conditions that continued in the east for another 500 years.

During the Younger Dryas, Heinrich HO, sea surface temperatures in the northwestern North Atlantic were about the same as they were during the late glacial maximum;

much warmer than conditions during H1 (de Vernal *et al*., 1996). The evidence for a less intense H0 comes from a number of proxies and suggests important climatic implications. Although the peak of the H0 ice-rafting lasted from ~10,900 ^{14}C BP to 10,500 ^{14}C BP, it was confined to a smaller area of geographic distribution and had a shorter duration than H1 (Clark *et al*., 2001). Similarly, tetra-unsaturated $C_{37:4}$ alkenone proxies (temperature-sensitive alkenone in organic sediments) from the subtropical Northeast Atlantic show up as a distinct peak around ~14,100 ^{14}C BP during H1 but only as a weak signal during H0, perhaps a reflection of the difference in magnitude (Bard *et al*., 2000:1322). H1 occurred before the end of the pleniglacial when glacial mode conditions dominated whereas H0 occurred subsequent to the ~13,000 ^{14}C BP termination of the pleniglacial after which modern mode conditions dominated.

The H0 event is also different in that lithic detritus on the ocean floor was deposited farther north and west, around 60° North latitude in the Labrador Sea area. Apparently, the direction of the ice-sheet being calved to sea originated from a northward advance of the Laurentide ice-sheet toward Cumberland Sound. This source of icebergs contained lithic detritus derived from a location about 400 km north of the H1, Hudson Strait source (Kirby, 1998).

The early Holocene, Preboreal oscillation, HGC, was weaker than the Pleistocene events. But evidence to be discussed in more detail below suggests that the Preboreal oscillation (Björck *et al*., 2002; Fisher *et al*., 2002) and its accompanying HGC Heinrich event (Kaufman *et al*., 1993) impacted the Southeastern US more than the subsequent Dansgaard–Oeschger event at ~8200 ^{14}C BP.

In sum, the climatic conditions of the late glacial recession frequently shifted into one of three climatic modes: (1) modern, (2) glacial, or (3) Heinrich (Alley and Clark, 1999). Throughout the Pleistocene and Holocene, millennial-scale Dansgaard–Oeschger cycles culminated with cool, glacial mode episodes from one to several hundred years in duration. With the exception of HGC, Heinrich events took place over millennial-scale durations. Once established, Heinrich events resulted in warm water pooling in the western tropical North Atlantic (Caribbean) due to the cessation of Gulf Stream and deepwater conveyor circulation. Dansgaard–Oeschger events resulted in generally cool sea states throughout the North Atlantic including the western tropics. Surface water temperatures during H1, after ~14,000 ^{14}C BP, and during the Younger Dryas H0 appear to have been one of the factors that caused tropical moisture to be transported atmospherically northward, past Florida, toward the ice-sheets in northern latitudes (Labeyrie, 2000)

5.4 Results

5.4.1 Chronostratigraphic and Geoclimatic Model of the Karst Region of North-central Florida

In this section the local stratigraphic sequence at Page-Ladson is compared to the event stratigraphy of the GRIP ice-core (Fig. 5.2 and Tables 5.1 and 5.2). The GRIP,

Table 5.2 Radiocarbon chronology of GRIP ice-core event stratigraphy based on a composite of INTIMATE Group and other data sources

MODE	GRIP Event ID	Informal Event Name	Estimated ^{14}C Age Onset	GRIP AGE	Comments	Other Calendar Dates	Late Pleistocene - Holocene Phases
GLACIAL	GS-2c	**Late Glacial Maximum**	18,500*–17,000	22,000	Steady-State Glacial Maximum	21,200 GISP2	**PLEISTOCENE - PLENIGLACIAL** Glacial and Heinrich Modes Dominant
Modern-like	GS-2b	Unnamed Late Glacial warm phase	17,000*–15,000	19,500	Glacial Thinning more than marginal retreat	20,000 GISP2	
First Major Meltwater Event of Glacial Recession			17,000 – 15,000		Atlantic and possible Gulf of Mexico Meltwater Discharge		
Heinrich Mode	GS-2a	**Heinrich 1 (H1)**	15,000*–14,400	16,900	Radiocarbon Plateau		
			14,400–14,100	N/A	Peak of Heinrich 1 Event		
			14,100–13,500	N/A	End of the H1 cold effects in the northwestern, North Atlantic.		
Modern Like	N/A	Unnamed	13,500–13,200	N/A	First conveyor currents to the Norwegian Trench. First meltwater to the Gulf of Mexico		
Glacial	N/A	Oldest Dryas	13,200 – 13,000	N/A	Radiocarbon Plateau		
Modern	GI-1e	Bølling	13,000* – 12,700	14,700	Initiation of full Modern Mode	14,600 GISP2	**PLEISTOCENE - LATE GLACIAL RECESSION** Variable Modes – Glacial, Heinrich, and Modern
Largest Mega-flood in the Gulf of Mexico MWP-1A			12,700 – 12,600	–	Gulf of Mexico Meltwater Discharge		
Glacial	GI-1d	Older Dryas	12,500*–12,300	14,050	Radiocarbon Plateau		
Modern	GI-1c	Allerød	12,300*–11,400	13,900			
Glacial Mode	GI-1b	Killarney-Gerzensee or Inter-Allerød Cold Period Onset	11,400*–11,300	13,150	Radiocarbon Plateau	13,100 GISP2	
Modern	GI-1a	Late Allerød Onset	11,300*–11,000	12,900			
Heinrich Mode	GS-1	**Younger Dryas Heinrich 0 (H0)**	11,000*–10,800	12,650	Onset	13,000 GISP2	
			10,800 – 10,300*	12,000	Radiocarbon Plateau		
Modern-like Mode	------	Younger Dryas Late Warming Phase	10,300* – 10,000*	12,000 – 11,500			
Return of Meltwater to Gulf of Mexico for First Time Since ~11,700 ^{14}C BP Meltwater Pulse 1-B			10,000 – 9,900	–	Gulf of Mexico Meltwater Discharge		**EARLY HOLOCENE** Modern Mode Dominant
Modern Mode	GH	Preboreal Onset and Warm Interval	10,000*–9,900	11,500	Radiocarbon Plateau	11,400 GISP2	
Muted Heinrich Mode	GH-11.2	**Preboreal Cooling Heinrich, (HGC)**	9,900*–9,500	11,305		10,545 Varve	
Modern Mode	–	First of the long term Holocene modern mode events	9,500*– 8,200	11,185		10,425 Varve	

* Radiocarbon age also expressed in GRIP (ice-core) calendar years before present in column to the right.

three-decade resolution ice-core stratigraphy will be used to identify occurrences of near synchronous versus asynchronous shifts reflected in the North Florida stratigraphic record. This comparison of the ice-core data with the local North Florida sequence follows recent methodological guidelines proposed by researchers of the INTIMATE Group (Lowe *et al*., 2001). The GRIP chronology only partially reflects the correlation of ice-core years to radiocarbon years, however, as some of the late glacial climatic events are not given and have not been correlated in the INTIMATE Group chronostratigraphy (Table 5.1). Therefore, uncorrelated glacial events not reported in the INTIMATE Group chronostratigraphy, but addressed by various other researchers (e.g. Kitagawa and van der Plicht, 1998; Friedrich *et al*., 1999; Hughen *et al*., 2000a,b, Friedrich *et al*., 2001) are included in this chapter (Table 5.2). The global–regional climatic intervals given in Table 5.2 also incorporate additional terrestrial, marine, and atmospheric data in order to provide comprehensive comparison of late Pleistocene events. These temporally placed global–regional climatic intervals allow the Page-Ladson data to be considered within a larger scale of reference. This is accomplished by the establishment of a local proxy for paleowater tables through time at the Page-Ladson site. Attention is given to points at which the local sequences do and do not have counterparts in the event stratigraphy of global and regional proxies. Particular attention is also given to shifts between climatic modes (modern, glacial, Heinrich) as well as the timing of regional factors such as meltwater discharge routes.

A working set of environmental interpretations is presented with an explanation as to why local depositional events may have occurred. For example, in Florida, the Heinrich mode events appear to have differed through time. Only the first Heinrich event, H1, appears to have resulted in a return of conditions similar to, if not more severe than, the glacial maximum climate of North Florida. Heinrich event H1 corresponds with the only southerly extension of spruce into Florida. Heinrich event H0 (Younger Dryas) does not appear to have wrought cold conditions and the third Heinrich, HGC, even less so. Another example of non-impact is the unchanged deposition of Unit 4 in the Test C-F area before, during, and after the onset of the Younger Dryas (H0). The absence of meltwater in the Gulf of Mexico is believed to explain the conditions observed in Unit 4 at the Page-Ladson site.

5.4.2 Chronostratigraphy of the Late Pleistocene Pleniglacial

5.4.2.1 Pleniglacial – Late Glacial Maximum

Unit 1L at the Page-Ladson site corresponds to the late glacial maximum (Table 5.3). The sediment is dominated by small and large pieces of botanical material (woody peat) with occasional insect remains and small fauna but no mega-faunal remains. The preservation of the botanical remains is outstanding. The deposit has little clastic material and is consistent with a quiet water depositional environment where floating botanical material became waterlogged and settled to the bottom in a shallow swamp-forest bog.

Including the Page-Ladson site, deep sinkholes in the Half Mile Rise section of the Aucilla River collected shallow-water, swamp forest-like woody peat accumulations during the late glacial maximum. The elevation of these sediment fills is about 8–10 m below present sea level. Because cypress logs and knees are a component of these

Table 5.3 Pleniglacial chronostratigraphy

GRIP Ice-core Event ID	Informal Name	Global Event Radiocarbon Chronology For Duration	The Florida Radiocarbon Chronology	Page-Ladson Stratigraphic Unit or Other Florida Site Data	Geographic Location in Florida	Comments	Late Pleistocene Holocene Phase
GS-2c	Late Glacial Maximum (LGM), Glacial Mode	22,000–18,000	18,441 ± 88 (n=3)	Page-Ladson (PL) Unit 1L and Ta98 and IF71	North Florida	Ta98 Aucilla River Black Hole Cave and IF71 Santa Fe River Munroe Quarry	**PLEISTOCENE - PLENIGLACIAL Heinrich and Glacial Modes Dominant**
GS-2b	Pleniglacial Modern-like Mode	17,000–15,000	15,910 ± 160 (n=1)	Aucilla 3B	North Florida	Aucilla 3B Mammoth Site	
			15,390 ± 120 (n=1)	PL Unit 1U (presumed mid-column)	North Florida	First through flowing water in Aucilla channel	
			15,142 ± 77 (n=3)	PL Unit 1U (top of column) and Je608	North Florida	Averaged date from top of shell marl at Page-Ladson and Aucilla 3B	
GS-2a	Heinrich (H1)	15,000–13,500	14,870 ± 200 (n=1)	PL bottom of Unit 2	North Florida	Return to little if any through flowing water in the Aucilla River and the reestablishment of LGM-like woody peat deposition at the Page-Ladson site	
			14,580 ± 83 (n=2)	PL middle of Unit 2			
			14,275 ± 81 (n=2)	PL top of Unit 2			
			13,820 ± 190 (n=1)	PL Unit 2-3 Hiatus Older End[1]			
	Modern Mode in all seaboards of the North Atlantic	13,500–13,200	N/A	PL	North Florida	Meltwater begins to discharge to discharge in the Gulf of Mexico	
	Oldest Dryas Glacial Mode (Dansgaard-Oeschger event)	13,200–13,000	13,130 ± 460 (n=1)	8Je603, Tree Stump in Aucilla River Channel	North Florida	Little River Rapids site, subaerial channel, water < 4m below present	
			13,059 ± 41 (n=2)	Page-Ladson (PL) Unit 2-3 Hiatus Younger End[1]	North Florida	Bottom of Page-Ladson sink in Test C-F area subaerially exposed	

[1] Based on dated samples from displaced context in trampled zone of Unit 2 - Unit 3 interface.

PL= Page-Ladson site.

sediment fills, and because *Taxodium* appears to have been scarce elsewhere in Florida during the late glacial maximum (Watts and Hansen, 1988:314), locations like the Page-Ladson site probably represented refugia for the species. Another North Florida site, the Munroe Quarry (8If71) in the Santa Fe River lies at a higher elevation and is about 20 m above present sea level. At the Munroe Quarry, *Pinus* stump casts and wood from the late glacial maximum survive as testimony of a formerly dry channel populated with terrestrial vegetation. Finally, shallow lake basins in Florida were dry for considerable durations, although perhaps episodically, from the late glacial maximum into the early Holocene (Watts and Hansen, 1988:319–320). Water tables were substantially below present levels during the glacial maximum with few habitable places for wetland species such as cypress.

Depressed water tables do not necessarily indicate that atmospheric moisture was low. The occurrence of *Pinus*-dominated woodlands in Florida during the late glacial maximum when sea level was at its lowest suggests that cooler climatic conditions maintained higher soil and atmospheric moisture, but not necessarily in the form of increased precipitation (Grimm *et al*., 1993:198–200).

5.4.2.2 Pleniglacial – Modern-like Mode

Investigations at Page-Ladson did not test the full stratigraphic column. The unexcavated gap between the woody peat of Unit 1L and the shelly silt of Unit 1U represents an interval from ~18,500 ^{14}C BP to ~16,000 ^{14}C BP. The excavated section of Unit 1U at the Page-Ladson site spans the latter part of the Pleniglacial modern-like mode (Table 5.3).

The modern-like mode during the Pleniglacial was unique in several respects. It represents the initial reduction in continental ice mass during an interval otherwise dominated by cold glacial and Heinrich mode conditions. Second, it resulted in a substantial reduction of the thickness (height) of the continental glaciers without regression of their geographic margins. Third, this vertical reduction took place without Heinrich ice-rafting (Lambeck *et al*., 2000:513–527) and meltwater discharge took place via the northeastern Hudson and St. Lawrence River routes in North America between ~17,000 ^{14}C BP and 15,100 ^{14}C BP (Clark *et al*., 2001:283–287), although some meltwater may have discharged to the Gulf of Mexico (Rittenour *et al*., 2003).

It should be mentioned that the timing of the first discharge of large volumes of meltwater to the Gulf Mexico might be later than first reported. Prior to modern calibration data, the first major discharge events in the Gulf of Mexico were believed to have taken place as early as ~16,000 ^{14}C BP (Leventer *et al*., 1982), but problems and disagreements about the proxies and their timing ensued (Berger, 1985). Data from more recent investigations indicate that the margins of the Laurentide ice-sheet did not recede prior to ~14,000 ^{14}C BP and kept the Mississippi River meltwater route closed (Clark *et al*., 2001). Therefore, from as far west as the Lake Michigan area, the first phases of glacial meltwater discharge prior to ~14,000 ^{14}C BP appear to have funneled eastward to the North Atlantic via the St. Lawrence–Hudson River routes (Clark *et al*., 2001; Dyke *et al*., 2002).

At the Page-Ladson site and elsewhere in the Aucilla River, the shell-rich fluvial silt of Unit 1U began deposition before ~15,900 ^{14}C BP. Based on samples from three sites, the excavated section of Unit 1U dates from ~15,900 ^{14}C BP to ~15,125 ^{14}C BP. The termination of Unit 1U sedimentation appears to coincide with the end of Pleniglacial modern-like mode conditions.

Environmental indicators suggest that the inland water table in the North Florida was elevated during the period of Unit 1U deposition and that through-flowing water, albeit slow-moving, gentle deposition occurred in the river channel. The transgression of the local water table was very likely prompted by increased precipitation. The Unit 1U silt also suggests that the water was clear enough to support both vegetation (not identified or recovered) and the abundant freshwater gastropods dependent on freshwater vegetation that requires clear water and sunlight for photosynthesis (Means, 1999). Today, the Aucilla River is dominated by dark, tannin-stained water that greatly discourages underwater plant growth and gastropods are uncommon. Today Aucilla's tributary, the Wacissa River, is a clear water, spring fed run with an abundance of freshwater vegetation and numerous gastropod species. Had the limestone-held Floridan Aquifer been depressed during this period, surface runoff would have been diverted underground via open karst features rather than discharged in surface channels. Surface flow in the Aucilla River took place during the Pleniglacial, modern-like mode.

As a result of research efforts in 1968 and 1969, the remains of two complete skeletons, one *Mammut americanum* and other *Mammuthus columbi*, were recovered from Unit 1U at paleontological sites Aucilla 3B and the Serbousek-Cotrill site (8Je608), respectively, in the Half Mile Rise section of the river (Webb, 1968, 1974). These remains represent the oldest megafauna identified from the late glacial of the lower Aucilla River basin. In addition the *in situ* position of the Aucilla 3B mammoth indicates that it became bogged in the silt deposits in the bottom of the river and provides evidence that the water table was sometimes low enough for large animals to access the channel bottom. At the Page-Ladson site, preserved digesta in Unit 1U is evidence of *Mammut americanum* activity in the sinkhole during the Pleniglacial modern-like mode.

5.4.2.3 Pleniglacial – Heinrich 1 (H1)

Unit 2 at the Page-Ladson site represents a return to woody peat deposition for the period from ~14,900 ^{14}C BP to ~13,800 ^{14}C BP (Table 5.3). This Page-Ladson stratum mirrors other proxies indicative of the duration of Heinrich 1 in the western North Atlantic. Clearly Heinrich 1 (H1) was the most severe post-glacial maximum ice-rafting event in the North Atlantic (Alley and Clark, 1999). It was also a time during which *Picea* spp. (spruce) invaded Florida from North Georgia by ranging into the Apalachicola River valley (Watts *et al.*, 1992). Finally, the return of woody peat deposits at the Page-Ladson site mimics the type of sediment deposited during the Late Glacial Maximum in Unit 1L. Therefore, Unit 2 appears to reflect conditions imposed by a cool, if not cold, climatic downturn during H1. The occurrence of moisture-dependent spruce in the Apalachicola River basin (Jackson and Weng, 1999; Jackson *et al.*, 2000) and a non-fire-dependent species *Pinus* elsewhere in Florida indicate cool, atmospherically moist conditions (Watts and Hansen, 1994; Grimm *et al.*, 1993). Nevertheless, the water table at the Page-Ladson site was low and non-flowing, still-water conditions persisted during H1.

5.4.2.4 Pleniglacial – Modern Mode and Oldest Dryas

From ~13,500 ^{14}C BP to 13,200 ^{14}C BP global proxies indicate that a 300-radiocarbon-year modern mode event transpired and was followed by the Oldest Dryas glacial mode from ~13,200 ^{14}C BP to 13,000 ^{14}C BP (a Dansgaard–Oeschger episode). During the modern mode event meltwater drained to the Gulf of Mexico. This also coincided with the first post-glacial maximum reestablishment of the NADW conveyor current in the Norwegian Trench on the European side of the North Atlantic

(Lehman and Keigwin, 1992). However, the return of NADW toward its modern position was not reestablished in a stable way until the Holocene.

Due to the lack of sedimentation at the Page-Ladson site, there were no sediments identified for either of these time intervals. This timegap is recognized as the Unit 2–3 hiatus (Table 5.3). The absence of sedimentation is interpreted as a very low water table interval during a period of dry climatic conditions brought on by meltwater in the Gulf of Mexico. The modern mode, meltwater event just before the Oldest Dryas represents the first arid episode in the Southeast after the late glacial maximum. The Oldest Dryas cooling event that followed may have attenuated the situation, but was followed by the most devastating arid episode, the Bølling.

5.4.3 Chronostratigraphy of the Late Pleistocene Glacial Recession

5.4.3.1 Glacial Recession – Bølling Modern Mode and Meltwater Pulse-1A

The Page-Ladson sinkhole was subaerially exposed during the Bølling. The Unit 2–3 non-depositional hiatus formed from ~13,000 ^{14}C BP to ~12,600 ^{14}C BP and almost perfectly occupies the interval of MWP-1A (Table 5.4).

Evidence from a number of Florida sites, including the Page-Ladson site, suggests that water tables were very low. At the Little River Rapids site, trees grew in the channel bottom ~13,100 ^{14}C BP (Muniz, 1998b). Spruce, dependent on atmospherically moist conditions, disappeared from the Apalachicola River basin (Watts *et al*., 1992), apparently withdrawing up its tributaries, the Flint and Chattahoochee River basins, to the mountains of northern Georgia. At Little Salt Springs in Southwest Florida, terrestrial plant and animal remains were being deposited on a limestone ledge 26 m below the present water table ~13,100 ^{14}C BP (Gifford, 2002). That ledge is located in a cenote sinkhole with walls that are undercut (descend inwardly) (Clausen *et al*., 1979), thus negating the possibility that objects fell onto the ledge from above. Plant and animal remains on the ledge originally may have entered the central water-filled sinkhole and then floated or climbed onto the ledge when the water table was at or just below the ledge.

The timing of the Bølling and MWP-1A from ~13,000 ^{14}C BP to ~12,600 ^{14}C BP was the largest mega-flood discharged to the Gulf of Mexico (Brown and Kennett, 1998). The hypothesis that meltwater in the Gulf of Mexico perpetuated prolonged dry conditions in Florida during MWP (Grimm *et al*., 1993) is strongly supported by the evidence from the Page-Ladson site. The development of Unit 2–3 hiatus is evidence of that arid episode at the Page-Ladson site. Conversely, the Southwest US experienced wet conditions until ~11,700 ^{14}C BP (Haynes *et al*., 1999). MWP-1A was followed by the Older Dryas, Dansgaard–Oeschger cooling event (Lehman and Keigwin, 1992).

5.4.3.2 Glacial Recession – Older Dryas Glacial Mode

The duration of the Older Dryas took place from ~12,500 ^{14}C BP to ~12,300 ^{14}C BP (Lowe *et al*., 2001; Lowe, 2002). Unit 3 represents this interval at the Page-Ladson site. The deposition of Unit 3 took place after the water table in the sinkhole rose to a

Table 5.4 Late glacial recession chronostratigraphy

GRIP Event ID	Informal Name	Global Event Radiocarbon Chronology	Florida Radiocarbon Chronology	Page-Ladson Stratigraphic Unit or Other Florida Site Data	Geographic Location in Florida	Comments	Late Pleistocene Holocene Phase
GI-1e	Bølling Modern Mode	13,000–12,700	12,951 ±90 (*n*=2) $^{\text{NR}}$	8So18 giant tortoise bone dates	Gulf Coast, Southwest Florida	Little Salt Springs, water table at or near ledge now 26 m below present. Average of statistically unrelated samples from ledge	**PLEISTOCENE - LATE GLACIAL RECESSION Variable Modes Including Heinrich, Glacial and Modern**
Meltwater Pulse 1A		12,700–12,600	No Data	PL	–	Largest Mega–flood in Gulf of Mexico-	
GI-1d	Older Dryas Glacial Mode	12,600–12,300	12,425 ±32 (*n*=7)	PL Unit 3	North Florida	Range 12,570 ± 100 to 12,370 ± 90	
			12,351 ±39 (*n*=3)	PL Unit 3–4 Transition Zone	North Florida	Dansgaard–Oeschger event Colluvial deposition at PL	
			12,300 ±50 (*n*=1)	8Je121, Test 22, Level 7	North Florida	Sloth Hole site, Lower Aucilla River	
GI-1c	Early Allerød Modern Mode	12,300–11,400	12,289 ±30 (*n*=3)	PL Unit 4L	North Florida	Resumption of through flowing water at the Page-Ladson site	
			12,107 ±37 (*n*=3)	PL Unit 4L-4U Contact	North Florida	Increasing flow and water table elevations	
			12,030 ±200 (*n*=1)	8So18 burned wood (wooden stake?)	Gulf Coast, Southwest Florida	Deep ledge in cenote sinkhole, water table ~26 m below present	
			11,930 ±99 (*n*=2)	8Je603, Zone 4, Level 3	North Florida	Onset of fluvial conditions, water > 4 m below present	
			11,735 ±41 (*n*=3)	PL Unit 4U,	North Florida	Lower bracket of peak fluvial conditions based on findings at Je603	
			11,628 ±120 (*n*=2)	8Je603, Zone 4, Level 2	North Florida	Peak fluvial conditions	
			11,523 ±91 (*n*=2) $^{\text{NR}}$	PL Unit 4U, Level 5, Test F	North Florida	NR – Samples were not statistically related but from same level	
GI-1b	Killarney-Gerzensee Glacial Mode	11,400–11,300	11,270 ±64 (*n*=2)	PL Unit 4U, Level 4, Test F	North Florida	Dansgaard–Oeschger event Might be reflected in Test B, Level 14c	
GI-1a	Late Allerød Modern Mode	11,300–11,000	11,170 ±130 (*n*=1)	8Je570	North Florida	*Bison antiquus* kill, Wacissa channel subaerially exposed	
GS-1	Younger Dryas Heinrich 0 (H0) Onset Younger Dryas Cold Phase	Onset 11,000–10,800	10,980 ±210 (*n*=1)	8So18, in spring basin level below burial	Gulf Coast, Southwest Florida	Water table experience dramatic rise from 26 m to 7.4 m below present	
			10,910 ±220 (*n*=1)	8Je603, Test 2, Zone 3, Level 2	North Florida	Hiatus, subaerial channel exposure, water < 4 m below present	
			10,885 ±109 (*n*=3)	8So19, Feature 30	Gulf Coast, Southwest Florida	Warm Mineral Springs, initiation of peat preservation, water tables estimated ~7.5 m below present	
		Duration 11,000–10,300	10,721 ±57 (*n*=2) $^{\text{NR}}$	PL Unit 4U, Upper Levels, Test C-F	North Florida	NR – Samples were not statistically related.	
			10,750 ±190 (*n*=1)	8Br246	Atlantic Coast, South Central Florida	Windover site, bottom of water lily peat level, old end	
			N/A	PL 4–5 Hiatus	North Florida	–	
	Younger Dryas Late Warming Phase Modern-like?	10,300–10,000	10,271 ±67 (*n*=5)	8So19, Burial I	Gulf Coast, Southwest Florida	Basal peat below laterally beside level of burial, water tables 11 m to 13 m below present	
			10,200 ±84 (*n*=2) $^{\text{NR}}$	PL Unit 5 (top of column)	North Florida	Period of shallow water, pond-like environment, young end. NR – Samples were not statistically related, but from same level.	
			10,160 ±160 (*n*=1)	8Br246	Atlantic Coast, S-C Florida	Water lily peat level, young end	

PL= Page-Ladson site.

shallow level in the aftermath of MWP-1A, beginning around ~12,570 ^{14}C BP. Unit 3 represents a mix of still-water and colluvial sediments affected by large animal trampling that took place during its deposition. Seven statistically related radiometric dates from Unit 3 averaged 12,420 ± 80 ^{14}C BP with a range from ~12,600 ^{14}C BP to ~12,400 ^{14}C BP (Table 5.4).

Unit 3 at the Page-Ladson site is significant because it produced evidence of large animal butchering. Chert debitage and butcher-marked bone and tusk came from Unit 3. One of the chert flakes came from the surface of Unit 2 and was partially in contact with Unit 3. That artifact probably represents an older human presence during the time of the Unit 2–3 hiatus. However, the majority of artifacts clearly originated in Unit 3; a stratigraphic unit sealed beneath the Unit 3–4 transition zone, and Units 4 through 7.

Prior to the termination of the Older Dryas, the Unit 3–4 transition zone was deposited above Unit 3 at the Page-Ladson site. The Unit 3–4 transition zone represents a change from shallow water colluvial deposition to one of deeper water fluvial deposition. Three statistically related radiometric dates averaged 12,362 ±102 ^{14}C BP within a range from ~12,400 ^{14}C BP to ~12,300 ^{14}C BP (Table 5.4).

At the Sloth Hole site in the lower Aucilla River, another artifact-bearing stratum (Level 7) has been dated to 12,300 ± 50 ^{14}C BP (Beta 95341, *n* 1) (Table 5.4) and lies at a depth of 8–10 m below present (Hemmings, 1999). The Sloth Hole artifact-bearing level is equivalent in age to the Unit 3–4 transition zone at the Page-Ladson site and is at about the same elevation below present low river stage.

5.4.3.3 Glacial Recession – Allerød Modern Mode

The Allerød warming episode began ~12,300 ^{14}C BP and endured until ~11,000 ^{14}C BP. During this time, meltwater, which had previously discharged into the Gulf of Mexico, began to be diverted to the North Atlantic. By ~12,500 ^{14}C BP, meltwater was partially captured by the Hudson River and even greater volumes of meltwater were captured by the St. Lawrence River by ~12,000 ^{14}C BP. After ~11,700 ^{14}C BP, meltwater no longer flowed to the Gulf of Mexico because the glacial recession had opened unobstructed flow via the North Atlantic routes (Wright, 1989).

In South Florida, water tables in the deeply buried Floridan Aquifer did not rebound as they did in North Florida. By ~12,000 ^{14}C BP, the water table at Little Salt Spring in Southwest Florida was still around its pre-Allerød low, 20 m or more below present (Gifford, 2002). However, freshwater, shell-rich silts were beginning to form in Lake Okeechobee and Lake Flirt around this same time (Brooks, 1974) indicating the climate had ameliorated. The lag in water table rise in the cenote sinkholes of Southwest Florida may have been caused by differences in character of the Floridan Aquifer between North and South Florida. Today the Northern Gulf Coast of Florida clearly is one of the major places of aquifer groundwater discharge (Faught and Donoghue, 1997:424–425), not the southern peninsula of Florida. It is also important to remember that organic peat deposition either did not take place or did not survive subsequent arid episodes in South Florida lake basins prior to the Younger Dryas ~10,900 ^{14}C BP (Doran and Dickel, 1988a,b). Allerød-age lake basin sediments in South Florida consist exclusively of shell-rich, calcareous silt deposits without preserved botanical remains (Brooks, 1974).

At the Page-Ladson site in North Florida, Unit 4 is indicative of elevated water tables and flowing-water regimes. The transition from Unit 4L to Unit 4U suggests a trend toward rising water tables which is supported by the findings of Muniz (1998a,b) at the Little River Rapids site in the Aucilla River. At Little River Rapids, peak fluvial conditions are estimated to have occurred from ~11,500 ^{14}C BP to 10,900 ^{14}C BP (Muniz, 1998b). It is significant that the local evidence of peak fluvial conditions occurs after the diversion of meltwater away from the Gulf of Mexico. At least some of the shallow, freshwater shell marl deposits in the Wacissa River may also represent the mid-Allerød reestablishment of fluvial water conditions (Dunbar *et al*., 2006).

The occurrence of flowing rivers in North Florida and perched ponds and lakes in South Florida during the mid-Allerød is opposite of the arid climate experienced in the Southwest US. Two hundred radiocarbon years after meltwater ceased discharging in the Gulf of Mexico, Clovis people dug a well for water at Blackwater Draw, New Mexico; a feature that is dated ~11,500 ^{14}C BP (Haynes *et al*., 1999). The southwestern lithostratigraphic sequence appears to correlate with the southwestern biostratigraphic sequence in offset fashion with Pleistocene mega-mammals becoming extinct by the end of the Allerød prior to the Younger Dryas at ~11,000 ^{14}C BP. A prolonged arid climate is suspected to be a causal factor of southwestern mega-mammal extinction (e.g. Haynes, 1991). In the chapter on Paleoindian archaeology (Chapter 14), I contend that this factor did not come into play in the Southeast US.

5.4.3.4 Glacial Recession – Killarney-Gerzensee Glacial Mode

A brief return to glacial mode conditions is recognized as an interruption of the Allerød modern mode between ~11,400 ^{14}C BP and 11,300 ^{14}C BP. In the Test C-F there was no apparent change in sedimentation or visual evidence of a hiatus in Unit 4. However, a noteworthy change in Unit 4 was identified in the Test B area indicating that there had been one episode of depressed water table and still-water deposition. This low water episode is suspected to have taken place during the onset of the Killarney-Gerzensee, but the level was radiometrically dated and the timing remains uncertain (Dunbar, 2002:121–126, 166–167). The Test B stratigraphic sequence reflects a low water table interval during the Killarney-Gerzensee. It was short duration with the water table rebounding quickly afterward and the river resuning flow.

5.4.3.5 Glacial Recession – Late Allerød, Resumption of Modern Mode

After the culmination of the Killarney-Gerzensee, the Allerød and modern mode conditions resumed until the onset of the Younger Dryas.

5.4.3.6 Glacial Recession – Younger Dryas Heinrich 0 (H0) Heinrich Mode

The Younger Dryas, Heinrich event (H0), is probably the most widely recognized late glacial climatic event among North American archaeologists interested in New World Paleoindian and Early Archaic cultures (Haynes, 1991; Holliday, 2000). The onset of the Younger Dryas began ~11,000 ^{14}C BP with a cold phase in the northern North

Atlantic that lasted until ~10,300 ^{14}C BP. A warmer phase of the Younger Dryas took place from ~10,300 ^{14}C BP until its culmination ~10,000 ^{14}C BP.

The Younger Dryas was much milder than Heinrich 1 (H1) of the Pleniglacial. Possibly because Younger Dryas had a milder effect on climate, or because there is insufficient evidence for the types of climatic effects that H1 imposed on South Florida; comparison of North and South Florida proxies is only possible for Heinrich 0. There was a true latitudinal difference in climate between North and South Florida during the Younger Dryas much like there is today.

At the Page-Ladson site in North Florida, the deposition of Unit 4U continued unabated and without noticeable change in the Test C-F area. However, once again in Test B, a second, undated change from flowing-water to still-water sedimentation occurred and is believed to be related to the onset of the Younger Dryas (Dunbar, 2002:121–126, 166–167). Like a similar event believed related to the Killarney-Gerzensee, the local water table declined. Shortly after the Younger Dryas onset the water table rose sufficiently at the Page-Ladson site to allow the resumption of through-flowing water. At the Little River Rapids site, a depositional hiatus began at the onset of the Younger Dryas and endured into the early Holocene (Muniz, 1998b). At the inundated Alexon Bison site in the Wacissa River, *Bison antiquus* bones show stage 1 desiccation caused by subaerial exposure during the time of prehistoric site activity (Behrensmeyer, 1978). The site may have been formed about 100 radiocarbon years prior to the Younger Dryas onset suggesting lower water table conditions.

The Middle Paleoindian Ryan-Harley site in the central Wacissa River basin is located at an elevation now 1 m below the present water table. It is, perhaps, the best age indicator of lowland habitats during the Younger Dryas. The Ryan-Harley Suwannee point level yielded a variety of faunal remains. The wetland fauna recovered from the site indicates that the area supported still water as opposed to flowing-water habitats (Dunbar *et al*., 2006; Vojnovski and Dunbar, in press). Combined, these data indicate that the local water table in North Florida had declined from its mid-Allerød high, but remained elevated enough to support rich wetlands habitats.

South Florida again appears to differ from North Florida in terms of climatic changes during the Younger Dryas. By the onset of the Younger Dryas, the precipitation rate appears to have markedly increased in South Florida. Evidence supporting this notion is found at the Windover site near Titusville, Cutler Ridge in south Miami, and the Little Salt and Warm Mineral Spring sites near Venice, Florida (Cockrell and Murphy, 1978; Clausen *et al*., 1979; Carr, 1987; Doran and Dickel, 1988a,b).

The onset of the Younger Dryas coincides with the initiation of peat preservation in totally saturated conditions at the Windover and Warm Mineral Spring sites (Cockrell and Murphy, 1978; Clausen *et al*., 1979; Doran and Dickel, 1988a,b; Tesar, 1997). At Little Salt Spring, the water table rose perhaps as high as 1 m below the present level (Clausen *et al*., 1979). At the Cutler Ridge site, a cave-like sinkhole accumulated prey animal bones in and around an active carnivore den. The species of animals present indicate a “forest environment surrounded by open grassland and lowland marshes and wetlands” (Emslie and Morgan, 1995).

The South Florida evidence indicates abundant atmospheric moisture and rainfall amounts during the Younger Dryas. Therefore, the South Florida data appear to support the hypothesis that the tropical western North Atlantic was affected by this Heinrich event. That hypothesis proposes that the Heinrich event caused increased heat in the low latitudes setting up a moisture wick of evaporation driven northward over the South Florida peninsula. This northward diversion of atmospheric moisture is believed to have dramatically increased snowfall, new ice growth, rapid ice-sheet advance in the northern latitudes, and may have been a factor contributing to Heinrich ice-rafting in the northern North Atlantic (Labeyrie, 2000). For whatever reason, South Florida was wet during the cold phase of the Younger Dryas. In contrast, North Florida became somewhat dryer with shallow sections of previously flowing channels, like those at the Little River and Ryan-Harley sites, relegated to non-flowing wetlands and ponds. Through-flowing water, however, continued in the more deeply recessed Page-Ladson site.

5.4.3.7 Glacial Recession – Late Younger Dryas Modern-like Mode

Proxies from the end of the Younger Dryas indicate that a warming trend began ~10,300 ^{14}C BP on the American side of the Atlantic (de Vernal *et al.*, 1996) and by ~10,200 ^{14}C BP on the European side of the Atlantic (Jiang and Klingberg, 1996). In both cases, the evidence indicates a marked increase in meltwater discharge from continental glaciers.

At the Page-Ladson site, an erosional hiatus occurred well after the Younger Dryas onset and was followed by shallow-water sedimentation in Unit 5. The erosional event marks the first episode of channel-cutting as opposed to Pleistocene channel-filling in the Page-Ladson stratigraphic sequence. The upper part of Unit 5 yielded two related radiometric dates with a combined average of 10,162 ± 62 ^{14}C BP. This places Unit 5 in the latter warm phase of the Younger Dryas. The local water table also declined during this time and a still water, pond-like environment was established. Unit 5 yielded numerous Late Paleoindian artifacts.

In South Florida at Warm Mineral Springs, the deposition of peat on the 13 m ledge accelerated because the local water table dropped far enough to expose the top of a solution notch that forms a ledge. This greatly increased the potential for deposition of peat on the ledge. Because the water table was above the bottom of the ledge and botanical material floated over ledge before becoming waterlogged and settling on the ledge. Statistically related dates from the basal peat below and surrounding Burial 1 yielded an averaged age of 10,271 ± 67 ^{14}C BP (*n* 5). Elsewhere in South Florida, at the Windover site the young end of the water lily peat yielded an age of 10,160 ± 160 ^{14}C BP.

5.4.4 Chronostratigraphy of the Early Holocene

5.4.4.1 Early Holocene – Preboreal Modern Mode and Meltwater Pulse-1B

The onset of the Preboreal is recognized as the major shift to modern mode conditions beginning at ~10,000 ^{14}C BP and ending at 9,900 ^{14}C BP (Björck *et al.*, 1996; Clark *et al.*, 2001) (Table 5.5). Presumably, the muted warming trend at the end of the

Table 5.5 Early Holocene chronostratigraphy

GRIP Ice-core Event ID	Informal Name	Global Event Radiocarbon Chronology	Florida Radiocarbon Chronology	Page-Ladson Stratigraphic Unit or Other Florida Site Data	Geographic Location in Florida	Comments	Late Pleistocene Holocene Phase
GH	Meltwater returns to Gulf of Mexico Meltwater Pulse 1B Preboreal Onset Modern Mode	10,000 | | 9,900	9,953 ±40 (*n*=3)	Page-Ladson (PL) Unit 5-6L Surface Test C	North Florida	Sudden drop in water table and time of subaerial exposure in the Test C-F area. Primary Bolen level on U5 surface & bottom most U6L	**EARLY HOLOCENE Modern Mode Dominant**
			9,967 ± 58 (*n*=5)	Warm Mineral Springs 8So19, Burial I	Gulf Coast, Southwest Florida	Water tables 11 m–13 m below present. Samples associated with Burial 1.	
			9,920 ± 120 (*n*=1)	8So18, Shelley calcitic mud in basin at sinkhole drop-off	Gulf Coast, Southwest Florida	Drop in local water table of ~5 m from Younger Dryas high of 7.4 m below present to Preboreal low of South Florida 12.5 m below present	
GH-GCH	Preboreal Oscillation Heinrich, Gold Cove Cooling	9,900 | | 9,500	9,697 ± 130 (*n*=1)	PL Unit 6U, Test B (near base of column)	North Florida	Time of slightly higher water table and still-water deposition (peat) in Test B area	
			9,670 ± 120 (*n*=1)	Cutler Ridge 8Da2001, fire hearth	Atlantic Coast, South Florida	Bolen artifact level	
			9,560 ± 78 (*n*=2)	8Br246	Atlantic Coast, South Central Florida	Sandy level between water lily and rubbery peat	
			9,555 ± 100 (*n*=2)	8So18	Gulf Coast, Southwest Florida	Samples from wooden stakes in basin at sinkhole drop-off, water table increase of 0.1 m to 0.5 m	
GH-Boreal	Boreal Holocene Modern Mode	9,500 | | | | Onward	9,466 ± 105 (*n*=1)	PL Unit 6U, Test B (near top of column)	North Florida	Top of still-water peat zone in Test B	
			8,860 ± 220 (*n*=1)	8Je603, Test 2, Zone 2, Level 2	North Florida	Resumption of fluvial conditions, at the Little River Rapids site, water table 3 m or less below present	
			8,810 ± 130 (*n*=1)	8So19, Burial I	Gulf Coast, Southwest Florida	Upper most peat deposited before water tables become too elevated. Water table depressed several meters below present but rising.	
			~8,500 ^{14}C BP	Various Florida sites	Holocene water tables established in Florida and south Georgia	Shallow lake basins in Florida flooded by 8,500 ^{14}C BP and remain that way perennially (Watts and Hansen 1988 and 1994). Dansgaard–Oeschger event at 8,200 ^{14}C BP does not cause return to dry conditions.	
GH-DO	8.2 ka Glacial-like Mode		~8,200 ^{14}C BP	Various Global Sites			

PL= Page-Ladson site.

Younger Dryas helped launch this intense warming event. The Laurentide ice-sheet advanced during the Younger Dryas cold phase so as to block meltwater discharge to the Atlantic via the St. Lawrence and Hudson River routes. During the Preboreal warm phase, part of the discharge from MWP-1B drained to the Gulf of Mexico (Spero and Williams, 1990; Alley and Clark, 1999). Recent evidence indicates that large volumes of meltwater also were discharged northward into the Arctic Sea. The Arctic meltwater discharge is an important factor that probably led to the Preboreal Oscillation or HGC event at 9,900 ^{14}C BP (Fisher *et al.*, 2002).

At the Page-Ladson site, four notable events took place very close to the Younger Dryas–Preboreal boundary. First, there was an abrupt drop in the local water table and an erosional event took place on the eastern side of the sinkhole. Second, following the decline in the water table, the surface of Unit 5 (Test C) on the western side of the sinkhole was subjected to an episode of subaerial exposure. Third, the period of subaerial exposure lasted long enough for people to access and utilize the surface of Unit 5. During this time of cultural activity most of the surviving botanical remains on the Unit 5 surface were desiccated (oxidized), but some specimens were partially to totally burned in fires. Fourth, the water table rose and shallowly inundated the surface of Unit 5 which led to the deposition of Unit 6L, shelly silt. Human activity continued to occur until the site became too deeply inundated and prohibited continued human use of the sinkhole.

Four statistically related dates from the Bolen activity level (Bolen surface, Unit 5–6 interface) yielded an averaged age of 9,959 ± 38 ^{14}C BP. The range of variation of the four related dates was from 10,016 ± 124 ^{14}C BP (Beta 21750) to 9,930 ± 60 ^{14}C BP (Beta 58858). Human activity in the sinkhole appears to have taken place throughout the 100-radiocarbon-year duration of the Preboreal from ~10,000 ^{14}C BP to ~9,900 ^{14}C BP. Evidence from Test B indicates that Bolen people did not abandon the terrestrial area around the sinkhole and continued to occupy the upland portion of the site until ~9,700 ^{14}C BP. These data indicate that the period of human activity inside the sinkhole, at an elevation now 5 m below the site datum, occurred for a brief radiometric interval and was followed by a longer interval of human activity around the sinkhole margins.

Another, unnamed North Florida site, LE2105, yielded a battery of three radiocarbon dates from the same feature with a range from 10,090 ± ^{14}C BP to 9,850 ± 80 ^{14}C BP (Hornum *et al.*, 1996). These dates are not statistically related at a 95% confidence level, but were nevertheless averaged because they originated from the same, Bolen-aged, archaeological feature. The average of these dates is 9,948 ± ^{14}C BP (*n* 3).

In Southwest Florida, human burials were being interred at Warm Mineral Springs at a time when the rate of peat deposition was accumulating most rapidly. Optimal conditions for peat deposition are likely to have occurred when the water table was at the same elevation as the limestone ledges horizontally expanding, solution-etched notch. Statistically related dates from Burial 1 yield a pooled average age of 9,967 ± 58 ^{14}C BP (*n* 5) for the interment. The Warm Mineral Springs dates ranged from 10,085 ± 145 ^{14}C BP (I-7218) to 9,860 ± 140 ^{14}C BP (I-7205).

At Little Salt Springs the deposition of shelly calcitic mud took place at the edge of the sinkhole drop-off at 9,920 ± 160 ^{14}C BP (Tx-2461) after the water table fell ~5 m below its previous Younger Dryas stand (Clausen *et al.*, 1979). At the Windover site, sand stringers form a hiatus between the water lily and rubbery peat levels. The deposition of sand stringers formed between ~10,160 ^{14}C BP and ~9,560 ^{14}C BP (Doran and Dickel, 1988a). In North and South Florida water tables in Holocene climatic episodes seemed to have acted in synchrony throughout the peninsula of Florida with a substantial decline during the time of the Preboreal onset.

In sum three sites in Florida characterized by notched-point Bolen artifacts, two of which are now inundated 5 m or more below the modern water table, and another located on the edge of the coastal plain near inundated karst features, have yielded suites of averaged radiocarbon dates that are virtually the same age. These are the Page-Ladson site at 9959 ± 38 ^{14}C BP (*n* 4), the Warm Mineral Springs Burial 1 at

9967 ± 58 ^{14}C BP (*n* 5) and Le2105 at 9948 ± 40 ^{14}C BP (*n* 3). A single radiocarbon date from Little Salt Springs also falls within this range, as does an undated, hiatus at the Windover site. The age of these clustered dates falls within the 100-radiocarbon-year span of the Preboreal onset when MWP-1B was taking place.

5.4.4.2 Early Holocene – Preboreal Oscillation and Gold Cove Heinrich Mode

The Preboreal oscillation heralded the last major advance of the Laurentide ice-sheet and Heinrich ice-rafting (Kaufman *et al*., 1993). Both events were related and probably triggered by part of the meltwater discharge being diverted to the Arctic Ocean during MWP-1B (Fisher *et al*., 2002). There was a major difference, however. The flotilla of icebergs calved during the Gold Cove Heinrich event did not drift eastward toward Europe but drifted down the coast of North America. Because the St. Lawrence and Hudson Rivers no longer served as drains for meltwater, their influence, which may have helped pushed icebergs eastward, was no longer present during the Preboreal. As a result, the east–west oceanic thermal zonation usually caused by Heinrich ice-rafting did not occur during the Gold Cove event and the polar front did not move south to its 37° North latitude position as it had during the other Heinrich events (Kaufman *et al*., 1993; Calvo *et al*., 2001). This, presumably, negated the potential for a diversion of tropical moisture to the northern latitudes. Indeed, the proxies throughout Florida indicate continued, although somewhat moderated, dry conditions during the period.

As mentioned, Bolen peoples continued to occupy the area around the Page-Ladson sinkhole until ~9700 ^{14}C BP. Subsequent to that, other Early Archaic peoples occupied the area and probably represented an offspring culture evolved from Bolen origins or a late-stage expression of Bolen. The water tables fluctuated during this interval, sometimes slightly higher allowing through-flowing water and sometimes slightly lower allowing the reestablishment of still-water pond conditions.

At the Cutler Ridge site in South Florida, human activity and burials took place in the rock shelter-like sinkhole around 9670 ± 120 ^{14}C BP (*n* 1) (Carr, 1987). In the sinkhole-like pond at the Windover site peat deposition resumed about 9560 ± 78 ^{14}C BP (*n* 2). Finally, at the Little Salt Springs site, wooden stakes driven in the ground at the edge of the sinkhole drop-off provided two statistically related dates yielding an average of 9552 ± 96 ^{14}C BP. Archaeological evidence from Little Salt Springs indicates the site was utilized until ~8500 ^{14}C BP before being abandoned for about 1000 radiocarbon years (Dietrich and Gifford, 1997). Thus, during the Preboreal oscillation and its muted Heinrich event, water tables in the peninsula remained low but slightly above the nadir experienced during MWP-1B.

5.4.4.3 Early Holocene – Modern Mode

The advance and recession of the Gold Cove lobe of the Laurentide ice-sheet took place between ~9900 ^{14}C BP and ~9500 ^{14}C BP (Kaufman *et al*., 1993). After that, from ~9500 ^{14}C BP to 8200 ^{14}C BP modern mode conditions prevailed and climates more typical of the Holocene were established.

In Florida, local water tables began steadily rising after ~9500 ^{14}C BP. By ~8500 ^{14}C BP water tables had risen sufficiently to permanently reflooded shallow lake basins for the first time since the previous interglacial period (Watts and Hansen, 1988; Watts *et al*., 1996). Around the beginning of the Boreal, sites such as Page-Ladson and Little Salt Springs remained occupied. However, as the water table rose and the wetlands expanded, settlement options increased and populations became more diffuse. Thus, by the end of the Boreal many of the earlier sites of focused human activity were abandoned or occupied less frequently.

5.4.4.4 Early Holocene – 8.2 ka Glacial-like Mode

The 8.2 ka glacial-like episode was the first of several Dansgaard–Oeschger cooling events that occurred in the Holocene. Although many global proxies have shown that some type of environmental oscillation took place during the 8.2 ka Dansgaard–Oeschger episode (Shuman *et al*., 2002), there is no evidence for a local water table decline in Florida.

Evidence thus far from the Page-Ladson site in the Aucilla River and the Ryan-Harley site in the Wacissa River indicate that near modern water levels were established ~4500 ^{14}C BP (Dunbar *et al*., 1989). Holocene peat deposits from ~8500 ^{14}C BP to ~4500 ^{14}C BP have only been identified in sections of the Aucilla and Wacissa rivers that are at or below about 2 m below modern, low river stage. Shallower peat deposits situated at depths of 2 m or less have yielded dates from ~4500 ^{14}C BP to present.

5.5 Discussion and Conclusions

5.5.1 Evidence of Climatic Response to Heinrich Events in the Southeast

One of the first comparative interpretations to link evidence of local, Southeastern environmental shifts with global climatic change was by Grimm *et al*. (1993). Lake Tulane (27° 35′ North latitude) in south-central Florida produced a continuous pollen record spanning the last 50,000 years. Peaks in *Pinus* (pine) pollen from Lake Tulane were correlated to Heinrich events H5, H4, H3, H2, and H1 (Fig. 5.7). The increase of *Pinus* versus the corresponding decrease in *Quercus-Ambrosia* (oak-ragweed) dominant assemblages is interpreted as evidence of moderation and wetter conditions or, at least, cooler, less arid ones.

For a more detailed picture during the last glacial recession, it is possible to use the *Pinus* profile from Sheelar Lake in northeast Florida for comparison to episodes of global climatic mode change. The Sheelar Lake pollen profiles are bracketed by 11 radiocarbon dates (Watts and Stuiver, 1980; Watts and Hansen, 1994), and the *Pinus* peaks appear to mirror the rhythms of several late glacial climatic oscillations (Fig. 5.8). It should be cautioned that the type of *Pinus* at Lake Tulane is believed to represent warm-temperate/subtropical pines whereas the types represented at Sheelar Lake appear to represent a mixture of boreal/cool-temperate as well as warm-temperate/subtropical pines (Jackson *et al*., 2000). It should also be noted that it was not until the mid-Holocene when fire-adapted *Pinus* communities became dominant in the Southeast, apparently with the establishment of yearly summertime thundershowers, which provided the reproductive spark for these fire dependent communities (Watts and Hansen, 1994). Thus the *Pinus* species of Pleistocene Florida differ from the modern, Holocene assemblage. The primary point made here is that the late Pleistocene *Pinus* pollen record of Florida appears to be another possible indicator of late Pleistocene global mode shifts.

5.5.1.1 Heinrich 1 (H1)

During the earlier H1 Heinrich event, cool-temperate species of *Picea* (spruce) may have migrated to their farthest southern extent at Camel Lake, Florida (Watts *et al*., 1992). Camel Lake is located in the North Florida Panhandle about 100 km west of the Aucilla–Wacissa River basins at latitude 30° 16′ North. Camel Lake is adjacent to the Apalachicola River basin, the only Florida river with headwaters originating as small mountain springs in the Blue Ridge physiographic region of the Appalachian Mountains of North Georgia (Watts *et al*., 1992; Upper Chattahoochee RiverKeeper, 1999). The Apalachicola's major tributaries include the Flint River of Georgia, the Chattahoochee River of Alabama and Georgia, and the Chipola of Alabama and Florida.

Farther west, another southern stand of *Picea* thrived in the Tunica Hills area of southeast Louisiana (Delcourt and Delcourt, 1977). However, the interpretation of the Tunica Hills *Picea* proxy (Delcourt and Delcourt, 1996) has recently changed with the recognition that it represents the extinct species, *Picea critchfieldii*, that existed until ~12,000 ^{14}C BP (Jackson and Weng, 1999). The Tunica Hills *Picea critchfieldii* ranged from latitude 30° North to 35° North in the Mississippi River Valley and may not represent a cool-temperate species of that conifer.

A recent compilation of isopoll maps for selected pollen types of the late glacial maximum shows *Pinus* dominating along the Atlantic coast and *Picea* in the continental interior particularly the lower Mississippi Valley and, to the north, along the glacial ice margins (Jackson and Weng, 1999). "Boreal (*Picea glauca*, *Pinus banksiana*) and cool-temperate conifers (*Pinus resinosa* and *Pinus strobes*) grew at least as far south as 34° North (Northwest Georgia [Bob Black Pond]), and may have extended as far south as the Gulf Coast of Florida" (based on data from Camel Lake)(Jackson and Weng, 1999). By inference, Jackson *et al*. (1999:502) point to the possible importance of the Apalachicola River drainage basin as the possible expansion corridor for these northern boreal species. The occurrence of *Picea* at Camel Lake begins to peak about ~14,300 ^{14}C BP and comes to an end by ~12,600 ^{14}C BP (Watts *et al*., 1992). The peak in *Picea* pollen at Camel Lake appears to begin at or shortly after the height of H1 and ends prior to or by the onset of the Older Dryas. Investigation of the paleohydrology of the Apalachicola River reveals that its Pleniglacial (~16,500 ^{14}C BP to ~13,000 ^{14}C BP) discharge was at a ~70% greater volume than its maximum, flood-stage discharge of historic record (Donoghue, 1993:199, 202). The Pleniglacial Apalachicola River was a much larger river compared to its Holocene counterpart.

Thus the only full-blown Heinrich event of the last glacial recession coincides with the unique southern expansion of boreal and cool conifers in North Florida at Camel Lake. It appears that the attenuating effects of H1 reached North Florida during the Pleniglacial. H1 climatic event provided both the atmospheric moisture and cool conditions necessary to support a species of *Picea* displaced from its glacial maximum range in the mountains of northern Georgia.

5.5.1.2 The Younger Dryas, Heinrich 0 (H0)

From the hypothesis that the western tropical Atlantic acted as the moisture source feeding ice-sheet growth during the Younger Drays (Labeyrie, 2000), it appears that the Cutler Ridge fossil site (8Da 2001) near Miami, Florida provides supporting evidence. Cutler Ridge, at latitude 25° 34′ North, is located between the western, equatorial tropics and the Canadian Laurentide ice-sheet then located above 45° North latitude. During the Younger Dryas, five mammal and two bird species, representing tropical or subtropical affinities, inhabited the Cutler Ridge area. This Rancholabrean fauna is indicative of a “forest environment surrounded by open grassland and lowland marshes and wetlands” (Emslie and Morgan, 1995). The Pleistocene faunal assemblage was recovered in stratigraphic position directly below an early Holocene level dating ~9,700 ^{14}C BP (Carr, 1987). The Cutler Ridge site provides evidence of moderate to wet conditions at a time prior to the Preboreal oscillation and is also located along the hypothesized path of moisture being wicked northward from the tropics during the Younger Dryas (H0). Because the Cutler Ridge megafauna component has not been dated, the Windover site (8Br246) near Cape Canaveral, Florida (27° 50′ North latitude) provides a more precise temporal context for wet conditions during the Younger Dryas. Water lily peat was deposited at the Windover site during the Younger Dryas from ~10,800 ^{14}C BP to ~10,200 ^{14}C BP (Doran and Dickel, 1988a). In Southwest Florida evidence of increased moisture in the climates during the Younger Dryas comes from the Little Salt Springs site (8So18) with ages ranging from ~11,000 ^{14}C BP to ~10,000 ^{14}C BP for the event (Clausen *et al*., 1979).

5.5.2 Summary of Other Chronostratigraphy and Geoclimatic Evidence

In North Florida two episodes of low water tables and dry climatic conditions took place during the late glacial recession. Both occurred during global modern modes, the first coinciding with MWP-1Aand the second with MWP-1B (Plate paleoclimate chart color). Conversely, there were two episodes of elevated water tables and wet conditions in North Florida that also coincided with global modern mode events. The first episode of high water and moist conditions occurred during the pleniglacial modern-like mode and the second during the Allerød after meltwater discharge was rerouted to the North Atlantic. During the first Heinrich event (H1) the water table dropped in North Florida and supported non-flowing conditions, even in the deeper areas of the river channel such as the Page-Ladson site. During subsequent Heinrich and Dansgaard–Oeschger events, the North Florida water tables may have experienced short term, perhaps decadal declines in water table that resulting in still-water conditions. Nevertheless, the evidence also suggests that still-water conditions, if they occurred, were relatively short term and that the water table rebounded quickly because through-flowing water (in other words water levels above the 3.5 m bench) existed or were reestablished at the Page-Ladson site.

Perhaps the most peculiar stratigraphic unit at the Page-Ladson site is Unit 5, which reflects a low energy predominantly still-water environment which existed during the late Younger Dryas after the effects of Heinrich conditions (H0) had waned. The character of Unit 5 is unique because it is a mineral-rich, smectite deposit. The mineral-rich nature of the unit may have been deposited at the time of its deposition or may have formed after its deposition, during the Preboreal onset when Unit 5 was subaerially exposed. The smectite content in Unit 5 may have developed during the subsequent Preboreal when the unit was exposure as a subaerial surface, but located at a low elevation. Sediments located in similar lowland situations may be altered and become mineral-rich wetland discharge soils. "Soil" in this case refers to the subsequent deposition of solution precipitated minerals in an existing sediment (geologic usage, e.g. Richardson, 1996) instead of "soil" defined as an agricultural term requiring longer term development of terrestrial features such as soil horizons and ped structures (e.g. Scudder, Chapter 15). Either way, the original deposition of Unit 5 represents a major decline of water table during the late Younger Dryas. Further north, at Dust Cave in northern Alabama (see Fig. 5.1), a similar decline in the local water table allowed Late Paleoindian activity to take place for the first time in the cave. Prior to the late Younger Dryas Dust Cave had been inundated (Collins *et al*., 1994; Driskell, 1994, 1996).

The South Florida pollen profiles provide an interesting latitudinal comparison with the North Florida data. South Florida proxies from Lake Tulane (Watts and Hansen, 1994) agree with the North Florida data and indicate a period of substantially low water tables during the Late Glacial Maximum. There is a gap in the South Florida proxy record after the glacial maximum and throughout the remainder of the pleniglacial. After that, South Florida proxies again corroborate the North Florida data and indicate that the peninsula as well as the panhandle of Florida experienced dry climatic conditions and low water tables during Meltwater Pulses 1A and 1B. However, South Florida appears to have lagged behind the north during the Allerød as the Floridan Aquifer remained well below present. Nevertheless, moderate climatic conditions prevailed in South Florida (25–27° North latitude) during the middle Allerød because freshwater shell marls also formed in shallow lake basins. During the cold phase of the Younger Dryas, climatic conditions in South Florida became divergent from the climatic regime in the northern part of the state. Abundant moisture, hammocks, and wetland prevailed in the south while conditions, although still moderate, became dryer in North Florida (30–31° North latitude). The Polar Front shifted southward to approximately 37° North latitude in the northern North Atlantic during the cold phase of the Younger Dryas, which may have been a factor resulting in these differences. The South Florida proxy data appear to support the proposition that an atmospheric moisture conveyor originating in the tropics was driven over the southern peninsula on its way north, toward the Polar Front. The South Florida proxy data are therefore in general agreement with the North Florida data except for its early Younger Dryas, monsoon-like wet phase.

The North and South Florida proxy data provide support for the hypothesis that the presence or absence of meltwater buildup in the Gulf of Mexico resulted in a seesaw of climatic events. During Meltwater 1A and 1B, the Southeast US became a very dry place. That seesaw effect flipped in the other direction during the latter Allerød after ~11,700 ^{14}C BP when meltwater discharged in the North Atlantic resulting in the Clovis drought Southwestern US.

The environmental episodes that took place in Florida after the late glacial maximum were both varied and numerous. Throughout the late glacial maximum the water table was a great deal below its present position. After that, there were two major episodes of high and of low water table stands. The onset of the low water table stands was abrupt, otherwise episodes of rising and falling water tables appear to have taken place gradually between the high and low extremes. The utilization of ancient water table elevations in an extensive karst area is an excellent proxy of reference because it more directly reflects the abundance or scarcity of atmospheric moisture contributed to local and regional catchments. The chronostratigraphy and geoclimatic data developed in this chapter provide the framework to better understand the Paleoindian (Chapter 14) and Early Archaic (Chapter 18) site components at the Page-Ladson site. It also provides a foundation for the Paleoindian land use model presented in Chapter 20. This is the first version of a chronostratigraphy and geoclimatic reconstruction for the Southeastern US and as such is offered for testing and revision as new data may dictate.

References

Alley, R. B., and P. U. Clark. 1999. The Deglaciation of the Northern Hemisphere; a Global Perspective. *Annual Review of Earth and Planetary Sciences*, 27:149–182.

Andrews, J. T., and D. C. Barber. 2002. Dansgaard–Oeschger Events: Is There a Signal Off the Hudson Strait Ice Stream? *Quaternary Science Reviews*, 21 (1–3):443–454.

Appenzeller, C., T. F. Stocker, and M. Anklin. 1998. North Atlantic Oscillation Dynamics Recorded in Greenland Ice Cores. *Science*, 282 (5388):446–449.

Bard, E., F. Rostek, L. Turon, and S. Gendreau. 2000. Hydrological Impact of Heinrich Events in the Subtropical Northeast Atlantic. *Science*, 289:1321–1324.

Behrensmeyer, A. K. 1978. Taphonomic and Ecological Information from Bone Weathering. *Paleobiology*, 4 (2):150–162.

Bentacourt, J. L., K. A. Rylander, Peñalba, and J. L. McVickar. 2001. Late Quaternary Vegetation History of Rough Canyon, South-Central New Mexico, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 165:71–95.

Berger, W. H. 1985. On the Time-Scale of Deglaciation: Atlantic Deep-Sea Sediments and Gulf of Mexico. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 50:167–184.

Björck, S., B. Kromer, S. Johnsen, O. Bennike, D. Hammarlund, G. Lemdahl, T. L. R. Goran Possnert, B. Wohlfarth, C. Uffe Hammer, and M. Spurk. 1996. Synchronized Terrestrial–Atmospheric Deglacial Records Around the North Atlantic. *Science*, 274:1155–1160.

Björck, S., M. J. C. Walker, L. C. Cwynar, S. Johnsen, K.-L. Knudsen, J. J. Lowe, B. Wohlfarth, and INTIMATE Group. 1998. An Event Stratigraphy for the Last Termination in the North Atlantic Region Based on the Greenland Ice-Core Record: A Proposal by the INTIMATE Group. *Journal of Quaternary Science*, 13 (4):283–292.

Björck, J., T. Andren, S. Wastegard, G. Possnert, and K. Schoning. 2002. An Event Stratigraphy for the Last Glacial-Holocene Transition in Eastern Middle Sweden: Results from Investigations of Varved Clay and Terrestrial Sequences. *Quaternary Science Reviews*, 21 (12–13):1489–1501.

Bloom, A. L. 1998. Late Quaternary Climatic Geomorphology. *Geomorphology: A Systematic Analysis of Late Cenozoic Landforms*, editor Arthur L. Bloom, pp. 395–416. Prentice Hall, Upper Sabble River, NJ.

Bond, G., H. Heinrich, W. Broecker, L. Labeyrie, J. McManus, J. Andrews, S. Huon, R. Jantschik, S. Clasen, M. Klas, G. Bonani, and S. Ivy. 1992. Evidence for Massive Discharges of Icebergs into the North Atlantic Ocean During the Last Glacial Period. *Nature*, 360:245–249.

Bond, G., W. Showers, M. Cheseby, R. Lotti, P. Almasi, P. deMenocal, P. Priore, H. Cullen, I. Hajdas, and G. Bonani. 1997. A Pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates. *Science*, 278 (5341):1257–1266.

Boyle, E. A. 2000. Is Ocean Thermohaline Circulation Linked to Abrupt Stadial/Interstadial Transitions? *Quaternary Science Reviews*, 19 (1–5):255–272.

Brauer, A., C. Endres, and J. F. W. Negendank. 1999. Late glacial Calendar Year Chronology Based on Annually Laminated Sediments from Lake Meerfelder Maar, Germany. *Quaternary International*, 61 (1):17–25.

Broecker, W. S. 1997. Thermohaline Circulation, the Achilles Heel of Our Climate System: Will Man-Made CO_2 Upset the Current Balance? *Science*, 278:1582–1588.

——— . 2000. Abrupt Climate Change; Causal Constraints Provided by the Paleoclimate Record. *Earth-Science Reviews*, 51 (1–4):137–154.

Broecker, W. S., J. P. Kennett, B. P. Flower, J. T. Teller, S. Trumbore, G. Bonani, and W. Wolf. 1989. Routing of Meltwater from the Laurentide Ice Sheet During the Younger Dryas Cold Episode. *Nature*, 341:318–321.

Brooks, H. K. 1974. Lake Okeechobee. *Environments of South Florida: Present and Past*, editor Patrick J. Gleason, pp. 256–286. Miami Geological Society, Miami.

Brown, P. A., and J. P. Kennett. 1998. Megaflood Erosion and Meltwater Plumbing Changes During Last North American Deglaciation in the Gulf of Mexico Sediments. *Geology*, 26 (7):599–602.

Calvo, E., J. Villanueva, J. O. Grimalt, A. Boeaert, and L. Labeyrie. 2001. New Insights into the Glacial Latitudinal Temperature Gradients in the North Atlantic. *Earth and Planetary Science Letters*, 188:509–519.

Carr, R. S. 1987. Early Man in South Florida. *Archaeology*, 62–63.

Chapman, M. R., N. J. Shackleton, and J.-C. Duplessy. 2000. Sea Surface Temperature Variability During the Last Glacial–Interglacial Cycle: Assessing the Magnitude and Pattern of Climate Change in the North Atlantic. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 157 (1–2):1–25.

Chappell, J. 2002. Sea Level Changes Forced Ice Breakouts in the Last Glacial Cycle: New Results from Coral Terraces. *Quaternary Science Reviews*, 21 (10):1229–1240.

Chen, E., and J. F. Gerber. 1991. Climate. *Ecosystems of Florida*, editors Ronald L. Myers, and John J. Ewel, pp. 11–34. University of Central Florida Press, Orlando, FL.

Clark, P. U., R. B. Alley, L. D. Keigwin, J. M. Licciardi, S. J. Johnsen, and H. Wang. 1996. Origin of the First Global Meltwater Pulse Following the Last Glacial Maximum. *Paleoceanography*, 11 (5):563–577.

Clark, P. U., R. B. Alley, and D. Pollard. 1999. Northern Hemisphere Ice-Sheet Influences on Global Climate Change. *Science*, 286 (5442):1104–1111.

Clark, C. D., J. K. Knight, and J. T. Gray. 2000. Geomorphological Reconstruction of the Labrador Sector of the Laurentide Ice Sheet. *Quaternary Science Reviews*, 19:1343–1366.

Clark, P. U., S. J. Marshall, G. K. C. Clarke, S. W. Hostetler, J. M. Licciardi, and J. T. Teller. 2001. Freshwater Forcing of Abrupt Climate Change During the Last Glaciation. *Science*, 293 (5528):283–287.

Clausen, C. J., D. A. Choen, C. Emiliani, J. A. Holman, and J. J. Stipp. 1979. Little Salt Springs: A Unique Underwater Site. *Science*, 203:609–614.

Cockrell, W. A., and L. Murphy. 1978. Pleistocene Man in Florida. *Archaeology of Eastern North America*, 6:1–12.

Collins, M. B., W. A. Gose, and S. Shaw. 1994. Preliminary Geomorpgological Findings at Dust and Nearby Caves. *Journal of Alabama Archaeology*, 40 (1 & 2):35–56.

Cortijo, E., L. Labeyrie, M. Elliot, E. Balbon, and N. Tisnerat. 2000. Rapid Climate Variability of the North Atlantic Ocean and Global Climate: A Focus of the IMAGES Program. *Quaternary Science Reviews*, 19:227–241.

de Vernal, A., C. Hillaire-Marcel, and G. Bilodeau. 1996. Reduced Meltwater Outflow from the Laurentide Ice Margin During the Younger Dryas. *Nature*, 381:774–777.

Delcourt, P. A., and H. R. Delcourt. 1977. The Tunica Hills, Louisiana–Mississippi: Late Glacial Locality for Spruce and Deciduous Forest Species. *Quaternary Research*, 7:218–237.

——. 1996. Quaternary Paleoecology of the Lower Mississippi Valley. *Engineering Geology*, 45:219–242.

Dietrich, P. M., and J. A. Gifford. 1997. *Early–Middle Archaic Paleoenvironments and Human Populations at Little Salt Springs, Florida*, pp. 1–22. Unpublished paper presented at the Geological Society of America, Southeast section, 46th annual meeting. Available through John Gifford Rosenstiel School of Marine and Atmospheric Science University of Miami, Key Biscayne, FL.

Donoghue, J. F. 1993. Late Wisconsinan and Holocene Depositional History, Northeastern Gulf of Mexico. *Marine Geology*, 112:185–205.

Doran, G. H., and D. N. Dickel. 1988a. Multidisciplinary Investigation at the Windover Site. *Wet Site Archaeology*, editor Barbara A. Purdy, pp. 263–290. Telford Press, Caldwell, NJ.

——. 1988b. Radiometric Chronology of the Archaic Windover Archaeological Site (8Br246). *Florida Anthropologist*, 41 (3):365–380.

Driskell, B. N. 1994. Stratigraphy and Chronology at Dust Cave. *Journal of Alabama Archaeology*, 40 (1 & 2):17–34.

——. 1996. Stratified Late Pleistocene and Early Holocene Deposits at Dust Cave, Northwest Alabama. *The Paleoindian and Early Archaic Southeast*, editors David G. Anderson, and Kenneth E. Sassaman, pp. 315–330. University of Alabama Press, Tuscaloosa, AL.

Dunbar, J. S. 2002. *Chronostratigraphy and Paleoclimate of Late Pleistocene Florida and the Implications of Changing Paleoindian Land Use*, Masters of Sciences Thesis, Florida State University, Tallahassee, FL.

Dunbar, J. S., S. D. Webb, and D. Cring. 1989. Culturally and Naturally Modified Bones from a Paleoindian Site in the Aucilla River, North Florida. *Bone Modification*, editors Robson

Bonnichsen, and Marcella Sorg, pp. 473–497. Center for the Study of the First Americans, Orno, Main.

Dunbar, J. S., C. A. Hemmings, P. K. Vojnovski, S. D. Webb, and W. Stanton. 2006. The Ryan/Harley Site 8Je1004: a Suwannee Point Site in the Wacissa River, North Florida. *Paleoamerican Prehistory: Colonization Models, Biological Populations, and Human Adaptations*, editor Rob Bonnichsen. Center for the Study of the First Americans, College Station, TX.

Dyke, A. S., J. T. Andrews, P. U. Clark, J. H. England, G. H. Miller, J. Shaw, and J. J. Veillette. 2002. The Laurentide and Innuitian Ice Sheets During the Last Glacial Maximum. *Quaternary Science Reviews*, 21 (1–3):9–31.

Edwards, R. L., J. W. Beck, G. S. Burr, D. J. Donahue, M. A. Chappell, A. L. Bloom, E. R. M. Druffel, and F. W. Taylor. 1993. A Large Drop in Atmospheric $^{14}C/^{12}C$ and Reduced Melting in the Younger Dryas, Documented with ^{230}Th Ages of Corals. *Science*, 260:962–968.

Emslie, S. D., and G. S. Morgan. 1995. Taphonomy of a Late Pleistocene Carnivore Den, Dade County Florida. *Late Quaternary Environments and Deep History: A Tribute to Paul S. Martin*, editors David W. Stedman, and Jim I. Mead, pp. 65–83. The Mammoth Site of Hot Springs, South Dakota, Inc., Hot Springs, SD.

Fanning, A. F., and A. J. Weaver. 1997. Temporal-Geographical Meltwater Influences on the North Atlantic Conveyor: Implications for the Younger Dryas. *Paleoceanography*, 12 (2):307–320.

Faught, M. K., and J. F. Donoghue. 1997. Marine Inundated Archaeological Sites and Paleo-Fluvial Systems: Examples from a Karst Controlled Continental Shelf Setting Apalachee Bay, Northeast Gulf of Mexico. *Geoarchaeology*, 12 (5):417–458.

Fiedel, S. J. 1999. Older Than We Thought: Implications of Corrected Dates for Paleoindians. *American Antiquity*, 64 (1):95–115.

Fisher, T. G., D. G. Smith, and J. T. Andrews. 2002. Preboreal Oscillation Caused by a Glacial Lake Agassiz Flood. *Quaternary Science Reviews*, 21 (8–9):873–878.

Flower, B. P., and J. P. Kennett. 1995. Biotic Responses to Temperature and Salinity Changes During Last Deglacial, Gulf of Mexico. *Effects of Past Global Change on Life*, editor anonymous. National Academy Press, Washington, DC.

Friedrich, M., B. Kromer, M. Spurk, J. Hofmann, and K. F. Kaiser. 1999. Paleo-Environment and Radiocarbon Calibration as Derived from Late Glacial/Early Holocene Tree-Ring Chronologies. *Quaternary International*, 61 (1):27–39.

Friedrich, M., B. Kromer, K. F. Kaiser, M. Spurk, K. A. Hughen, and S. J. Johnsen. 2001. High-Resolution Climate Signals in the Bølling Allerød Interstadial (Greenland Interstadial 1) as Reflected in European Tree-Ring Chronologies Compared to Marine Varves and Ice-Core Records. *Quaternary Science Reviews*, 20 (11):1223–1232.

Gagan, M. K., L. K. Ayliffe, J. W. Beck, J. E. Cole, E. R. M. Druffel, R. B. Dunbar, and D. P. Schrag. 2000. New Views of Tropical Paleoclimates from Corals. *Quarterly Science Reviews*, 19:45–64.

Gifford, J. A. 2002. *Little Salt Springs Radiocarbon Dates on Samples from the 26 m Ledge*, Rosenstiel School of Marine and Atmospheric Science University of Miami e-mail to James S. Dunbar from jgifford@rsmas.miami.edu.

Grimm, E. C., G. L. Jacobson, W. A. Watts, B. C. S. Hansen, and K. A. Maasch. 1993. A 50,000-year Record of Climate Oscillations from Florida and its Temporal Correlation with the Heinrich Events. *Science*, 261 (5118):198–200.

Haynes, C. V. 1991. Geoarchaeological and Paleohydrological Evidence for a Clovis-age Drought in North America and its Bearing on Extinction. *Quaternary Research*, 35:438–450.

Haynes, C. V., D. J. Stanford, M. Jordy, J. Dickinson, J. L. Montgomery, P. H. Shelley, I. Rovner, and G. A. Agogino. 1999. A Clovis Well at the Type Site 11,500 B.C.: The Oldest Prehistoric Well in America. *Geoarchaeology*, 14 (5):455–470.

Heine, K. 1994. The Late-Glacial Moraine Sequences in Mexico: Is There Evidence for the Younger Dryas Event? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 112:113–123.

Hemming, S. R., P. E. Biscaye, W. S. Broecker, N. G. Hemming, M. Klas, and I. Hajdas. 1998a. Provenance Change Coupled with Increased Clay Flux During Deglacial Times in the Western Equatorial Atlantic. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 142 (3–4):217–230.

Hemming, S. R., W. S. Broecker, W. D. Sharp, G. C. Bond, R. H. Gwiazda, J. F. McManus, M. Klas, and I. Hajdas. 1998b. Provenance of Heinrich Layers in Core V28-82, Northeastern Atlantic; (Super 40) Ar (Super 39) Ar Ages of Ice-Rafted Hornblende, Pb Isotopes in Feldspar Grains, and Nd–Sr–Pb Isotopes in the Fine Sediment Fraction. *Earth and Planetary Science Letters*, 164 (1–2):317–333.

Hemmings, C. A. 1999. *The Paleoindian and Early Archaic Tools of Sloth Hole (8Je121): An Inundated Site in the Lower Aucilla River, Jefferson County, Florida*. Masters Thesis, Department of Anthropology, University of Florida, Gainesville, FL.

Hendy, E. J., M. K. Gagan, C. A. Alibert, M. T. McCulloch, J. M. Lough, and P. J. Isdale. 2002. Abrupt Decrease in Tropical Pacific Sea Surface Salinity at End of Little Ice Age. *Science*, 295 (5559):1511–1514.

Holliday, V. T. 1997. *Paleoindian Geoarchaeology of the Southern High Plains*. University of Texas Press, Austin, TX.

——. 2000. Folsom Drought and Episodic Drying on the Southern High Plains from 10,900–10,200 ^{14}C Yr B.P. *Quaternary Research*, 53:1–12.

Holmgren, M., M. Scheffer, E. Ezcurra, J. R. Gutierrez, and G. M. J. Mohren. 2001. El Niño Effects on the Dynamics of Terrestrial Ecosystems. *Trends in Ecology & Evolution*, 16 (2):89–94.

Hornum, M. B., D. J. Maher, C. Brown, J. Granberry, F. Vento, A. Fardkin, and M. Williams. 1996. *Phase III Data Recovery at Site LE2105 for the Proposed Florida Gas Transmission Phase III Expansion Project, Leon County, Florida*. R. Christopher Goodwin and Associates, Inc., New Orleans, LA.

Huckleberry, G., C. Beck, G. T. Jones, A. Holmes, M. Cannon, S. Livingston, and J. M. Broughton. 2001. Terminal Pleistocene–Early Holocene Environmental Change at the Sunshine Locality, North-Central Nevada, USA. *Quaternary Research*, 55:303–312.

Hughen, K. A., J. T. Overpeck, L. C. Peterson, and S. Trumbore. 1996. Rapid Climate Changes in the Tropical Atlantic Region During the Last Deglaciation. *Nature*, 380:51–54.

Hughen, K. A., J. R. Southon, S. J. Lehman, and J. T. Overpeck. 2000a. Synchronous Radiocarbon and Climate Shifts During the Last Deglaciation. *Science*, 290 (5498):1951–1954.

Hughen, K. A., J. R. Southon, S. J. Lehman, and J. T. Overpeck. 2000b. Cariaco Basin 2000. Deglacial ^{14}C and Grey Scale Data, *NOAA/NGDC Paleoclimatology Program, IGBP Pages/World Data Center A for Paleoclimatology, Data Contribution Series #2000-069*, Boulder, CO.

Humphrey, J. D., and C. R. Ferring. 1994. Stable Isotopic Evidence for Latest Pleistocene and Holocene Climatic Change in North-Central Texas. *Quaternary Research*, 41 (2):200–213.

Jackson, S. T., and C. Weng. 1999. Late Quaternary Extinction of a Tree Species in Eastern North America. *PNAS*, 96 (24):13847–13852.

Jackson, S. T., R. S. Webb, K. H. Anderson, J. T. Overpeck, T. Webb, J. W. Williams, and B. C. S. Hansen. 2000. Vegetation and Environment in Eastern North America During the Last Glacial Maximum. *Quaternary Science Reviews*, 19:489–508.

Jahren, A. H., R. Amundson, C. Kendall, and P. Wigand. 2001. Paleoclimate Reconstruction Using the Correlation in ^{18}O of Hackberry Carbonate and Environmental Water, North America. *Quaternary Research*, 56:252–263.

Jiang, H., and F. Klingberg. 1996. The Transition from the Younger Dryas to the Preboreal: A Case Study from the Kattegat, Scandinavia. *Boreas*, 25 (2):271–282.

Kahl, J. D. W., J. A. Galbraith, and D. A. Martinez. 1999. Decadal-Scale Variability in Long-range Atmospheric Transport to the Summit of the Greenland Ice Sheet. *Geophysical Research Letters*, 26 (4):481–484.

Kaufman, D. S., G. H. Miller, J. A. Stravers, and J. T. Andrews. 1993. Abrupt Early Holocene (9.9–9.6 ka) Ice-Stream Advance at the Mouth of Hudson Strait, Arctic Canada. *Geology*, 21:1063–1066.

Keefer, D. K., S. D. de France, M. E. Moseley, J. B. Richardson, D. R. Satterlee, and A. Day-Lewis. 1998. Early Maritime Economy and El Niño at Quebrada Tacauay, Peru. *Science*, 281:1833–1835.

Kirby, M. E. 1998. Heinrich Event-0 (DC-0) in Sediments Cores from the Northwest Labrador Sea: Recording Events in Cumberland Sound? *Canadian Journal of Earth Sciences*, 35:510–519.

Kitagawa, H., and J. van der Plicht. 1998. Atmospheric Radiocarbon Calibration to 45,000 Yr B.P.: Late Glacial Fluctuations and Cosmogenic Isotope Production. *Science*, 279 (5354):1187–1190.

Labeyrie, L. 2000. Paleoclimate: Glacial Climate Instability. *Science*, 290 (5498):1905–1907.

Lambeck, K., Y. Yokoyama, P. Johnston, and A. Purcell 2000. Global Ice Volumes at the Last Glacial Maximum and Early Lateglacial. *Earth and Planetary Science Letters*, 181 (4):513–527.

Lapointe, M. 2000. Late Quaternary Paleohydrology of the Gulf of St. Lawrence (Quebec, Canada) Based on Diatom Analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 156 (3–4):261–276.

Lehman, S. J., and L. D. Keigwin. 1992. Sudden Changes in North Atlantic Circulation During the Last Deglaciation. *Nature*, 356:757–762.

Leventer, A., D. F. Williams, and J. P. Kennett. 1982. Dynamics of the Laurentide Ice Sheet During the Last Deglaciation: Evidence from the Gulf of Mexico. *Earth and Planetary Science Letters*, 59:11–17.

Leyden, B. W., M. Brenner, H. D. A., and J. H. Curtis. 1994. Orbital and Internal Forcing of Climate on the Yucatan Peninsula for the Past Ca. 36 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 109:193–210.

Liu, H.-S. 1995. A New View on the Driving Mechanism of Milankovitch Glaciation Cycles. *Earth and Planetary Science Letters*, 131 (1–2):17–26.

Liu, T., W. S. Broecker, J. W. Bell, and C. W. Mandeville. 2000. Terminal Pleistocene Wet Event Recorded in Rock Varnish from Las Vegas Valley, Southern Nevada. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 161 (3–4):423–433.

Lowe, J. J. 2001. Abrupt Climatic Changes in Europe During the Last Glacial–Interglacial Transition: The Potential for Testing Hypotheses on the Synchroneity of Climatic Events Using Tephrochronology. *Global and Planetary Change*, 30 (1–2):73–84.

——. 2002. *INTIMATE Event Stratigraphy Radiocarbon Correlation for the Older Dryas Onset*, e-mail Center for Quaternary Research, University of London, Egham, Surrey, UK to James S. Dunbar, Florida State University and Florida Bureau of Archaeological Research.

Lowe, J. J., W. Z. Hoek, and the INTIMATE Group. 2001. Inter-Regional Correlation of Paleoclimate Records for the Last Glacial–Interglacial Transition: A Protocol for Improved Precision Recommended by the INTIMATE Project Group. *Quaternary Science Reviews*, 20:1175–1187.

Maasch, K. A., and R. J. Oglesby. 1990. Meltwater Cooling of the Gulf of Mexico: A GCM Simulation of Climatic Conditions at 12 Ka. *Paleoceanography*, 5:977–996.

Manabe, S., and R. J. Stouffer. 1997. Coupled Ocean-Atmosphere Model Response to Freshwater Input: Comparison to Younger Dryas Event. *Paleoceanography*, 12 (2):321–336.

Mangerud, J., S. T. Andersen, B. E. Berglund, and J J. Donner. 1974. Quaternary Stratigraphy of Norden, a Proposal for Terminology and Classification. *Boreas*, 3 (3):109–127.

Marchitto, T. M., and K.-Y. Wei. 1995. History of Laurentide Meltwater Flow to the Gulf of Mexico During the Last Deglaciation, as Revealed by Reworked Calcareous Nannofossils. *Geology*, 23 (9):779–782.

Means, R. C. 1999. *A Late Pleistocene Freshwater Shell Marl from the Ryan-Harley Site (8Je1004), Wacissa River, Jefferson County, Florida*. Manuscript on File at the Florida Bureau of Archaeological Research, CARL Archaeological Survey, 4. Tallahassee, FL.

Muniz, M. 1998a. *E-Mail Correspondence About the Timing of Subaerial Versus Inundated Episodes of the Little River Rapids Site (8Je603)*, e-mail to James S. Dunbar Florida Bureau of Archaeological Research.

——. 1998b. Untitled Report on the Investigations of Little River Sites. Aucilla River Research Project, Florida Museum of Natural History, Gainesville, FL.

Peterson, L. C., G. H. Haug, K. A. Hughen, and U. Rohl. 2000. Rapid Changes in the Hydrologic Cycle of the Tropical Atlantic During the Last Glacial. *Science*, 290 (5498):1947–1951.

Polyak, V, J., J. Rasmussen, and Y. Asmerom. 2004. Prolonged Wet Period in the Southwest United States Through the Younger Dryas. *Geology*, 32 (1):5–8.

Renssen, H., and R. F. B. Isarin. 2001. The Two Major Warming Phases of the Last Deglaciation at ~14.7 and ~11.5 Ka Cal BP in Europe: Climate Reconstructions and AGCM Experiments. *Global and Planetary Change*, 30 (1–2):117–153.

Renssen, H., R. F. B. Isarin, J. Vandenberghe, and Workshop participants. 2001. Rapid Climatic Warming at the End of the Last Glacial: New Perspectives. *Global and Planetary Change*, 30:155–165.

Richardson, J. L. 1996. Mixing Soil and Water: The Geology of Wetlands. *Geotimes*, 41 (7):26–29.

Richerson, P. J., R. Boyd, and R. L. Bettinger. 2001. Was Agriculture Impossible During the Pleistocene but Mandatory During the Holocene? A Climate Change Hypothesis. *American Antiquity*, 66 (3):387–411.

Rittenour, T. M., R. J. Globe, and M. D. Blum. 2003. An Optical Age Chronology of Late Pleistocene Fluvial Deposits in the Northern Lower Mississippi Valley. *Quarterly Science Reviews*, 22 (10–13):1105–1110.

Rühlemann, C., S. Mulitza, P. Müller, G. Wefer, and R. Zahn. 1999. Warming of the Tropical Atlantic Ocean and Slowdown of the Thermohaline Circulation During the Last Deglaciation. *Nature*, 402:511–514.

Sarnthein, M., E. Jansen, M. Weinelt, M. Arnold, J. P. Duplessy, H. Erlenkeuser, A. Flatøy, G. Johannessen, T. Johannessen, S. Jung, N. Koc, L. Labeyrie, M. Maslin, U. Pflaumann, and H. Shulz. 1995. Variations in Atlantic Surface Ocean Paleoceanography, 50°–80°N: A Time-Slice Record of the Last 30,000 Years. *Paleoceanography*, 10 (6):1063–1094.

Seidov, D., and M. A. Maslin. 2001. Atlantic Ocean Heat Piracy and the Bipolar Climate See-Saw During Heinrich and Dansgaard–Oeschger Events. *Journal of Quaternary Science*, 16 (4):321–328.

Shuman, B., P. Bartlein, N. Logar, P. Newby, and T. Webb III. 2002. Parallel Climate and Vegetation Responses to the Early Holocene Collapse of the Laurentide Ice Sheet. *Quaternary Science Reviews*, 21 (16–17):1793–1805.

Spero, H. J., and D. F. Williams. 1990. Evidence for Seasonal Low-Salinity Surface Waters in the Gulf of Mexico Over the Last 16,000 Years. *Paleoceanograph*, 5 (6):963–975.

Stuiver, M., and P. J. Reimer. 1993. *CALIB 4.1 Manual*. Quaternary Isotope Lab., University of Washington, Seattle, WA.

Suarez, M. J., and I. M. Held. 1976. Modeling Climatic Response to Orbital Parameter Variations. *Nature*, 263 (5572):46–47.

Tesar, L. 1997. *Notes Concerning the Age of Human Remains at Warm Mineral Springs*, pp. 1–3. Unpublished research paper on file at the Florida Bureau of Archaeological Research.

Thouveny, N., E. Moreno, D. Delanghe, L. Candon, Y. Lancelot, and N. J. Shackleton. 2000. Rock Magnetic Detection of Distal Ice-Rafted Debris: Clue for the Identification of Heinrich Layers on the Portuguese Margin. *Earth and Planetary Science Letters*, 180 (1–2):61–75.

Tudhope, A. W., C. P. Chilcott, M. T. McCulloch, E. R. Cook, J. Chappell, R. M. Ellam, D. W. Lea, J. M. Lough, and G. B. Shimmield. 2001. Variability in the El Niño-Southern Oscillation Through a Glacial–Interglacial Cycle. *Science,* 291 (5508):1511–1517.

Upper Chattahoochee RiverKeeper. 1999. Headwaters: Watershed Description Atlanta, GA. At web page Http://Www.Ucriverkeeper.Org/Mmnavind.Htm, date accessed.

USGS, U.S. Geological Survey Boundary Descriptions and Names of Regions, Subregions, Accounting Units and Cataloging Units, of Drainage Basins; Region 3, South Atlantic-Gulf Region, 03110103– Aucilla Basin. Florida, Georgia. At web page http://water.usgs.gov/GIS/huc_name.txt, date accessed 2002.

Vidal, L., L. Labeyrie, E. Cortijo, M. Arnold, J. C. Duplessy, E. Michel, S. Becque, and T. C. E. van Weering. 1997. Evidence for Changes in the North Atlantic Deep Water Linked to Meltwater Surges During the Heinrich Events. *Earth and Planetary Science Letters*, 146 (1–2):13–27.

Vojnovski, P. K. and J. S. Dunbar. in press. Early Floridians and Late Mega-Mammals: Some Technological and Dietary Evidence from Four North Florida Paleoindian Sites. *Foragers of the Terminal Pleistocene*, editors Renee B. Walker, and B. N. Driskell. University of Nebraska Press, Lincoln, Nebraska.

Walker, M. J. C. 2001. Rapid Climate Change During the Last Glacial–Interglacial Transition; Implications for Stratigraphic Subdivision, Correlation and Dating. *Global and Planetary Change*, 30 (1–2):59–72.

Walker, M. J. C., S. Björck, J. J. Lowe, L. C. Cwynar, S. J. Johnsen, K.-L. Knudsen, B. Wohlfarth, and INTIMATE Group. 1999. Isotopic “Events” in the GRIP Ice Core: A Stratotype for the Late Pleistocene. *Quaternary Science Reviews*, 18 (10–11):1143–1150.

Walker, M. J. C., S. Björck, and J. J. Lowe. 2001. Integration of Ice Core, Marine and Terrestrial Records (INTIMATE) from Around the North Atlantic Region: An Introduction. *Quaternary Science Reviews*, 20 (11):1169–1174.

Watts, W. A. 1975. A Late Quaternary Record of Vegetation from Lake Annie, South-Central Florida. *Department of Botany, Trinity College*, 344–346.

——. 1983. Vegetational History of the Eastern United States 25,000 to 10,000 Years Ago. *Late-Quaternary Environments of the United States*, 294–310.

Watts, W. A., and B. C. S. Hansen. 1988. Environments of Florida in the Late Wisconsin and Holocene. *Wet Site Archaeology*, editor Barbara A. Purdy, pp. 307–324. Telford Press, Inc., Caldwell, NJ.

——. 1994. Pre-Holocene and Holocene Pollen Records of Vegetation History from the Florida Peninsula and Their Climatic Implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 109:163–176.

Watts, W. A., and M. Stuiver. 1980. Lake Wisconsin Climate of Northern Florida and the Origin of Species-Rich Deciduous Forest. *Science*, 210 (4467):325–327.

Watts, W. A., B. C. S. Hansen, and E. C. Grimm. 1992. Camel Lake: A 40,000-year Record of Vegetational and Forest History from Northwest Florida. *Ecology Society of America*, 73 (3):1056–1066.

Watts, W., E. C. Grimm, and T. C. Hussey. 1996. Mid-Holocene Forest History of Florida and the Coastal Plain of Georgia and South Carolina. *Archaeology of the Mid-Holocene Southwest*, editors Kenneth E. Sassaman, and David G. Anderson, pp. 28–40. University Press of Florida, Gainesville, FL.

Weaver, A. J., C. M. Bitz, A. F. Fanning, and M. M. Holl. 1999. Thermohaline Circulation: High-Latitude Phenomena and the Difference Between the Pacific and Atlantic. *Annual Reviews Earth Planet Sciences*, 27 (1):231–285.

Webb, S. D. 1968. *Aucilla River Field Notes*. Misc. Manuscript Files. An unpublished document on file at the Florida Museum of Natural History in Gainesville, Florida.

——. 1974. Underwater Paleontology of Florida's Rivers. *National Geographic Society Research Reports*, 1968 Projects:479–481.

Weng, C., and S. T. Jackson. 1999. Late Glacial and Holocene Vegetation History and Paleoclimate of the Kaibab Plateau, Arizona. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 153:179–201.

Wohlfarth, B. 1996. The Chronology of the Last Termination: A Review of Radiocarbon-Dated, High-Resolution Terrestrial Stratigraphies. *Quaternary Science Reviews*, 15 (4):267–284.

Wright, Jr. H. E. 1989. The Amphi-Atlantic Distribution of the Younger Dryas Paleoclimatic Oscillation. *Quarterly Science Reviews*, 8:295–306.

Yon, W. J. 1966. Geology of Jefferson County, Florida. *Geological Bulletin No. 48*. Florida Geological Survey, Tallahassee, FL.

Zhou, W., M. J. Head, Z. An, P. De Deckker, Z. Liu, X. Liu, X. Lu, D. Donahue, A. J. T. Jull, and J. W. Beck. 2001. Terrestrial Evidence for a Spatial Structure of Tropical–Polar Interconnections During the Younger Dryas Episode. *Earth and Planetary Science Letters*, 191:231–239.

SECTION B: PALEOBOTANY

> "... vegetation has two aspects: It is part of the living world that is studied for its own sake, and it is also the biological setting that, combined with the physical setting, forms the total environment of all life."
>
> **E.C. Pielou**.

In this section the nearly continuous accumulation of rich organic sediments in the Page-Ladson site complex is seen as a series of snapshots of ancient vegetation. In turn those samples of vegetation are interpreted as proxy records of environmental change. These paleobotanical studies are divided by size range into two rather distinct disciplines, one microphytic and the other macrophytic. Chapter 6 features pollen, stomata, and charcoal as the subject materials. Chapter 7 reports on a wide variety of larger plant parts ranging from wood to leaves, nuts, and seeds.

These two botanical approaches are complementary. Palynological data tend to sample a broader area than macrophytic data, with wind-pollinated trees such as pine and oak predominating. For this reason Chapter 6 readily connects environmental history at Page-Ladson with the regional late Pleistocene picture ranging from Central Florida into the Florida Panhandle and adjacent parts of the Gulf of Mexico. The macrophytic chapter, on the other hand, features vegetation that lived immediately adjacent to the sinkhole site of deposition. This consists of a diverse set of trees and shrubs that lived in sheltered bottomland. It also reflects some of the immediate cultural modifications of wood and also samples digesta of mastodons. It is less sensitive to regional shifts in climate, hydrology, and edaphic change away from the site. Both chapters relate their evidence to modern samples of living plant communities, and both convincingly construct the changing environments around the Page-Ladson site and the region during the late Pleistocene and the early Holocene.

Part of the change recorded in these chapters represents the ecological impact of the earliest people in Florida. The charcoal samples in particular are sensitive to disturbance by clearing. They show increasing inputs during the early Holocene even when the background rain of pollen and water-level data indicate more mesic (less fire-prone) natural conditions. Similarly an important subset of the wood specimens, ranging from small wedges to great hollow logs, shows clear evidence of modification by humans during several time intervals.

Chapter 6

Setting the Stage: Fossil Pollen, Stomata, and Charcoal

BARBARA C. S. HANSEN
Barbara C. S. Hansen Limnological Research Center, 220 Pillsbury Hall, University of Minnesota, Minneapolis, MN 55455-0219, USA.

6.1 Introduction

The question being posed in this chapter is what were the roles of climate and man in changing the face of the Florida landscape. At the Page-Ladson Site, we have a nearly continuous stratigraphic sequence sampling several millenia before, during, and after the arrival of Paleoindians in north Florida. This question is linked to the overall issue being addressed in this volume regarding the disappearance of some of the large vertebrates such as the mastodon and mammoth at the end of the Pleistocene. Between 14.0 and 10.0 ^{14}C BP, the Florida panhandle experienced, as did most of the world, rising global temperatures as glaciers retreated in both the northern and southern latitudes. Large lakes in front of the retreating glaciers discharged volumes of glacial melt water into the Gulf of Mexico via the Mississippi River. These events directly or indirectly affected the climate of Florida, the vegetation, the survival of many large vertebrates, and the hunting and gathering strategies of the first Floridians at Page-Ladson.

Because vegetation is strongly influenced by its environment, one of the ways to deduce past climatic change is through the study of plant fossils, including pollen and

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 159–179

stomata (lignified guard cells which regulate transpiration), as well as seeds and leaves (Chapter 7 by Newsom). Such proxy records for climate may also include charcoal fragments (as evidence of fire), diatoms, and sediment chemistry. Lakes and wetlands in sinkholes act as collecting basins for these various fossil elements which accumulate over time in a sequential manner.

Few continuous fossil pollen records span the time interval of 14.0–8.0 ^{14}C BP in Florida, because many lakes dried up sometime during the early to mid-Holocene (10,000–5,000 yr BP). Of the long pollen records that do exist in northern Florida, many have pollen and sediment hiatuses (gaps) caused by lowered water table with ensuing removal of lake sediments by wind or erosion (Watts *et al*., 1992; Watts and Hansen, 1994) (Fig. 6.1 maps several important sites). The Page-Ladson sinkhole sediments appear to have survived this period because of the sinkhole's connection to underground aquifers or other subterranean water sources. The depth of Unit 3, for example, is 8–10 m below present sea level. Because of these conditions, Page-Ladson presents a unique opportunity to study a continuous fossil pollen record for the late-glacial period in conjunction with archeological remains and other proxy records for clues as to the role of man and climate in shaping the vegetation and ultimately the fate of some of the Pleistocene vertebrates.

6.1.1 Interpreting Fossil Pollen Records

Fossil pollen analysis is based on the premise that as plant communities and species respond to a changing environment, the composition of the "pollen rain" or the fossil pollen record changes as well. Many vegetation communities have a recognizable pollen "signature". This signature may be determined by collecting and analyzing pollen in surface samples, including moss, duff, or the surface mud in lakes surrounded by different plant communities (Davis and Goodlett, 1960; Wright, 1966). The results of surface-sample analyses are then compared to the existing vegetation at the collection site. Not all trees, shrubs, or herbs are represented in direct ratio to their occurrence in the vegetation as some species are palynologically "quiet". For example, basswood (*Tilia*) is mainly pollinated by insects rather than wind, so few pollen grains of this tree are found in fossil records; however, just the presence of basswood pollen is an important indicator of mesic hardwood forest. Other species are quite "noisy", producing and dispersing lots of pollen (e.g. pine and oak), presenting the other dilemma that these trees may not have been important in the local vegetation. Still other taxa have pollen that does not preserve well or at all (e.g. rushes).

In spite of these limitations, analysis of the pollen from surface samples makes it possible to differentiate the pollen signatures of different plant communities. These pollen assemblages can then be compared with the fossil pollen record to identify changes in past plant communities as the result of climate change, anthropogenic disturbance, or natural community succession. Fossil pollen can also aid in the identification of cultigens such as squash, gourds, and corn in middens and fields or lakes adjacent to major archeological sites.

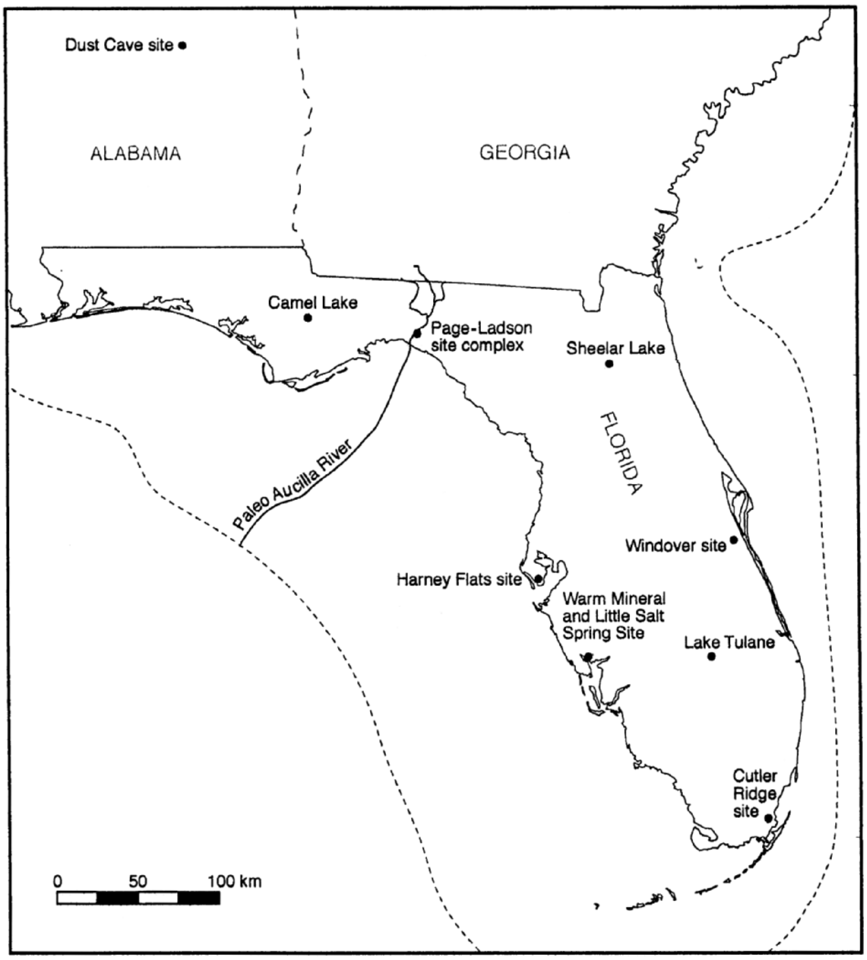


Figure 6.1 Map of Florida showing locations of sites discussed: including Page-Ladson, Camel Lake, Sheelar Lake, Windover, Little Salt Spring.

Other fossils that help to substantiate the composition of vegetation, when pollen is misleading, such as the case with pine pollen, are stomata (Hansen et al., 1996). Stomata are found in leaves, stems, and roots of plants (Fig. 6.2e and f). They have an advantage over some types of pollen, in particular pine pollen, because they are not easily transported long distances. Pine trees are notorious for their prodigious pollen production as well as their widespread dispersal (Davis and Goodlett, 1960). Moderate percentages of pine pollen (10–30%) may be misconstrued as indicating the local presence of pine forest when in actuality the nearest pine trees could be 50–l00 miles away. In Florida, where pine pollen dominates many fossil pollen

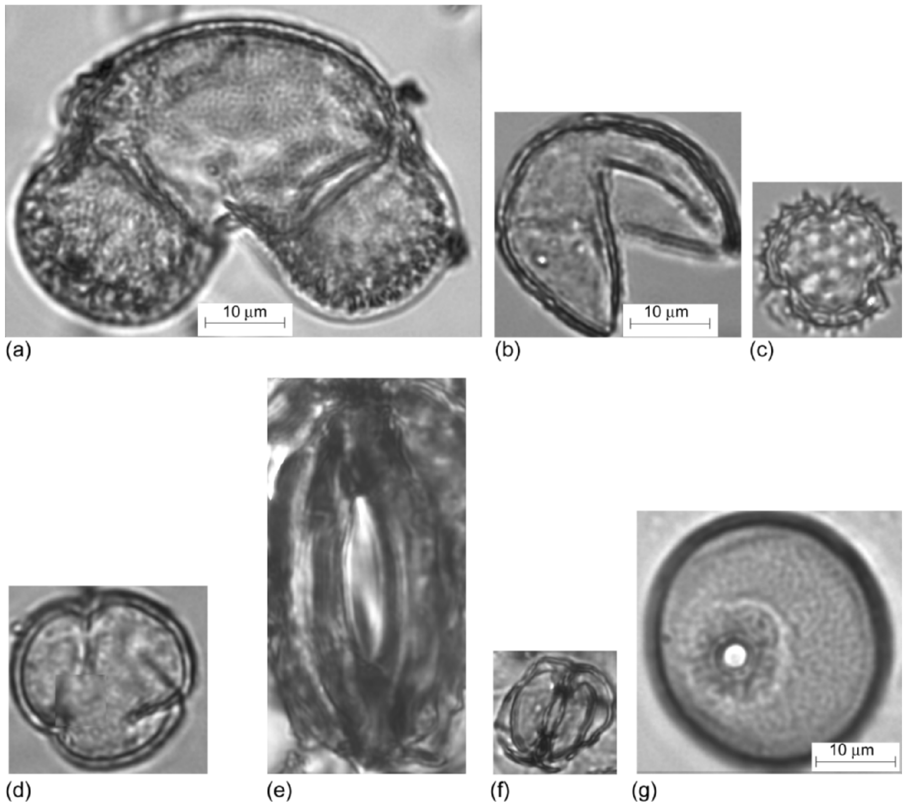


Figure 6.2 Images of several common representative pollen and stomata types found at Page-Ladson and at other fossil pollen sites in Florida: (a) Fossil pine (*Pinus*) pollen from sample 3917 cm, Lake Tulane Florida; (b) Bald cypress (*Taxodium distinctum*) reference pollen; (c) Aster (Asteraceae*, Baccharis halmifolia*) reference pollen; (d) Oak (*Querus virginiana*) reference pollen; (e) Pine (*Pinus*) stomata, reference slide; (f) Bald Cypress (*Taxodium distinctum*) stomata, reference slide.

records, having pine stomata can corroborate local presence. The presence of charcoal fragments in sediments is also useful in reconstructing climatic change and anthropogenic disturbances. Lightning was the major source of fire ignition in Florida prior to the arrival of man (Myers and Ewel, 1990). With the arrival of Paleoindians the presence of charcoal in pollen records suggests other interpretations such as charcoal from cooking fires, from fires used to flush out large game in dense vegetation, or from fires used to clear land for agriculture. When we examine the charcoal data from the Page-Ladson samples, it will be important to see if the clues present in the pollen and charcoal records corroborate the archeological or the vegetation/climate record or both.

6.2 Modern Vegetation

Vegetational surveys at Page-Ladson were completed by Lee Newsom and David Kendrick in 1992. Dominant species were noted along with percent cover, soil conditions, and site situation. Due to time constraints, surface samples were analyzed for pollen from the plots surveyed by Newsom only; these samples are arranged according to a relative moisture gradient from the wettest site, a Cypress swamp, to the driest, a highland pine plantation (Fig. 6.3).

The following plant communities were surveyed: (a) a cypress swamp (pollen site 5); (b) a mature floodplain hardwood forest (pollen site 1); (c) a mesic hardwood hammock (pollen site 2); (d) a mesic hardwood forest (pollen site 3); (e) a disturbed oak woodland (pollen site 4); and (f) an upland pine plantation (pollen site 6).

The cypress swamp (a) at the north end of the Little River section is dominated by bald cypress (*Taxodium* sp.), but red maple (*Acer rubrum*), sweet gum (*Liquidambar*), swamp hickory (*Carya aquatic*), ironwood (*Ostrya* sp.), and hackberry (*Celtis*) are also present. Grasses (Poaceae) and other herbs are infrequent. Soils are a wet, clayey loam (Newsom, 1992, personal communication). Flooding is seasonal and may be frequent. The cypress swamp sampled at Page-Ladson is similar to other northern temperate swamps (Ewel in Myers and Ewel, 1990). *Taxodium distichum* occurs frequently in flowing-water swamps in Florida and is assumed to be the major pollen producer at Page-Ladson (Ewel in Myers and Ewel, 1990). This was the wettest of the vegetation communities sampled.

The floodplain hardwood forest (b) is located on the southern end of the Little River section. Dominant trees on this floodplain included ash (*Fraxinus pennsylvanica*), ironwood (*Carpinus caroliniana*), water hickory (*Carya aquatica*), box elder (*Acer negundo*), hackberry (*Celtis laevigata*), sweetgum (*Liquidambar styraciflua*), and some live-oak hybrids (*Quercus* spp.) (Newsom and Kendrick, personal communication). Common shrubs include blueberry (*Vaccinium*) and possumhaw (*Ilex decidua*) (Platt and Schwartz, in Myers and Ewel, 1990). Soils are organic and sandy, subject to periodic flooding, but during the late summer are dry (Newsom, 1992, personal communication).

A pioneer mesic hardwood forest (c) lies at the northwest end of the Little River section. The glade portion of this ecotone is dominated by grasses (Poaceae), particularly giant cane (*Arundinaria gigantea*) at the forest edge. Southern red cedar (*Juniperus silicicola*) has been planted near one end of the glade while hackberry, sweetgum, oak, cabbage palm, and ironwood grow near the forest edge. Other taxa present and commonly represented in the Florida pollen rain are grape (*Vitis* sp.), St. Johns Wort (*Hypericum*) and blackberry (*Rubus* sp.). Members of the aster family, which includes the groundsel tree (*Baccharis halimifolia*), and mint (Lamiaceae), are also present. The soil is basically a sandy organic loam.

The most mesic of the hardwood communities, site (d), lies on a limestone bluff along the Half-Mile Rise section of the Aucilla River about 30 m from the archeological excavations. Hickory (*Carya*), live oak (*Quercus virginiana*), elm (*Ulmus americana*), ash (*Fraxinus*), southern magnolia (*Magnolia grandiflora*), and cabbage palms (*Sabal palmetto*) dominate this community. Button bush (*Cephalanthus occidentalis*), river birch (*Betula nigra*), blueberry (*Vaccinium* sp.), and elm were near the collecting plot. Ground cover consists of wood violet, sedges (Cyperaceae), and occasional grasses. Soils appeared to be a mottled sandy loam.

The disturbed oak woodland (e) is located northeast of Skimmey Sink. Live oaks (*Quercus* spp.) dominate the canopy, and various asters (Asteraceae) and grasses form a dense ground cover. Other taxa present include cabbage palm (*Sabal palmetto*), switch cane (*Arundinaria* sp.), hickory (*Carya*), sweetgum (*Liquidambar*), St. Johns Wort (*Hypericum* sp.), sedges (Cyperaceae), and winged sumac (*Rhus copallina*). An old bald cypress (*Taxodium* sp.) grows near the sample plot along with plain willow (*Salix caroliniana*). The soil is a dark sandy loam, and the site is relatively dry and open.

The slash pine plantation (f) occurs near the turn to Nutall Rise. This site is both the highest and driest of the six pollen sampling sites and is the closest approximation to a full-glacial Pleistocene pine forest near Page-Ladson today (Watts and Stuiver, 1980; Watts *et al*., 1992; Watts and Hansen, 1994). The ground cover is rich in members of the aster family and in grasses. The soil under the pine forest is very sandy and lacks appreciable organic matter.

6.3 Methods

Soil and moss polsters were collected from within the six different plant communities described above. Four teaspoons of soil or moss were collected within a plant community and placed in a whirl-pack bag, labeled and refrigerated until laboratory preparation.

Samples for fossil pollen analysis at Page-Ladson were removed underwater from test pit faces by Quitmyer, Carter, and Kendrick and other experienced excavators. The test pit exposure on the edge of the sinkhole was first cleared of recent debris, and then samples were collected from distinct sedimentary units. These units were sampled in stratigraphic order from older to younger and then were later dated by radiocarbon samples from within each unit (Chapter 4 by Webb and Dunbar).

Two major concerns at the initiation of this project were contamination of pollen samples by adjacent sediments of older or younger ages and also reworking of sediments during the time of deposition. Considering the relatively isolated nature of the deposition site from an actively aggrading or degrading river until about 5000 ^{14}C BP, the risk of major reworking appears minimal. The duplication of test pit pollen stratigraphies and lack of degraded or reworked pollen also implies sediment continuity. Stratigraphic correlations among the test pits are based on carbon-14 dates by counts or accelerator mass spectrometry (AMS) dates of macrofossils. Where dates are not available, correlations are based on the similarity of pollen assemblages. Standard procedures for obtaining sediment cores from lakes or bogs for pollen analysis can be found in Faegri and Iversen (1964).

Once in the laboratory, sediment samples from surface collections or sinkholes were subsampled and weighed. A known volume and concentration of exotic pollen was added prior to laboratory preparation to determine pollen and charcoal concentrations. Samples were prepared by standard laboratory procedures including hot 10% KOH, 10% HCl, 48% HP, and acetolysis (Faegri and Iversen, 1975) at the Limnological Research Center, University of Minnesota. Samples were mounted in silicone oil (2000 ctsk), and slides scanned at 400× until a sum of 200 or more pollen grains was counted. Pollen grains difficult to identify were examined at 630× and under oil immersion at 1000×. The reference pollen and spore collections of the Limnological Research Center and the Department of Ecology, University of Minnesota, were available for comparison with fossil grains. A personal collection of pollen specific to southeastern US and central America was also used. A key to conifer stomate types, conifer stomate reference slides, and descriptions and photos of conifer stomata aided in the identification of conifer stomata in Page-Ladson fossil material (Trautmann, 1953; Hansen, 1995). Examples of commonly occurring fossil pollen grains and conifer stomata are shown in Fig. 6.2.

Charcoal fragments were counted in pollen slides after pollen analyses were completed. Charcoal fragments were assigned to one of two size categories, 30–100 μm and >100 μm. When size was in doubt, a calibrated ocular micrometer was used to check the measurements of charcoal fragments. Methods for quantifying charcoal in lake sediments are detailed in the following references: Clark (1982), and MacDonald *et al*. (1991).

Pollen, stomata, and charcoal data are summarized in percentage diagrams (Cushing, 1993), with pollen percentages based on all taxa except aquatics, unknown pollen, and indeterminable pollen. Pollen taxa occurring as less than 1% of the pollen sum, were not plotted in the pollen diagrams although included in the pollen sum. Stomate data are summarized as percentages of total pollen (Ammann and Wick, 1993; Hansen, 1995). Not all diagrams have charcoal, pollen concentration, or stomate data, because methodology was still evolving during exploratory work. Unit designations follow the stratigraphic scheme presented in Chapter 2 by Kendrick and the vertical scale in the pollen diagrams indicates the stratigraphic position of the sample according to the level excavated. Pollen types are grouped according to the habitat in which the plants most frequently occur in the vegetation surveys by Newsom and Kendrick, and according to ecological assessment of Clewell (1993). The overlapping habitat headings in the pollen diagrams indicate the occurrence of some species in neighboring communities.

6.4 Surface-sample Pollen: Results and Discussion

6.4.1 Surface-sample Pollen

Surface-sample pollen results (Fig. 6.3) suggest a modest correlation between the pollen assemblage and the plant community from which samples were collected. The sample

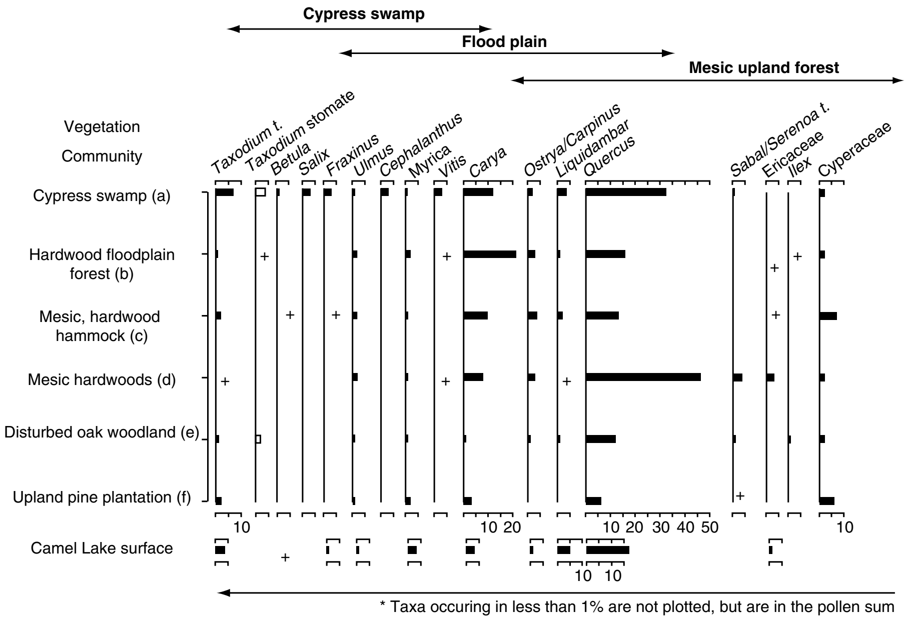


Figure 6.3 Surface-sample pollen percentage diagram summarizing the occurrence of frequent pollen and stomata types; charcoal fragments are plotted as percent of total pollen counted. Surface samples are arranged from the wettest vegetation community at the top of the diagram to driest at the bottom; a sediment sample from the surface of nearby Camel Lake Pond is included for comparison.

from the cypress swamp has relatively high percentages (8% and 5%, respectively) of cypress (*Taxodium*) pollen and stomata and moderately high percentages of oak and hickory pollen (*Quercus* and *Carya*). Other floodplain and swamp species include elm (*Ulmus*), ash (*Fraxinus*), willow (*Salix*), river birch (*Betula nigra*), and button bush (*Cephalanthus*). The floodplain pollen assemblage is similar to the cypress swamp pollen assemblage (a), with relatively high percentages of hickory and oak pollen. But in contrast to the cypress swamp surface pollen sample, *Taxodium* pollen and stomata are insignificant in the floodplain pollen sample, and sweet gum (*Liquidambar*), ash (*Fraxinus*), and willow (*Salix*) are absent or unimportant. Pine pollen percentages are relatively high (ca. 40%), but no pine stomata are present.

The mesic hardwood plant community samples (Fig. 6.3 (c) and (d)) are characterized by 15–50% oak (*Quercus*) and 5–10% hickory (*Carya*) pollen; few floodplain or swamp species are present. Sedge (Cyperaceae) and blueberry (Ericaceae) pollen appear relatively more abundant in these samples than at the other sites.

The disturbed oak woodland exhibits relatively high percentages of ragweed pollen (*Ambrosia*), a disturbance indicator, and considerable amounts of aster pollen (Asteraceae) and ferns *(Polypodium* type); cypress pollen is insignificant, and oak com-

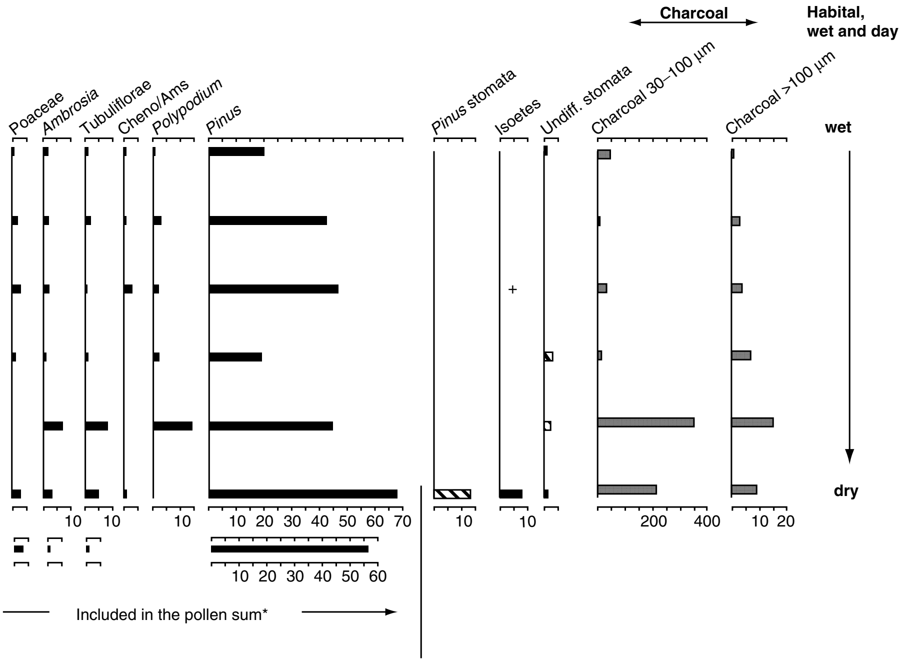


Figure 6.3 (*Continued*)

prises less than 20%. Other mesic hardwood and floodplain species are minimally present. Pine pollen is 40% of the pollen assemblage, but no pine stomata are present.

The driest site, the pine plantation, is characterized by high percentages of pine pollen (70%), very low percentages of oak (5%) and hickory (<3%) pollen and little or no pollen of floodplain species. Pine stomata are present (>10%). Whereas relatively high percentages of pine pollen are present in all surface samples (20–50%), pine stomata are only present in the pine plantation surface sample. Herbs, in particular grasses (Poaceae), asters (Asteraceae), and sedges (Cyperaceae), are well represented in the pollen assemblage from the disturbed site and pine plantation.

Charcoal percentages are highest in the pine plantation surface sample and the disturbed oak woodland (Fig. 6.3 (f)).

In general, the surface-sample pollen assemblages from the different plant communities reflect the vegetation present. The wettest sites had significant pollen percentages of ash (*Fraxinus*), river birch (*Betula*), elm (*Ulmus*), willow (*Salix*), and button bush (*Cephalanthus*), and the cypress swamp is further distinguished by significant percentages of bald cypress (*Taxodium* sp.), both pollen and stomata.

The surface samples from upland mesic hardwood forests have the highest percentages of oak and hickory pollen together. The most heavily disturbed sites, which are also the driest sites, exhibit the highest percentages of ragweed (*Ambrosia*) and asters (Asteraceae) and lower oak (*Quercus*) pollen percentages. Charcoal concentrations are highest in the most heavily disturbed plots. Overall, these data give us some criteria to separate wetland pollen assemblages from pollen assemblages of more mesic, xeric, and/or disturbed vegetation communities in the fossil pollen record.

6.5 Fossil Pollen Diagrams: Results and Discussions

The two test pits for which we will be presenting pollen profiles are both located within a 100 m^2 area of the Aucilla River. This is important to note when trying to identify regional and local pollen signals. A local pollen signal would be what is recorded in the surface samples (Fig. 6.3). An example is the difference between the cypress swamp with high percentages of cypress pollen and stomata and the mesic hardwood floodplain forest with little or no cypress pollen. Here hydrology determines the local presence or absence of bald cypress and thus its representation in the surface pollen record. A regional pollen signal would be replicated at Page-Ladson as well as at pollen sites 50–100 miles away (Figs. 6.1 and 6.7) When pollen diagrams exhibit similar age-constrained shifts at distant sites, one can assume a similar climate forcing mechanism for vegetation change. Pollen diagrams exhibiting dissimilar changes in the pollen record from sites lying in close proximity, such as Page-Ladson test pits, however, would more likely indicate local causes of vegetation change such as ground disturbance or hydrology.

6.5.1 Test F (Fig. 6.4)

The pollen diagram from Test F separates into three main pollen zones and two subzones based on changes in the pollen record. The basal sample from Unit 2 is #28 in pollen zone PLF-1 (14,800–14,000 ^{14}C BP) is dominated by goosefoot pollen (Chenopodiales, >40%) and prairie or dry forest taxa (sedges, grasses, and asters). Cypress, sycamore (*Platanus*), and oak pollen are present in low values. Lower Unit 3 pollen zone PLF-2a (12,500 ^{14}C BP) is characterized by a shift to mesic forest dominated by oak (*Quercus*), with hickory (*Carya*), maple (*Acer*), and basswood (*Tilia*). Floodplain species such as elm (*Ulmus*), hackberry (*Celtis*), and ash (*Fraxinus*) are also present. High percentages of cypress pollen and stomata characterize the lower part of zone PLF-2a and then decline or disappear in the upper portion. Charcoal presence is negligible and pollen concentrations decline from the base to the top of this zone.

Pollen zone PLF-2b from upper Unit 3 and the transition to Unit 4, between 12,400 and 12,300 ^{14}C BP, is characterized by high pollen percentages (20–30%) of ragweed (*Ambrosia*), corresponding to a decline in oak pollen percentages from ca. 45% to <25%. The basal sample, #22, from Unit 3 about 50 cm below the base of Unit 4, is somewhat anomalous in that, except for oak pollen, mesic upland and floodplain tree pollen is absent. Above level 22 in Unit 3, mesic tree pollen reappears and maintains a modest representation up to the upper zone boundary. During this depositional period, charcoal concentrations begin to increase, peaking in Units 4, 5, and 6. Ragweed (*Ambrosia*) pollen percentages decline in Unit 4.

Pollen concentrations are low in the basal samples of Unit 4, rise and peak in level 15, decline in levels 12 and 7, and peak again in samples from the surface of Unit 5, which harbors the major concentration of Early Archaic artifacts (e.g. Bolen points) and early Holocene faunal remains.

On the Bolen surface of Unit 5 (PLF-3), cypress and other mesic forest pollen percentages decline or disappear except for oak. Chenopodiales and Asteraceae pollen percentages peak, together with charcoal concentrations (sizes 30–100 µm) above Unit 5 and the Bolen surface. Degraded pollen, which can be symptomatic of erosion and reworked sediments, is significant both in the basal sample from Test pit F at the hiatus between Units 2 and 3 (PLF-1), and in the Bolen surface sediments, and above the hiatus between Units 5 and 6 (PLF-3).

6.5.2 Test F Discussion

Forty percent Chenopodiales (goosefoot and amaranth families) type pollen in the basal pollen sample of Unit 2 (PLF-1) of Test F indicates an environment radically different from today's. Surface pollen samples from vegetation communities near Page-Ladson consistently record low (<5%) Chenopodiales pollen. Although most Chenopodiales found in Florida now are aggressive weeds, some species are important components of salt flat communities bordering lake beds or marshes. Other pollen records from Florida link high percentages of Chenopodiales to periods of extreme aridity during full-glacial or glacial-like conditions (14,800–14,000 ^{14}C BP) or during the Holocene Hypsithermal period (Watts, 1969; Holloway, 1985). The high percentages of Chenopodiales pollen concentrations in Unit 2 correlate with the Heinrich 1 event in the North Atlantic (Chapter 5 by Dunbar). Lower sea level and shallower lakes may have provided additional habitat for Chenopodiales such as *Amaranthus australis*, a brackish-water taxon identified as present during the last glacial maximum at Mud Lake (Watts, 1969).

Modest percentages of cypress (*Taxodium*) pollen and stomata indicate that cypress trees were locally present, probably in the protected environment of the sinkhole basin. The dominance of goosefoot/amaranth pollen (Chenopodiales) and lack of mesic hardwood forest suggests that the climate was drier and probably cooler around 14,800–14,000 ^{14}C BP at Page-Ladson. This interpretation is consistent with other depictions of climate for north-central Florida during the pleniglacial between 18,000 and 13,000 ^{14}C BP (Watts and Stuiver, 1980; Watts *et al.*, 1992; Watts and Hansen, 1994).

At 12,500 ^{14}C BP in the base of stratigraphic Unit 3 cypress (*Taxodium*) pollen and stomate percentages peak and then decline as floodplain and mesic hardwood forest become more important. The expansion of mesic and floodplain hardwood forest suggests that temperatures and precipitation were increasing to present day levels. The

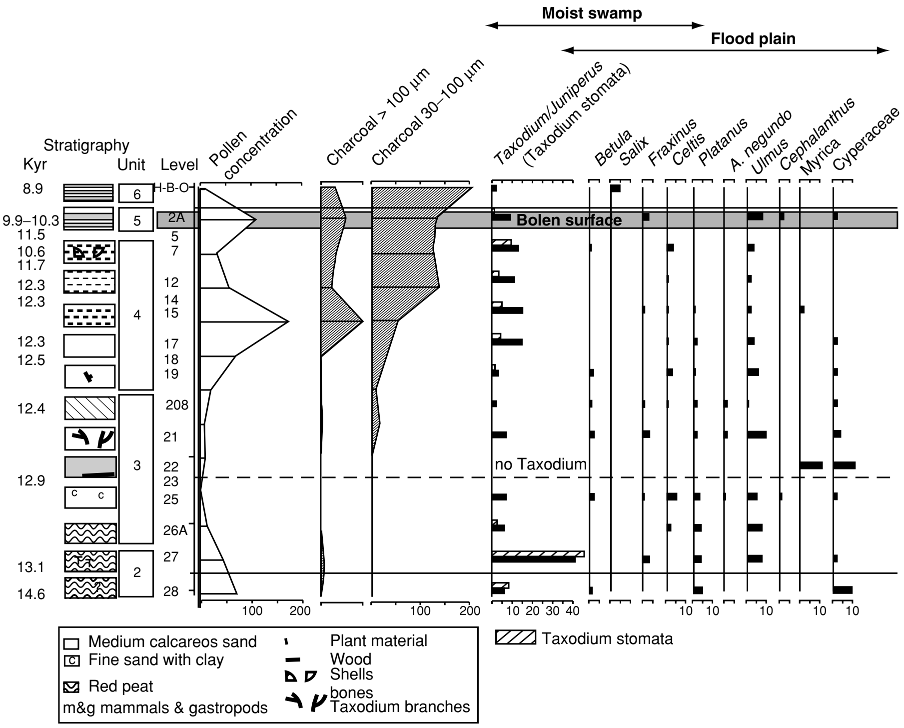


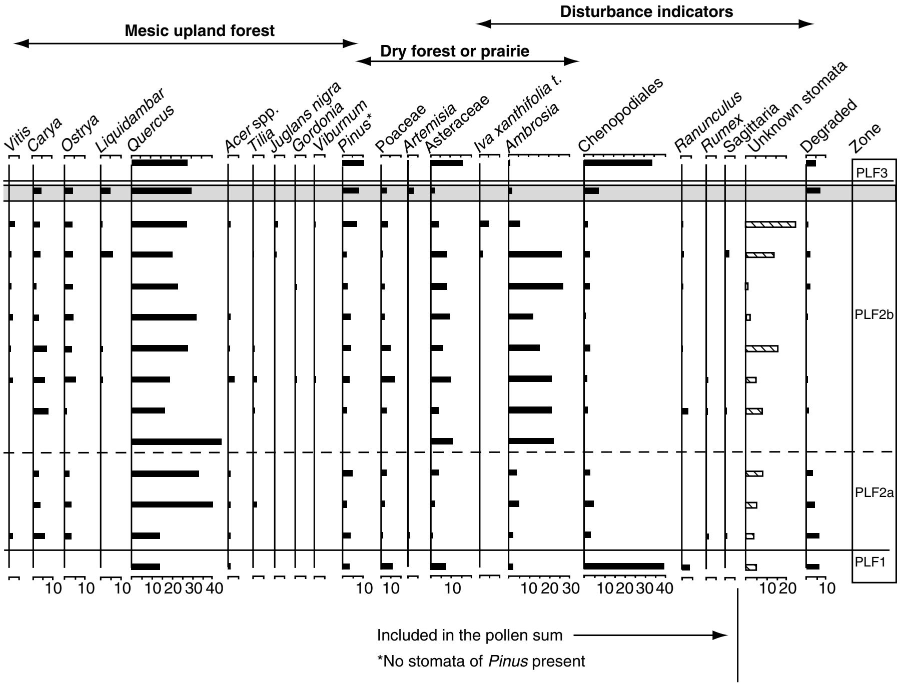
Figure 6.4 Pollen percentage diagram for Test pit F.

high percentages of cypress pollen and stomata at the base of this zone with subsequent decline are of hydrological interest.

From 12,500 to 12,300 ^{14}C BP ragweed (*Ambrosia*) pollen increases abruptly at the expense of oak, although other mesic hardwood forest elements continue unchanged.

Three species of ragweed, all of which are weedy invaders of disturbed sites, grow in the Florida panhandle today (Clewell, 1993). The highest percentages of ragweed pollen (5–10%) in the modern samples from the Page-Ladson area occur in the disturbed oak woodland. The coincident increase of ragweed pollen with the first clearly identifiable cultural remains and with proboscidian bones in Unit 3 suggests possible anthropogenic or large-animal disturbance of the landscape, rather than climate change between zone PLF-2a and PLF-2b. This issue will be addressed again during a comparison among Test F and other regional pollen diagrams later in the chapter.

Above Unit 3 charcoal concentrations increase, a phenomenon consistent with increased mesic forest and fuel for lightning-ignited fires. Charcoal is absent in Unit 2, but present at 18,400 ^{14}C BP in the form of charred cypress during the full-glacial.



Included in the pollen sum

*No stomata of *Pinus* present

Figure 6.4 (*Continued*)

Mesic forest is scant in Unit 2 at Page-Ladson. It is noteworthy that the highest concentrations of charcoal in the Page-Ladson surface samples occur in the disturbed oak woodland and in the pine plantation, the sites most subject to human interference. Therefore, anthropogenic sources for the increased charcoal present in Unit 3, pollen zone PLF-2b, cannot be ruled out. The charcoal increase is probably the result of both climatic and human ignition of fire during this time period.

Within the century between 10,000 and 9,900 ^{14}C BP, when the Bolen surface was exposed and then covered gently by the shelly silt of Unit 6L, mesic forest disappears (except for oak), Chenopodiales reach maximum levels, charcoal concentrations peak, and degraded pollen percentages increase. These data suggest drier conditions similar to the full-glacial and Heinrich 1. As precipitation diminished, areas of exposed mud expanded, and mesic forest and shrub disappeared; erosion of the sinkhole basin probably also increased as suggested by the increase in degraded pollen. The decline in ragweed (*Ambrosia*) prior to the Bolen concentration of artifacts suggests less disturbance around the sinkhole basin. Except for fire-tolerant oak, most mesic hardwood forest is absent at 9,900 ^{14}C BP. This represents a major vegetational and climatic change corresponding possibly with Meltwater Pulse 1B (Chapter 5 by Dunbar).

6.5.3 Test C (Fig. 6.5)

Three sections sampled in different parts of the enlarged Test C, including G(n), G(w) and H(w) (Fig. 6.5), exhibit a positive correlation among their respective pollen sequences. Pollen concentrations peak in the Bolen surface sediments at the top of

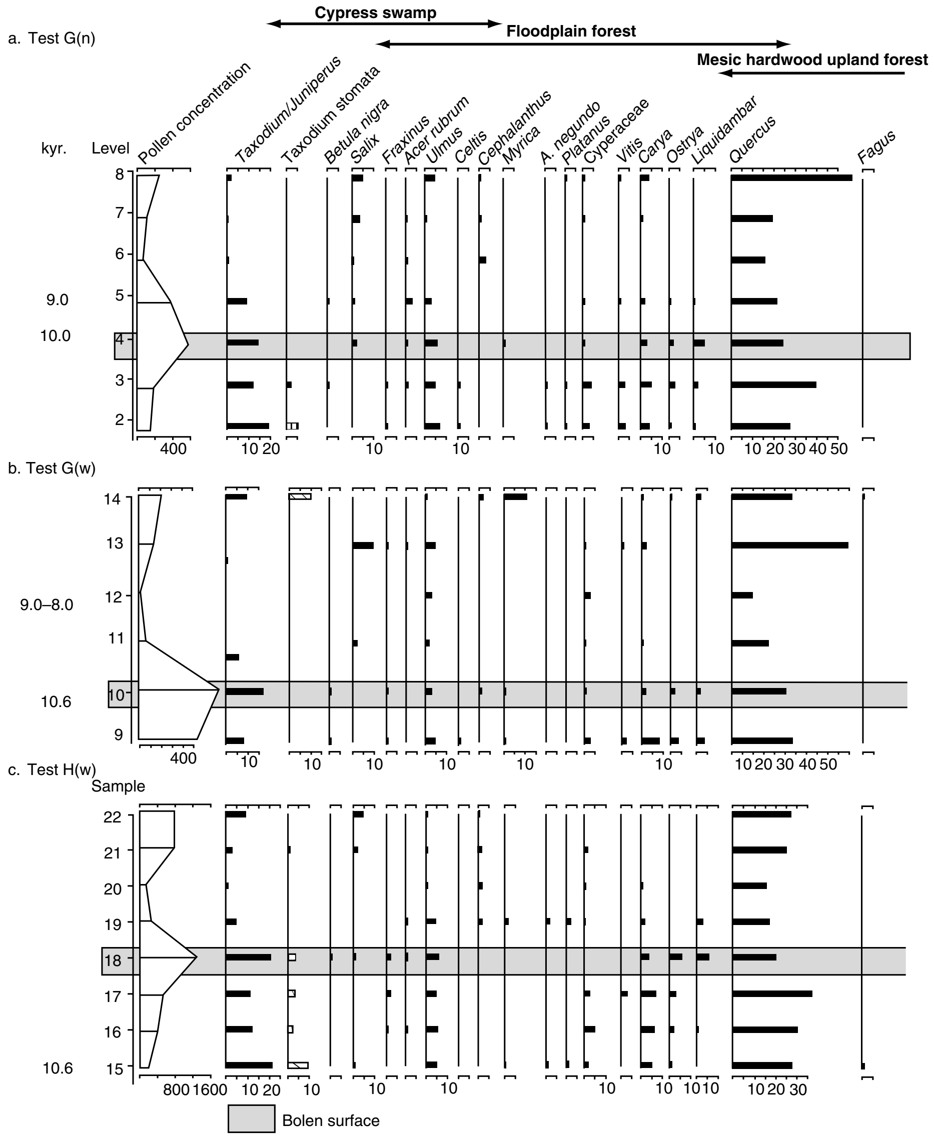


Figure 6.5 Select pollen percentages for sample taken from sections G(n), G(w), and H(w) from Test C.

Unit 5 and subsequently decline. Cypress (*Taxodium*) pollen is important prior to and in Unit 5, followed by a significant decline above the Bolen surface in all three sections. The stomata record for cypress (*Taxodium*) varies among three sample sequences (G(n), G(w), and H(w)). In test pit G(w) (Fig. 6.5), cypress stomata are present only in Unit 6L. Many mesic hardwood forest pollen types, e.g. walnut (*Juglans*), maple (*Acer* sp.), basswood (*Tilia*), occur below and on the Bolen surface sample, but then disappear above. Very little pine pollen is present pre- and post-Bolen period and no stomata of pine were present. Beginning at the time of the shelly silt of Unit 6, goosefoot (Chenopodiales) pollen increases and after 10,000 ^{14}C BP rises to

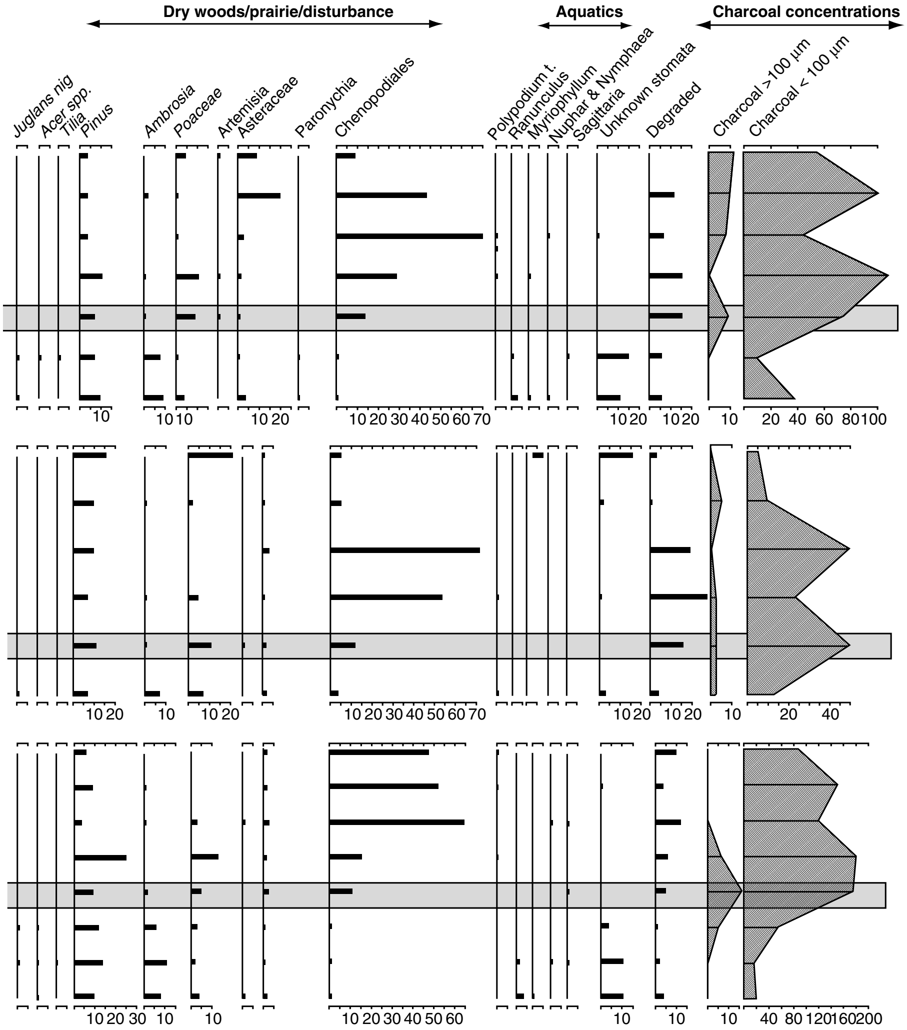


Figure 6.5 (*Continued*)

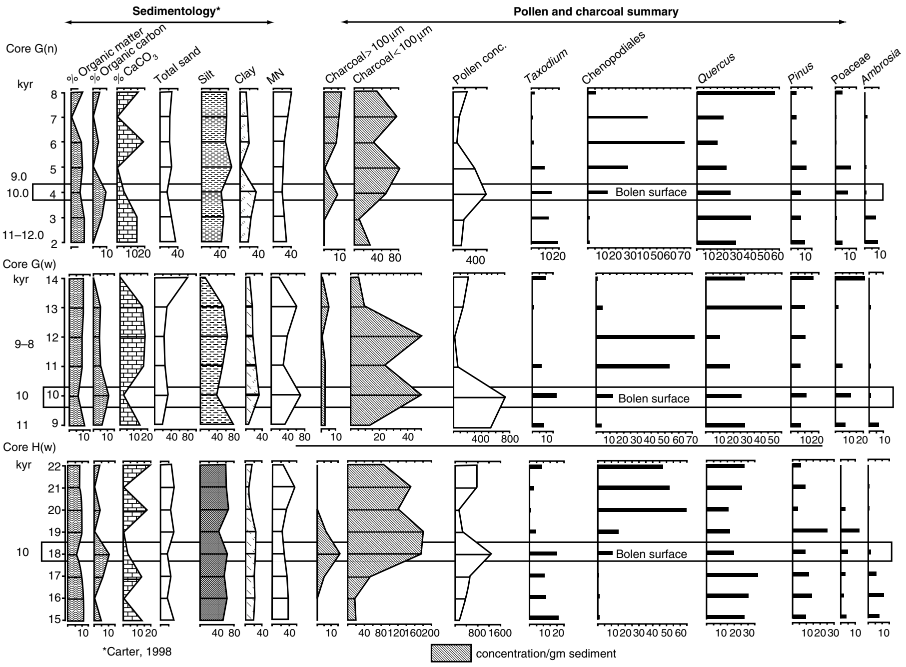
between 60% and 70% at the expense of all other taxa. Ragweed (*Ambrosia*) pollen percentages decline prior to the Bolen surface and remain low thereafter. Degraded or reworked pollen occurs in greater numbers in and above the Bolen surface, beginning at the hiatus between Units 5 and 6 and continuing within Unit 6. Charcoal fragments 30–100 µm in size peak in Bolen surface sediments in all three Test C sample sequences and remain high after 9900 ^{14}C BP. Concentrations of charcoal fragments >100 µm vary among the three sample sequences from Test C. Sediment analyses (see Chapter 18 by Carter and Dunbar) show minor variations among these sample sequences from Test C, but percent organic matter consistently drops off above the Bolen surface.

6.5.4 Test C Discussion

The synchroneity of the major changes, declining oak and cypress followed by an abrupt increase in goosefoot pollen among the pollen records for the three sections of enlarged Test C, namely G(n), G(w), and H(w) (Fig. 6.5), suggests that these three sites reflect the same overall local vegetation shifts. The pre-Bo1en pollen records from Units 3 through 5 generally resemble modern samples from mesic forest and cypress swamp, and therefore suggest that near-modern temperature and moisture regimes characterized the climate at Page-Ladson from about 12,500 to about 10,500 ^{14}C BP. Higher pollen percentages of the disturbance indicator, ragweed (*Ambrosia*), prior to the Bolen period could be the result of mastodon water hole activity, which had ceased by the Bolen period. This corresponds with increased aridity as indicated by expanding Chenopodiales and retreating mesic hardwood forest primarily oak (*Quercus*) and hickory (*Carya*). Cypress swampland contracts as well, but after the Bolen. Variations in the cypress stomate record confirm the demise of some trees as others survive in wetter areas of the Aucilla River region. Higher concentrations of the small charcoal fragments (30–100 µm) on the Bolen surface and above suggest that increased aridity may have affected the incidence of fire. Human contributions to this phenomenon may also be important, as suggested by the occurrence of fire hearths on the Bolen surface (Chapter 19 by Muniz and Hemmings).

6.6 Comparisons of Regional and Local Pollen Records (Fig. 6.7)

Among the pollen test samples from the Page-Ladson Site, there is a reasonable agreement as to late-glacial, pre- and post-Bolen period vegetation and climate. A moderate climate, not unlike that of today, fostered mesic forests in the southern Florida panhandle between about 12,500 and about 10,000 ^{14}C BP. Detailed hydrologic conditions varied among the test pit sites possibly due to channel shifts and changes in ground water levels. These varying hydrologic conditions, in turn, affected the character and extent of swamp and floodplain vegetation. Between about 10,600 and 9,900 ^{14}C BP temperatures rose, but precipitation declined affecting water balance in many of the lakes and sinkholes. At this time at Page-Ladson, sinkhole



*Carter, 1998

Figure 6.6 Summary diagram of selected sediment data, pollen percentages, and charcoal concentrations for sample sequences G(n&w) and H(w).

basin disturbance appears to decline, possibly as a consequence of the demise of the proboscidians resulting from the effects of heavy hunting pressure and declining forage. Conditions of aridity became extreme at Page-Ladson by 10,000–9,900 ^{14}C BP.

Elsewhere in Florida this same sequence of climatic change can be traced, albeit with some regional variations. At Lake Sheelar 130 miles east and south of Page-Ladson (Fig. 6.1), cold dry climatic conditions prevailed from 23,000 to 14,600 ^{14}C BP, according to the interpretation of a pine and herb-dominated pollen sequence (Fig. 6.6; Watts and Stuiver, 1980). This climatic assessment of early late-glacial conditions concurs with the implications of sample #28 (Unit 2) at Page-Ladson of colder, drier climate with the Chenopodiales-prairie dominated sample, dated between 14,800 and 14,000 ^{14}C BP. Sometime after 14,600 ^{14}C BP around Sheelar mesic forest emerged, similar to the forest expansion at 12,500 ^{14}C BP at Page-Ladson (Test pit F, zone 2 Fig. 6.4), indicating increased precipitation and warmer temperatures.

By 11,000 ^{14}C BP mesic forest had declined around Sheelar, replaced by pine, oak, and prairie (Sh-4) (Watts and Stuiver, 1980). The decline in mesic forest at Sheelar may precede the decline of mesic forest at Page-Ladson, but dates for this late-glacial portion of the Sheelar diagram may be too old (Watts, personal communication, 1999). Dates for Page-Ladson show some variation and inconsistency between 12,000 and 10,000 ^{14}C BP as well, consequently the exact timing of mesic

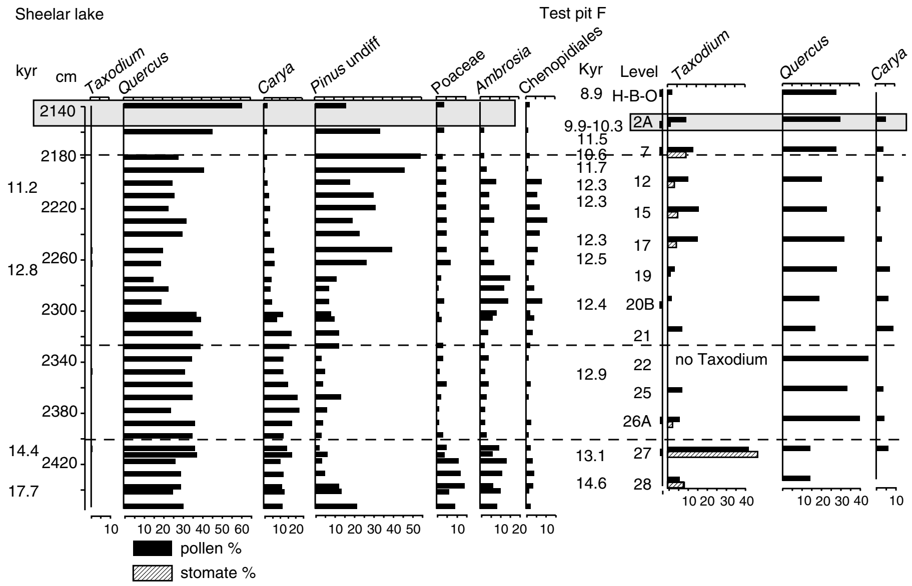


Figure 6.7 Selected pollen curves from Sheelar Lake (Watts and Stuiver, 1980), Test pit F, and Camel Lake Pond (Watts et al., 1982).

forest decline is somewhat problematical. A drier climate prevailed at Sheelar from 11,200 to 9,500 ^{14}C BP with an abundance of grasses (Poaceae), ragweed (*Ambrosia*), and goosefoot family members (Chenopodiales).

At Camel pond (Figs. 6.1 and 6.7), 60 miles north and west of Page-Ladson, pine and hickory (*Pinus* and *Carya*) dominate the forest between 14,000 and 12,600 ^{14}C BP, and spruce (*Picea*) is briefly present (Watts *et al.*, 1982). Cypress, ragweed, and grass are present, even if less than 5% each, throughout the late-glacial at this site. Cold, relatively moist conditions are inferred from the presence of spruce (*Picea*) at Camel pond (Watts *et al.*, 1982). Between 12,600 and 11,000 ^{14}C BP, oak (*Quercus*), beech (*Fagus*), and ironwood (*Ostrya*) expand in the upland forest as climate continued to moderate.

A hiatus in sediment deposition at Camel pond occurs between 10,900 and 7,800 ^{14}C BP. The sediment hiatus at Camel pond coincides with the expansion of Chenopodiales at Page-Ladson, suggesting a correlation with the inferred drier climate for Page-Ladson sometime after 10,500 ^{14}C BP.

The nearest other archeological sites with pollen records occur at Windover, near Titusville, Florida (Holloway, 1985), and Little Salt Springs, close to North Port, Florida (Brown and Cohen, 1985) (Fig. 6.1). The Windover pollen record is estimated to cover the time period from about 9000 years ago to the present and therefore cannot be correlated with the vegetation changes at Page-Ladson. However, of interest to the interpretation of the Page-Ladson sequence is the domination of the Windover pollen

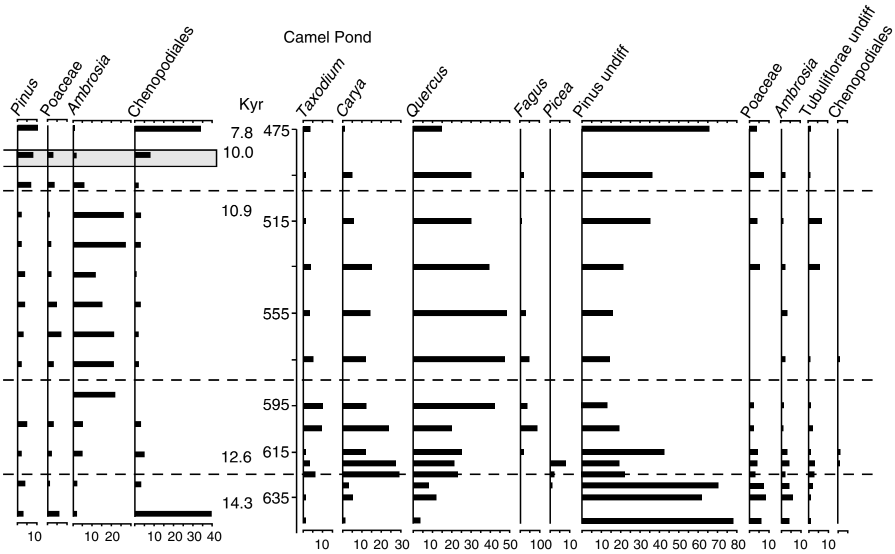


Figure 6.7 (*Continued*)

record by Chenopodiales between about 7000 and 4000 ^{14}C BP. This pollen assemblage is interpreted as a salt flat community resulting from drier climatic conditions associated with the Hypsithermal Climatic Interval, a warm dry period occurring during the Holocene (Holloway, 1985). This pollen assemblage resembles the post-Bolen pollen assemblages found at Page-Ladson (Figs. 6.4 and 6.7) and supports the interpretation of a warmer drier climate after 10,300 ^{14}C BP at Page-Ladson.

At Little Salt Spring (Fig. 6.1), a site in southern Florida, dry periods occurred prior to 9000 ^{14}C BP and again from 8000–to 5000 ^{14}C BP. The drier period prior to 9.0 ^{14}C BP may well correspond to the Page-Ladson post-Bolen arid climate. According to Brown and Cohen (1985) maximum human occupation tended to correspond with dry periods, when water was not readily available. At Page-Ladson, maximum disturbance of the sinkhole basin may have begun at 12.5 ^{14}C BP before the most extreme conditions of aridity set in. Depending upon the interpretation of the ragweed presence at Page-Ladson in Test F, human occupation and/or mastodon prevalence at Page-Ladson may have begun as early as 12.5 ^{14}C BP.

6.6.1 Charcoal Interpretation

Charcoal concentrations are highest in and above the Bolen surface sediments in sample sequences G(n), G(w), and H(w) (Fig. 6.6), at the time when the pollen record suggests a climate shift to increased aridity. But in Test F, charcoal is present shortly after

12.5 ^{14}C BP and increases up through the Bolen level at ca. 10.0 ^{14}C BP. High charcoal presence is generally associated with periods of expanded forest presence and therefore fuel. The triggering mechanism for increases in fire incidence appears to be climate aridity in the Test C sample sequences G(n), G(w), and H(w). At Test pit F, the earlier increase incidence of fire may be due to Paleoindian influence. Unfortunately, charcoal data are not available for the other regional pollen records referred to here which would help to sort out a regional climatic cause for fire from local and or anthropogenic cause.

In summary, prior to 14.6 ^{14}C BP a xeric prairie with scattered oak and extensive regions of salt flats dominated the area as cold dry conditions prevailed in the southern panhandle of Florida prior to the arrival of Paleoindians. With increasing temperatures and precipitation, mesic hardwood forest expanded in the area, and large animals such as mastodon sought out the rich vegetation and water afforded by the sinkhole and environs. By 12.5 ^{14}C BP Paleoindian populations began to follow the migration of mastodon and mammoth into the panhandle, where they congregated at available water sources such as the Page-Ladson sinkhole. Increases in human and animal activity around the sinkhole opened up the landscape to invasion of ragweed which peaked between 12.5 and about 10.6 ^{14}C BP. About 10.6 ^{14}C BP, temperatures reached their post-glacial maximum and water balance in the region's lakes and sinkholes became negative, causing mesic forest and cypress swamps to contract as open soil weeds and prairie covered much of the area, making subsistence a challenge. The dramatic shift to an arid environment at the time of the Bolen period at Page-Ladson suggests that a combination of hunting pressure and declining forage was responsible for the disappearance of the mastodon in the Florida panhandle.

References

Ammann, B. and Wick, L., 1993. Analysis of fossil stomata of conifers as indicators of the alpine tree line fluctuations during the Holocene. In Frenzel, B. (ed.), *Oscillations of the alpine and polar tree limits in the Holocene. Paläoklimaforschung* **9**: 175–185.

Brown, J.G. and Cohen, A.D., 1985. Palynologic and petrographic analyses of peat deposits, Little Salt Spring. NGR: 21–31.

Clark, R.L., 1982. Point count estimation of charcoal in pollen preparations and thin sections of sediment. *Pollen et spores* **24**: 523–535.

Clewell, A.F., 1993. *Guide to the vascular plants of the Florida Panhandle*. Florida State University Press, Tallahassee, 605 pp.

Cushing, E.J., 1993. *Psidium: pollen stratigraphy in diagrams imaged using Macintosh. Software program used for creating pollen and spore percentage diagrams.* Department of Ecology, University of Minnesota, St. Paul, Minnesota.

Davis, M.B. and Goodlett, J.C., 1960. Comparison of the present vegetation with pollen-spectra in surface samples from Browningion Pond, Vermont. *Ecology* **41**: 346–357.

Faegri, K. and Iversen, J., 1964. *Textbook of pollen analysis*, 2nd ed. Hafner publishing co., New York, NY, USA, 237 pp.

Hansen, B.C.S., 1995. Conifer stomate analysis as a paleoecological tool: an example from the Hudson Bay Lowlands. *Canadian Journal of Botany* **73**: 244–252.

Hansen, B.C.S., MacDonald, G.M., and Moser, K.A, 1996. Identifying the tundra-forest border in the stomate record: an analysis of lake surface samples from the Yellowknife area, Northwest Territories, Canada. *Canadian Journal of Botany* **74**: 796–800.

Holloway, R., 1985. Pollen analysis of Holocene sediments from a central Florida peat deposit, Report 8BR246.

MacDonald, G.M., Larsen, C.P.S., Szeicz, J.M., and Moser, K.A., 1991. The reconstruction of boreal forest fire history from lake sediments: a comparison of charcoal, pollen, sedimentological, and geochemical indices. *Quaternary Science Review* **10**: 53–71.

Myers, R.L. and Ewel, J.J., 1990. *Ecosystems of Florida*. University of Central Florida Press, Orlando, 765 pp.

Trautmann, W., 1953. Zur Unterscheidung fossiler Spaltöffnungen der mitteleuropäischen Coniferen. *Flora* **140**: 523–533.

Watts, W.A., 1969. A pollen diagram from Mud Lake, Marion County, north-central Florida. *Geological Society of America Bulletin* **80**: 631–642.

Watts, W.A. and Hansen, B.C.S., 1994. Pre-Holocene and Holocene pollen records of vegetation history from the Florida peninsula and their climatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* **109**: 163–176.

Watts, W.A. and Stuiver, M., 1980. Late Wisconsin climate of northern Florida and the origin of species-rich deciduous forest. *Science* **210**: 325–327.

Watts, W.A., Hansen, B.C.S., and Grimm, E.C., 1992. Camel Lake: a 40,000-year record of vegetational and forest history from northwest Florida. *Ecology* **73**: 1056–1066.

Wright, H.E., Jr., 1966. The use of surface samples in Quaternary pollen analysis. *Review of Palaeobotany and Palynology* **2**: 321–330.

Chapter 7

Paleoenvironmental Aspects of the Macrophytic Plant Assemblage from Page-Ladson

LEE A. NEWSOM
Pennsylvania State University

7.1 Introduction

In this chapter I describe paleobotanical remains from the Page-Ladson site and discuss the ecological relationships of the taxa identified to provide basic information about the vegetation communities that existed in and around the site during the various periods of site formation. The deposits and remains analyzed generally span the period of roughly 10,000 years, during approximately 18,000–8,000 yr BP (this volume, see Chapters 3 and 4). The paleobotanical data ultimately help to forward the reconstruction and our understanding of the paleoenvironmental aspects of the deposits, including the vegetation dynamics that were associated with climatic change in the transition from the late Pleistocene to the Holocene epoch. Macrophytic remains provide the basic data sets for this analysis, which involves study of the various types of macroscopic plant constituents of the deposits, most of which are visible without magnification. Among the specimens classified and analyzed are degraded (waterlogged) wood, carbonized wood, bark, thorns, seeds, fruits, leaves, and more. Together the information garnered from

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 181–211

this relatively rich data set provides complementary information to compare with the pollen analytical and other microbotanical data (Hansen, this volume).

When used in tandem, the micro- and macrobotanical data sets provide a more complete proxy record for the reconstruction of the late Quaternary paleoecology and environmental history of the Aucilla River area. In general, pollen and other plant microremains typically provide a regional-scale perspective on paleoenvironments due to the inherent nature of pollen dispersal, which typically occurs on a relatively broad scale due to dispersal by wind and water action. Thus palynology provides a regional and somewhat composite picture of paleoenvironments, although with certain limitations (e.g. some taxa have inherently low pollen profiles [see Hansen, this volume], and in forested settings filtering of pollen through dense woody vegetation may obscure the immediate area of study). The plant macroremain or macrophytic component, on the other hand, typically provides less of a regional view of vegetation but tends to yield finer-grained resolution of site/community level environmental details, that is, they typically describe the local ecology and microclimate. For example, the habitat zones of a pond or lake (e.g. profundal, limnetic, littoral, wetland [Fernald and Patten, 1984]) based on the characteristic vegetation of each zone, or the mosaic of forest taxa according to hydrology or other parameters, may be recognized on the basis of preserved seeds, wood, or other plant tissues. This is possible because macrophytic remains tend to be deposited in or near the immediate area of the parent plant due to their generally larger size and necessarily having a tighter range of dispersal by wind, faunal, and other dispersal agents. This is especially true of quiet, low-energy aquatic environments – as in the Aucilla River – where the seeds, fruits, wood, etc., from the aquatic and adjacent terrestrial vegetation settle in the wet bottom deposits where they become gently entombed and accumulate over time in the waterlogged, essentially anaerobic deposits where they may be preserved for extended periods. Understanding these benefits and differences in dispersal mode, range, and scale of environmental resolution is critical to the interpretation of macro- and microbotanical data sets and their potential to provide a detailed reconstruction of paleoenvironments.

The Page-Ladson site formed in an ancient sinkhole in the Aucilla River, which is part of a freshwater spring and stream ecosystem located in northwest Florida, bordering Jefferson, Taylor, and Madison counties (Fernald and Patten, 1984:218–232). Physiographically, the Aucilla transcends the western region of the Tallahassee Hills and traverses through the Gulf Coastal Lowlands to Coastal Swamp at the Gulf Coast; elevations run from sea level or nearly so in the coastal swamps, lowlands, and river valleys to over 200 feet above sea level in the Tallahassee Hills and the area is generally characterized by limestone karstic topography (Fernald and Patten, 1984:221–222). The soils are predominantly classified as Utisols in the hill region and Spodosols in the lowlands (Fernald and Patten, 1983:58). The climate is classified as humid subtropical, with average annual temperatures of around 68–72°F and annual precipitation of around 56 in. (1422 mm). A rainfall maximum generally occurs during the summer months, whereas the spring is typically the period when droughts of varying intensity and severity may occur, which on average happens once every eight to ten years (Fernald and Patten, 1984:222).

The modern vegetation in the vicinity of the site is predominantly comprised of hardwood-dominated bluff, bottomland, and swamp forest associations. The forested floodplains of the Aucilla and its tributary Wacissa River are extensive: 10,930 and 14,647 acres, respectively (Fernald and Patten, 1983:94). This provides for a strong presence of the bottomland hardwood ecological community, which is characterized by a high diversity of hardwoods and is best developed and typical of the floodplains of the river systems of northwest Florida (USDA Soil Conservation Service, 1985 and 1989:108; Ewel, 1990). The annual moisture regime is a critical factor in perpetuating this plant community, where the relatively rapid rise of water levels during seasonal flooding events, but with little or no inundation during the growing season, is followed by quick receding of floodwaters. The retention of floodwater in depressional areas within the alluvial floodplain results in the development of associated swamp hardwoods forest.

The floristic composition of the Ochlockonee River valley (Clewell, 1980), just west of the Aucilla River system, provides a good proxy for that of the Aucilla River to portray some of the microclimatic aspects and related details of the bottomland and adjacent forest habitats. On the highest elevations, specifically the uplands adjacent to the river bluffs, grows the longleaf pine-turkey oak (*Pinus palustrus*, *Quercus laevis*) forest with an open understory of post oak (*Q. stellata*) and Ericaceae (shrubs in the blueberry family). The bluff rim is primarily vegetated in laurel oak (*Q. hemisphaerica*) and mockernut hickory (*Carya tomentosa*). White oak (*Q. alba*) predominates on the upper slopes, and southern magnolia (*Magnolia grandiflora*) and beech (*Fagus grandiflora*) occur prominently on the lower slopes. Other trees found generally on the slopes are spruce pine (*P. glabra*), southern sugar maple (*Acer saccharum*), wild olive (*Osmanthus* sp.), flowering dogwood (*Cornus florida*), American holly (*Ilex opaca*), pignut hickory (*C. glabra*), basswood (*Tilia* spp.), sweetgum (*Liquidambar styraciflua*), and white ash (*Fraxinus americana*). The primary vegetation of the Tallahassee Hills is the magnolia–beech community, which is essentially the same bluff forest described here.

The floodplain vegetation on higher, better-drained soils is similar to that of the bluff slopes, but common includes also swamp-chestnut oak (also known as basket oak, *Q. michauxii*). Lower, wetter sites demonstrate a predominance of water hickory (*C. aquatica*), overcup oak (also known as water white oak, *Q. lyrata*), diamond leaf oak (*Q. laurifolia*), red maple (*Acer rubrum*), ironwood (*Carpinus caroliniana*), American elm (*Ulmus americana*), green ash (*F. pennsylvanica*), pop ash (also known as Carolina ash, *F. caroliniana*), and sweetgum. Still wetter, low areas include and may be dominated by water tupelo (*Nyssa aquatica*) and cypress (bald cypress, *Taxodium distichum*). The river banks are frequently bordered by Ogeechee-tupelo (*N. ogeche*) and river birch (*Betula nigra*), and this woody riparian vegetation typically also includes willow (*Salix* sp.), wild rose (*Rosa palustris*), and stiff-cornell (also known as swamp dogwood, *Cornus foemina*).

The Coastal Lowlands mentioned above, away from the river floodplain, bluffs, and higher terrain of the Tallahassee Hills are primarily vegetated in pine flatwoods, including several species of pine, some oaks, and in the low acid swamps very commonly are found cypress, black gum (*Nyssa sylvatica*), wax myrtle (*Myrica* spp.), possum haw (also known as swamp haw, *Viburnum nudum*), and titi (*Cyrilla racemiflora*).

This study uses the macrophytic component of the deposits at Page-Ladson to examine various aspects of the paleoenvironment and paleoecology in and around the sinkhole/river, particularly as these data compare with the palynological study (Hansen, this volume). Macrophytic specimens from the site include many that derive from plants associated with the aquatic environment of the sinkhole and river and the herbaceous growth of the encircling wet ground, but the emphasis here is placed on those items that are representative of the surrounding terrestrial vegetation, particularly arboreal taxa – trees and shrubs – but also including lianas (woody vines), ramblers, and climbers (herbaceous vines). This direction was pursued because the terrestrial vegetation has the greatest potential to illuminate changes in vegetation associated with the different time periods encompassed by the site, particularly the Pleistocene–Holocene transition. Secondly, sample recovery procedures over the course of several years of excavations at the site were changed and adapted to fulfill specific project goals, and the resulting collections are necessarily uneven in terms of analytical comparisons, a combination of course-versus fine-scale recovery methods having been variously employed during different field seasons. Placing emphasis on wood, seeds, and other plant materials from trees and other woody taxa (versus some of the smaller to very fine specimens from most herbaceous, including aquatic taxa) made for more equivalency between the total assemblage of samples thus facilitating comparison across all temporal and special units.

7.2 Sampling Methods and Analysis

The samples of plant remains incorporated in this analysis derive from separate excavation units, designated variously as either "Test Pits" (I and II) or "Test Units" (A, B, C, D, D′, E, E′, F, and G [see Chapters 1 and 3]). Test Units A and B were excavated in 1984–1985. Test Unit C was initially opened up in 1987, but was sampled for plant remains during a 1988 field season. Test Units D, D′, E, and E′ were excavated and sampled in 1987–1988. Finally, a more extensive excavation designated Test Unit F, from which a larger number of samples were recovered, was conducted in 1991 and again in 1997, at which time also Test Unit G was excavated and sampled. The Test F and G excavations concentrated in particular on distinctive sandy calcarenites deposits containing large volumes of woody organic debris. These strata were emphasized to recover samples to test the hypothesis that the unique composition of the organic-rich material was largely due to deposition of dung from large mammals, e.g. American mastodon (see Newsom and Mihlbachler, this volume). Test Pits I and II were excavated in 1988 and 1992, and the samples recovered were exclusively specimens that appear to have been humanly modified (that is, wood specimens with definitive or potential evidence for cultural modification).

Earlier excavations at the site – all those prior to the Test F and G excavations in the 1990s – were excavated and sampled according to several distinctive strata or "zones" that were recognized during excavation, compared and traced across the site. These individual zones were designated A through E, with E in deepest stratigraphic position and roughly attributed to the late Pleistocene, D essentially to the Pleistocene–Holocene transition, C to the early–middle Holocene, and Zones B and A to later Holocene and recent deposition. The basic sedimentary matrix of these various strata ranges very generally from woody peat and organic-rich clays, to calcareous sandy clays with high volumes of the coarse organics mentioned above, to predominantly quartz sands with lower organic content in more superficial levels.

With the exception of Test Units A and D, and the uppermost Zone A from throughout the excavations, virtually all of the excavations and their associated strata were sampled in one form or another for the presence of macrophytic specimens. Sample collection entailed three types of procedures: (1) *in situ* collection of items as they were encountered and observed during excavation; (2) direct collections, basically grab samples, of material captured in the excavation screens (1/4 in. mesh opening); and (3) bulk sediment samples collected and bagged as volumetric samples underwater and ranging from 0.5 to 2 l. The sediment samples were randomly collected, basically as a record of individual units and strata during the initial years of excavations. A systematic sampling procedure was carried out beginning with the Test F excavations in 1991; in this case four volumetric samples were recovered from each quadrant of each level of the excavations units comprising Test F. During the subsequent work in this area (Tests F and G, 1997), the direct sampling from the excavation screens was resumed.

The laboratory procedures followed to analyze the samples entailed direct examination of all specimens contained in the first two types of sample, that is, sorting the sample constituents according to basic categories – seeds, leaves, wood, bark, etc. – followed by identification of seeds and similar specimens under magnification using a dissecting microscope. Wood specimens were processed and analyzed according to the procedures described below. The bulk sediment samples were processed according to the following procedures: first the sample volumes were measured and recorded, then each sample was gently water sieved through a nested sieve series with mesh openings of 4, 2, 1, and 0.42 mm to partition the remains into standard size categories that facilitate sorting and analysis, and finally each subfraction was examined under magnification as described above to sort and identify the botanical constituents.

All seeds and similar remains were classified and identified using identification manuals, comparative specimens, and relevant floras (Martin and Barkley, 1961; Radford *et al.*, 1968; Hitchcock, 1971; Landers and Johnnson, 1976; Godfrey and Wooten, 1981; Nelson, 1994, 1996; Wunderlin, 1998). All degraded (waterlogged) wood specimens were prepared for analysis by removing ultra-thin sections from three specific dimensions (cross, radial, and tangential planes) by free-hand sectioning with a microtome blade, then mounting the sections on glass slides in glycerin and observing and documenting the anatomical structure with the aid of a compound microscope. Charcoal specimens were prepared by fracturing the specimens along the three anatomical planes, after which the cell structure was observed and recorded using a dissecting microscope with enhanced magnification. All wood specimens were identified using anatomical keys (Record and Hess, 1942–1948; Urling and Smith, 1953; Panshin and deZeeuw, 1980; Wheeler *et al*., 1986) and comparative specimens.

7.3 Results

7.3.1 Test Units A and B (1984–1985)

Ten samples from these excavation units were analyzed for their macrophytic content, including nine that were collected *in situ* or directly from the excavation screens (Table 7.1), and one bulk sediment sample (FS 9A, 500 ml [Table 7.2]). Zones E (tan-marl, "lower Zone E sediment") and D ("lime sand") are the deepest and oldest of the stratigraphic units sampled by these excavations. Plant specimens from these two lower strata consisted of single segments of oak (*Quercus* sp.) wood assigned to the red/black wood anatomical group (e.g. *Q. falcata*, *Q. laevis*, *Q. nigra*). The specimen from Zone E exhibited relatively narrow growth increments, which are indicative of stressful growth conditions resulting, for example, from strong variation in available moisture (e.g. extended drought conditions or conversely, flooding).

Zone C deposits include some stratigraphic partitioning according to differences in the sedimentary composition, designated levels 8, 9, 10a, b, c, and 11. The deeper levels 9–11 were initially described as the "Bolen-peat" or "Bolen-beveled horizon" (and level 9 was sometimes also described as the "gray clay" or "mulberry clay" [Tables 7.1 and 7.2]), whereas level 8 was termed the "antler-flaker zone". These descriptors for the strata were in recognition of the presence of human activity by the time these units formed, based on material culture evidence, and particularly modified lithics. Five *in situ* or screen samples (levels 8–11 [Table 7.1]) and one bulk sample (level 8) were recovered from this stratum.

A wood identification from a combined level 10–11 sample (FS 54, Table 7.1) demonstrates the continued presence at the site of oak assigned to the red/black anatomical group. This specimen, which was radiocarbon dated to 9730+/–120 BP (BETA – rest of date information), was partially charred and like the oak from the deeper strata, exhibited very narrow growth increments. Two samples were recovered from the overlying level 9 clayey peat (FS 44 and 45, Table 7.1) containing the following: partially charred and carbonized fragments of wood identified as red mulberry (*Morus rubra*), hickory nut specimens indicative of two species, e.g. water hickory (*Carya aquatica*) and pignut hickory (*C. glabra*), oak (*Quercus* sp.) acorn hull fragments, a sweetgum (*Liquidambar styraciflua*) fruit, and an unidentified insect gall (e.g. oak gall).

The three level 8 samples from near the top of Zone C ("antler-flaker zone" [Tables 7.1 and 7.2]) show further continuity of the red/black-group oak wood (FS 9, a sample of log from the west wall of Test Unit B, and a charcoal fragment from FS 41); however, acorns from these samples provide evidence for the presence of one or more additional oak species that are classified taxonomically with the "white" oaks.

Table 7.1 Macrophytic identifications of items in samples from Page-Ladson recovered in situ or from excavation screens (grab samples)

- FS 39, Level 6 “Archaic level” (west wall trimming of slumping profile) (grab sample)
  - *Carya* sp., cf. *C. aquatica* (2 nuts, whole)
  - *Carya* sp., cf. *C. glabra* (2 nutshell halves)
  - *Diospyros virginiana* (fruit exocarp and 1 seed)
  - *Fagus* sp. (involucre valve)
  - *Quercus* sp., cf. *Q. alba/michauxii* (acorn involucre)
  - *Sabal palmetto* (1 seed)
  - *Taxodium* sp. (wood)
  - Insect gall (cf. oak gall)

Zone C, “antler-flaker/mulberry clay/Bolen-Beveled horizon”

- FS 9 “antler-flaker zone” (Zone C, level 8) (*in situ* sample)
  - *Quercus* sp., red/black anatomical group (wood sample from log in west wall of unit)
- FS 41 “antler-flaker zone” (Zone C, level 8) (grab sample from 1 × 1 m pedestal in northwest corner of unit)
  - *Carya* sp. (6 nutshells)
  - *Carya* sp. (wood, carbonized, very narrow growth increments)
  - *Fagus* sp. (1 involucre valve)
  - *Fraxinus* sp., cf. *F. caroliniana* (wood, degraded)
  - cf. *Osmanthus* sp. (= Taxon 6, possibly *Franklinia* sp.; 3 seeds)
  - *Liquidambar styraciflua* (2 distorted fruits)
  - *Pinus* sp., section diploxylon, taeda anatomical group (wood, carbonized)
  - *Prunus* sp., cf. *P. angustifolia* (wild plum morphotype, 2 whole seeds)
  - *Quercus lyrata* (acorn with attached involucre)
  - *Quercus alba/michauxii* (2 acorns, 2 involucres)
  - *Quercus* sp. (aborted acorn)
  - *Quercus* sp., red/black anatomical group (wood, carbonized)
  - *Taxodium* sp. (3 cone scales)
  - *Taxodium* sp. (wood, carbonized)
  - Miscellaneous unidentified bark fragments
- FS 44 “Bolen-peat level” (Zone C, level 9) (*in situ* sample)
  - *Morus rubra* (red mulberry) (wood, charred)
- FS 45 “gray clay between antler-flaker and Bolen levels” (Zone C, level 9, “same as FS 44”) (grab sample)
  - *Carya* spp., cf. *C. aquatica* and cf. *C. glabra* (5 nuts indicating two morphotypes)
  - *Liquidambar styraciflua* (fruit)
  - *Morus rubra* (wood, carbonized)
  - *Quercus* sp. (acorn hull fragment)
  - Insect gall
- FS 54 “Bolen-peat level” (Zone C, levels 10b, 10c, 11 [bottom of Zone C]) (*in situ* sample from 1 × 1 m pedestal in NW corner of unit)
- *Quercus* sp., red/black anatomical group (wood, charred, with very narrow growth increments) (C14 9730+/−120)

Zone D, “lime sand”

- FS 48 “bottom of gray marl ‘Bolo-stone level’ [later called “lime sand”] (*in situ* sample)
  - *Quercus* sp., red/black-oak anatomical group (wood, degraded)

Zone E, “lower Zone E sediment”

- FS 49 “tan-marl zone, bottom of pit; NW corner of pit at 4.1 m below top of test pit” (*in situ* sample)
  - *Quercus* sp., red/black anatomical group, very narrow growth increments (wood, degraded)

Azonal

- FS 32 “general pit cleaning” (grab sample)
  - *Carya* sp. (3 nutshell fragments)
  - *Juglans nigra* (1 whole nut)
  - *Quercus* sp. (acorn, cracked but whole)
  - *Quercus* sp., white anatomical group (wood, carbonized)

(*Continued*)

Table 7.1 Macrophytic identifications of items in samples from Page-Ladson recovered in situ or from excavation screens (grab samples)—(*Continued*)

Test C (1988)
Zone A, "Deptford redeposited level"

Zone C, "Bolen/Clay B"
FS 60 "wood samples from clay over surface ("the dirt") below red ..." "Bolen level" "Clay B, level 2a" (Zone C)
  Carya sp., true anatomical group (wood stake from branch or young stem [heartwood] lacking, growth rings have pronounced curvature/arc)
FS 63 "wood samples from clay over surface ("the dirt") below red ..." "Bolen level" "Clay B, level 2a" (Zone C-upper portion)
  Quercus sp., cf. *Q. alba/michauxii* (acorn involucre)
  Salix sp., cf. *S. caroliniana* (4 degraded wood)
  Taxodium sp. (3 degraded wood, 2 exhibit compression wood anatomy)
  Ulmus sp., cf. *U. Americana* (1 degraded wood)
  Vitis sp. (1 long section of vine, broken into fragments)
  Miscellaneous unidentified bark (6 fragments)
  Miscellaneous unidentified small-diameter wood, knots (52 fragments)
FS 63 "wood samples from 'dirt surface' and at yellow clay/brown clay" "Clay B, level 2b" (Zone C-lower portion)
  Acer sp., soft anatomical group, cf. *A. rubrum* (1 wood, carbonized)
  Carpinus caroliniana (1 wood, degraded)
  Carya sp., true anatomical group (1 wood carbonized)
  Taxodium sp. (5 degraded wood, 2 with narrow growth increments and 1 exhibiting compression wood and wound tissue; 18 fragments of charcoal)
  Vitis sp. (1 wood, degraded)
  Miscellaneous unidentified bark (6 fragments)
  Miscellaneous unidentified small-diameter wood, knots (40 fragments, most appear to be *Taxodium* sp.)
FS 69 "wood in the dirt" (= "Bolen peat")
  Quercus sp. (1 degraded wood, anatomical characteristics of root wood)
  Taxodium sp. (7 degraded wood, 2 conform anatomically to aerial root, i.e. cypress "knee")
  Bark fragment, cf. hardwood (e.g. *Carya* or *Quercus* sp.)
  Miscellaneous unidentified small-diameter wood (20+ fragments, most appear to be *Taxodium* sp.) and 2 knots
FS 110 "Unit C-north expansion, Bolen level" (*in situ* sample)
  Quercus sp. (1 wood, degraded)
  Taxodium sp. (1 wood, degraded, plus additional specimens identified macroscopically)
FS 112 "Unit C-south expansion, Bolen level" (*in situ* sample)
  Quercus sp., (5 fragments, growth increments uniformly [all specimens] very narrow) unidentified bark fragment

Zone D, "upper colluviums" "mid-colluviums/lime-sand facies" "calcareous marl"
FS # (no number) "Test C, lower clay core; wood at 4 feet below top of clay" (*in situ* sample)
  Quercus sp., white oak anatomical group (wood, degraded)
FS # (no number) "Shell-marl zone 'tree'" (*in situ* sample)
  Quercus sp., white oak anatomical group (wood, degraded)

Test E (1987)
Zone E, "cypress forest"
FS 84 "upper 40 cm of 'swamp forest' clay" (grab sample)
  Acer sp., hard anatomical group (2 degraded wood, broken into four fragments)
  Carya sp., cf. *C. aquatica* (4 nutshell fragments)
  cf. *Gleditsia* sp. (1 robust thorn)
  Prunus sp., wild plum morphotype (1 seed)
  Taxodium sp. (6 cone scales)

Taxodium sp. (3 degraded wood, including a cypress knee and two samples with compression wood anatomy, one of which is flat and one entire side is charred or blackened; 1 fragment of carbonized wood)
Miscellaneous unidentified plant remains (twigs, bark, 3 insect galls)

Test E′
Zone E
FS 81 (one large fragment of wood) (*in situ* sample)
  Taxodium sp. (degraded wood with very narrow growth increments)
FS 87 "shell and wood" (grab sample)
  Taxodium sp. (wood, degraded)
  Unidentified bark

Test F, 97–1 (1997) (dung-bearing strata) (grab samples)
FS 08 "F-979-1/SE e.t." (8C)
  Carya sp. (1/2 nutshell)
  Coryleus sp., cf. *C. americana* (3 whole nuts, 2 of which have portions sheared off, also 1 nutshell fragment)
  Crataegus sp. (3 seeds)
  cf. *Osmanthus* sp. (= Taxon 6, possibly *Franklinia* sp.; 1 whole and 1 half seed, whole specimen has circular divit sheared from surface)
  Quercus sp. (1 whole acorn, heavily compressed)
  Vitis sp. (2 seeds, 4 tendril fragments)
  Xanthium sp. (3 whole and 1 fragmentary burr)
  cf. *Xanthium* (= Taxon 1; 1 seed)
  Unidentified seed Taxon 7 (1 whole specimen)
  Unidentified robust thorn (cf. *Gleditsia, Crataegus* sp.), 3.3 cm long (1 whole specimen)
  Unidentified insect gall (1 total)
FS 22 "F-97-1, gray sand with straw" (22C)
  Carya sp. (1 nutshell half and 3 nutshell fragments)
  Coryleus sp., cf. *C. americana* (2 whole nuts, one of which is flattened, and 4 nutshell fragments that probably equal one original nut)
  Quercus sp., cf. *Q. nigra/laurifolia* (4 acorn halves)
  Taxodium sp.
  Vitis sp. (1 seed fragment and 1 Vitaceae vine tendril)
  Xanthium sp. (2 fruits/burrs, one of which is whole, the other a proximal end fragment)
FS 29 "F-97-1" (29C)
  Coryleus sp., cf. *C. americana* (2 whole nuts)
  cf. *Xanthium* sp. (= Taxon 1; 1 whole seed)
FS 58 "F-97-1, straw mat" (58C)
  Taxodium sp. (3 cone scale fragments)
  Unidentified fruit (1 specimen)
  Unidentified fungi spore mass (e.g. wood-rotting fungi) (1 mass)
FS 86 "F-97-1, straw mat, lime sand" (86C)
  Carya sp. (a 1/2 and a 1/4 nutshell fragment, plus 4 smaller fragments)
  Coryleus sp., cf. *C. americana* (4 whole nuts, one had distal end sheared away, another is cracked)
  Crataegus sp. (1 seed)
  Prunus sp., wild plum morphotype (1 seed)
  Vitaceae (1 tendril fragment)
FS 90 "F-97-1/NE, straw mat, lime sand" (90C)
  Carya sp. (1 nutshell half, small, possibly immature)
  cf. *Osmanthus* sp. (= Taxon 6, possibly *Franklinia* sp.; 1 half seed)
FS 92 "F-97-1/NE" (92C)
  Carya sp. (2 nutshell halves, small specimens, possibly immature)
  Coryleus sp., cf. *C. americana* (1 nutshell fragment)

(*Continued*)

Table 7.1 Macrophytic identifications of items in samples from Page-Ladson recovered in situ or from excavation screens (grab samples)—(*Continued*)

  - cf. *Osmanthus* sp. (= Taxon 6, possibly *Franklinia* sp.; 1 seed)
  - *Vitis* sp. (1 seed)
  - Unidentified insect gall
- FS 94 “F-97-1/NE, straw mat” (94C)
  - *Carya* sp. (1 exocarp or ‘husk’ fragment)
  - *Quercus lyrata* (1 acorn with involucre)
- FS 102 “F-97-1/SE, straw mat and lime sand”
  - *Quercus* sp. (1 acorn, compressed, with portion of involucre still attached)
  - Vitaceae (2 seeds)
- FS 129 “F-97-1/NW (129C)
  - *Prunus* sp., wild plum morphotype (2 seeds)
  - *Vitis* sp. (1 seed)
  - Unidentified seed Taxon 6 (1 half seed)
- FS 132 “F-97-1/SE” (132C)
  - *Fagus* sp. (1 whole nut)
  - *Nuphar lutea* (1 seed)
  - Vitaceae (1 seed)
  - Unidentified insect gall (2 total)
- FS 135 “F-97-1/NW” (135C)
  - *Carya* sp. (1 nutshell, possibly immature specimen)
  - *Crataegus* sp. (1 seed)
  - cf. Cyperaceae (2 seeds, Taxon 4)
  - Vitaceae (4 seeds)
  - Unidentified insect gall (1 total)
- FS 196 “F-97-1, straw mat” (196C)
  - *Carya* sp. (one-third nutshell, small, possibly immature specimen)
  - *Coryleus* sp., cf. *C. americana* (2 whole nuts, both compressed and with circular divits sheared off of shell)
  - *Crataegus* sp. (1 seed)
  - *Prunus* sp., wild plum morphotype (2 seeds)
  - *Vitis* sp. (1 seed)
  - Unidentified insect gall (1 total)
- FS 203 “F-97-1/NE”
  - cf. Cyperaceae (2 seeds representing two morphotypes = Taxon 2 and Taxon 4)
  - *Carpinus caroliniana* (1 seed)
  - *Fagus* sp. (1 involucre)
  - cf. *Liquidambar styraciflua* (1 seed)
  - *Phytolacca americana* (1 seed)
  - cf. *Tilia* sp. (1 seed)
  - Vitaceae (two seeds)
  - cf. *Xanthium* (1 seed, Taxon 1)

Test F, 97–2 (1997) (dung-bearing strata) (grab samples)

- FS 78 “F-97-2/NE” (78C)
  - *Carya* sp. (1 whole immature nut)
  - *Rhynchospora* sp., cf. *R. corniculata*, *R. inundata* (1 whole seed)
- FS 82 “F-97-2/NE” (82C)
  - *Carya* sp. (4 small, possibly immature nuts)
  - cf. Cyperaceae (1 seed, Taxon 4)
  - *Coryleus* sp., cf. *C. americana* (3 nuts)
  - *Prunus* sp., wild plum morphotype (1 seed)
  - *Taxodium* sp. (1 cone scale)

FS 83 "F-97-2/NE area" (83C)
- *Taxodium* sp. (1 cone scale)
- *Vitis* sp. (1 seed)
- Unidentified insect gall (1 total)

FS 100 "F-97-2/SE"
- *Cucurbita* sp. (1 seed; see Newsom and Mihlbachler, this volume, for complete information on the distribution of *Cucurbita* sp. seeds from this site)
- cf. Cyperaceae (1 seed, Taxon 4)
- *Prunus* sp., wild plum morphotype (1 seed)
- Vitaceae (1 seed)

FS 110 "F-97-2/NE, straw mat" (110C)
- Vitaceae (5 seeds and 2 tendril fragments)
- Unidentified basal section of stout thorn or woody peduncle (2 specimens)
- Unidentified insect galls (2 total)

FS 114 "F-97-2/SE, straw mat"
- cf. *Malus* sp. (1 seed)
- *Quercus* sp., cf. *Q. alba/michauxii* (1/2 acorn)
- *Quercus* sp., cf. *Q. nigra/laurifolia* (1 acorn, flattened)
- *Quercus* sp. (1 involucre fragment)
- Vitaceae (1 seed)
- Unidentified insect galls (2 total)

FS 125 "F-97-1, straw mat" (125C)
- *Cucurbita* sp. (1 rind fragment with distal blossom scar; see Newsom and Mihlbachler, this volume, for complete information on the distribution of *Cucurbita* sp. seeds from this site)
- cf. *Maclura* sp. (2 whole seeds, Taxon 8)
- *Nuphar lutea* (1 seed)
- *Prunus* sp., wild plum morphotype (1 seed)
- Vitaceae (2 seeds)

Test G (1997)

FS 73 "level 2" (73C) (grab sample)
- *Prunus* sp., wild plum morphotype (1 seed)
- *Xanthium* sp. (3 whole burrs, all compressed)

Miscellaneous culturally modified wood

1) 1988 FS 95, Test Pit I, one 25-cm long, 2.5-cm diameter roundwood segment, and one adzed chip ca. 3.5 × 5 × 1 cm (both *Taxodium* sp.)
2) 1988 FS 99, Test Pit II, radially split (down center line) segment with pointed end showing facet marks (*Taxodium* sp.)
3) 1988 FS 105A, radial segment with end facets and visible adze marks (*Taxodium* sp.)
4) 1988 FS 105A, possibly worked piece of roundwood with apparently beveled end and indentations along length (*Taxodium* sp.; specimen may goes with above)
5) 1992 vertical post/stake from and penetrating beneath Bolen levels (*Taxodium* sp. – specimen was to be radiocarbon dated
6) 1992 large hollow (dugout canoe-like) bole segment (*Taxodium* sp.), ca. "10,000-yr-old levels" (specimen may simply have been a fallen tree with a naturally rotted and blackened, hollow interior)

Table 7.2 Bulk sediment samples from Page-Ladson

Test B (1985)

Zone C, "mulberry clay/Bolen-Beveled horizon"

FS 9A "antler-flaker zone" (Zone C, level 8) (peat sample, 500 ml)
- *Carex* sp. (1 seed)
- *Cephalanthus occidentalis* (4 seeds)
- cf. Fabaceae (1 seed, 1.5 mm long; possibly *Rhus copallina* of Anacardiaceae)

(*Continued*)

Table 7.2 Bulk sediment samples from Page-Ladson—(Continued)

- *Nuphar lutea* (1 seed)
- *Quercus* sp., (acorn fragments; one whole aborted acorn)
- *Rubus* sp. (1 seed)
- *Sabal palmetto* (2 seeds)
- *Taxodium* sp. (25 cone scales)
- Vitaceae (1 seed)
- 4 mm fraction fine wood (twigs, miscellaneous, 67 total)
- Leaves, cf. *Quercus* sp. (8 total fragments)
- Miscellaneous unidentified plant materials (bark fragments, galls, buds)

Test C (1988)

Zone D, “upper colluviums” “mid-colluviums/lime-sand facies” “calcareous marl”
FS 131 “lime sand” (2 liter bulk sample)

- *Berchemia scandens* (5 seeds)
- Betulaceae, cone scale, cf. *Alnus* sp. or *Betula* sp. (1 specimen)
- *Brasenia schreberi* (15 seeds)
- *Carex* sp., cf. *C. gigantea* (3 seeds)
- *Carpinus caroliniana* (5 seeds)
- cf. *Cephalanthus occidentalis* (3 degraded wood, twig size)
- *Ceratophyllum* sp., cf. *C. demersum* (24 seeds)
- *Cornus* sp. (2 seeds)
- *Coryleus* sp., cf. *C. americana* (13 nut shell fragments)
- *Crataegus* spp. (11 seeds, two morphotypes may suggest 2 species)
- *Cucurbita* sp. (2 seed fragments)
- Cucurbitaceae, cf. *Melothria* sp. (9 seeds)
- *Cyperus* sp. (1 seed)
- cf. Fabaceae (2 seeds; possibly *Rhus copallina* of Anacardiaceae, same as above)
- *Fagus* sp. (2 involucre valves)
- *Liquidambar styraciflua* (1 seed)
- *Phytolacca americana* (4 seeds)
- *Polygonum* sp. (4 seeds)
- *Quercus* sp. (2 acorn fragments)
- cf. *Salix* sp. (1 degraded wood, twig size)
- *Scirpus* sp. (1 seed)
- cf. *Scleria* sp. (1 seed)
- *Taxodium* sp. (109 cone scales)
- *Taxodium* sp. (4 degraded wood, twig size)
- *Viburnum* sp., cf. *V. prunifolium* (10 seeds)
- *Vitis* sp. (19 seeds and 28 tendril fragments)
- Unidentified robust thorn, cf. *Crataegus* or *Gleditsia* (three total)
- Unidentified seeds (47 total, most appear to be Cyperaceae)
- Miscellaneous unidentified plant remains (buds, bark, insect galls)
- Possible insect egg case; beetle wing; fish scales (2)

Test D′ (1987)
Zone D, “lime sand”
FS 73 “lime sand sample, Pleistocene strata; upper strata of test D′” (bulk sample, 550 ml)

- *Brasenia schreberi* (2 seeds)
- *Carex* spp., cf. *C. gigantea* and *C. joorii* (9 seeds, representing 2 morphotypes)
- *Carpinus caroliniana* (4 seeds)
- *Carya* sp. (4 nutshell fragments)
- *Ceratophyllum* sp., cf. *C. demersum* (35 seeds)
- *Coryleus* sp., cf. *C. americana* (4 nutshell fragments)
- *Crataegus* sp. (7 seeds)

cf. Fabaceae (68 seeds; possibly *Rhus copallina* of Anacardiaceae, same as above)
Fraxinus sp., cf. *F. caroliniana* (1 degraded wood)
Nuphar lutea (3 seeds)
Poaceae (1 seed)
Polygonum spp. (13 seeds, representing 2 morphotypes)
Quercus sp. (5 mature acorn fragments, 2 involucre fragments, 6 aborted acorns)
Rubus sp. (1 seed)
Scirpus sp. (4 seeds)
Sparganum sp. (1 seed)
Taxodium sp. (76 cone scales, one may be carbonized)
Taxodium sp. (2 fragments degraded wood)
Viburnum sp., cf. *V. prunifolium* (1 seed)
Vitis sp. (19 seed, one may be carbonized)
Robust thorn, *Crataegus* sp. or *Gleditsia* sp. (6 total)
Unidentified bark (1 fragment)
Miscellaneous unidentified plant materials (galls, buds, seeds [11])

Test E (1987)
Zone E, “cypress forest”
FS 77 “forest” (1 liter bulk sample)
Amaranthaceae (5 seeds)
Brasenia schreberi (2 seeds)
Carpinus caroliniana (10 seeds)
Carex sp., cf. *C. gigantea* (9 seeds)
Carex sp., cf. *C. joorii* (5 seeds)
Cephalanthus occidentalis (4 seeds)
Ceratophyllum sp., cf. *C. demersum* (1 seed)
Cornus sp., cf. *C. amomum* (4 seeds)
Coryleus sp., cf. *C. americanum* (2 fragments nutshell)
Crataegus spp. (12 seeds, possibly two morphotypes or species)
Cyperaceae (9 seeds)
Decodon verticillatus (1 seed)
cf. Fabaceae (112 seeds; possibly *Rhus copallina* of Anacardiaceae, same as above)
Fagus sp. (2 involucre valves)
cf. *Hydrolea* sp. (*H. corymbosa*) (5 seeds)
cf. *Iris* sp. (2 seeds)
cf. *Myrica cerifera* (2 seeds)
Nuphar lutea (1 seed)
Polygonum sp. (3 seeds)
cf. *Potamogeton* sp. (*P. nutans*) (1 seed)
Prunus sp., wild plum morphotype (1/2 seed)
Quercus sp. (1 aborted acorn)
cf. *Rubus* sp. (2 seeds)
Sparganum sp. (4 seeds)
Taxodium sp. (91 cone scales)
Taxodium sp. (2 degraded wood, one a flattened segment of mature branch/stem, the other a small branch fragment)
Vitis sp. (1 seed)
Robust thorn, cf. *Gleditsia* sp. (19 total)
Unidentified seeds or fruits (26 specimens)
Unidentified insect galls (37)

These include overcup oak (*Quercus lyrata*) and relatively large specimens that could belong to either white oak (*Q. alba*) or swamp chestnut oak (*Q. michauxii*). Small underdeveloped (aborted) acorns were also present in the samples (Tables 7.1 and 7.2). Additional wood and fruit identifications from level 8 include hickory (*Carya* sp., nutshells and wood), sweetgum, and several other taxa that were not identified from the underlying strata of these test units. The latter include seven additional arboreal (trees and shrubs) genera, specifically buttonbush (*Cephalanthus occidentalis*), American beech (*Fagus* sp.), ash (*Fraxinus* sp., cf. Carolina ash, *F. caroliniana*), pine (*Pinus* sp.), wild plum (*Prunus* sp.), cabbage palm (*Sabal palmetto*), and cypress (*Taxodium* sp., cone scales and wood), and provisionally identified wild olive (cf. *Osmanthus* sp., possibly *Franklinia* sp.). The last identification is of particular interest because an alternative assignment and potentially better identification for the taxon is the genus *Franklinia* sp. (Theaceae), a tree species that no longer occurs in Florida (present range is southern Georgia [Elias, 1980:430–431]). Also identified for the first time in these units were grape family (Vitaceae, woody vines or lianas), blackberry (*Rubus* sp., a thorny rambler), Fabaceae, and two aquatic or damp-ground herbs, i.e. spatterdock (*Nuphar lutea*, also know as yellow pond-lily; a member of the water lily family with floating or emerged leaves) and sedge (*Carex* sp.).

One screen sample was recovered from the next superior level, Zone B of Test Unit B (FS 39, level 6, "Archaic level" [Table 7.1]), resulting in the identification of seven taxa and an insect gall. These demonstrate the continued presence of some of the Zone C taxa, including the two types of hickory, beech, white-type oak acorns, cabbage palm, and cypress. Persimmon (*Diospyros virginiana*) was exclusively identified from this particular stratum of Test Unit B, but there is one additional specimen from the site, recovered with the Test F samples described below.

There are no data to report (no samples) for the stratigraphically most superior deposit, Zone A; however, one additional sample was recovered from Test Unit B (FS 32 [Table 7.1]). The sample was a loose collection of plant remains generally from the floor/walls of the excavation unit and included hickory nut and acorn fragments, oak wood belonging to the white oak anatomical group (potentially the same as either the overcup or white-type acorns mentioned above), and one whole black walnut (*Juglans nigra*), the latter is the sole record for walnut from the site.

7.3.1.1 Summary and Conclusions for Units A and B

The data are too few to specify much about the deepest levels (Zones D and E) of these excavation units, aside from noting the presence of red/black-type oak. On the other hand, numerous well-preserved plant specimens from the Zones B and C deposits demonstrate that a rich mesic forest was well established at the site by the time those strata formed, one very much mirroring the slope, floodplain, and swamp forest described above from the Ochlockonee basin. Collectively the plant identifications provide a strong signature for bottomland and swamp forest communities (Table 7.3) with so many of the associated trees and shrub taxa recorded, including at least three species of oak, the two species of hickory, beech, ash, cabbage palm, red mulberry, sweetgum, buttonbush, cypress, wild olive (cf.), and perhaps also black walnut. Persimmon and wild plum are generally associated with drier, upland habitats; however, they are both "pioneer" species, thus they frequently appear in disturbed locations, taking advantage of openings in the forest/tree canopy and so may also directly reflect the local forest community. It is important to note that some of the apparent initial records for given taxa – i.e. their first recorded appearance in Zones B or C of these excavation units – may be misleading. At least some of these same taxa occurred earlier, based on data from other excavation units at the site, as will become clear in succeeding sections of this chapter.

Also noteworthy are several carbonized wood specimens from Zones B and C of the excavation. The burned taxa include red/black-type oak, white-type oak, red mulberry, and pine, and they may represent additional evidence of human activity by this period. The possibility exists that specimens were carbonized by natural fire events, but the fact that the seeds, fruits/nuts, and galls found in same deposits are not carbonized, suggests that the burning was not due to natural random fires but represents human collection of fuel wood, the remnants of which subsequently washed into the sinkhole deposits from adjacent terrestrial encampments.

7.3.2 Test C (1987–1988)

This excavation unit was more intensively sampled than Units A and B, with several screen and bulk sediment samples collected from each of the depositional zones. The deepest deposits sampled for macrophytic remains are those designated collectively (in this case) Zone D – variously "upper colluviums" "mid-colluviums/lime-sand facies" "calcareous marl" "straw mat" (Tables 7.1 and 7.2). Two *in situ* recovered specimens of wood were identified to the white oak anatomical group (Table 7.1). Two bulk sediment samples were analyzed from this particular deposit, FS 119 (Table 7.2) and 131 (Table 7.2); the latter sample revealed a range of taxa. Arboreal taxa that are consistent with those identified from the 1985 excavation units, and so demonstrate greater time depth for each, include beech (*Fagus* sp.), sweetgum (*Liquidambar styraciflua*), oak (*Quercus* sp.), cypress (*Taxodium* sp.), and buttonbush (cf. *Cephalanthus occidentalis*, in this case provisionally identified due to insufficient preservation of the cell structure). Additional arboreal taxa from this Test C excavation/deposit that were not recorded from the 1985 excavation units include: ironwood (*Carpinus carolina*), swamp dogwood (*Cornus* sp.), American hazelnut (*Coryleus* sp., cf. *C. americana*), hawthorn (*Crataegus* spp.), provisionally identified willow (cf. *Salix* sp.), and black haw (*Viburnum* sp., cf. *V. prunifolium*). The provisional identification of *Viburnum* to the species *V. prunifolium* is based on seed identifications – the individual specimens being very strongly matched by the morphological characteristics – however this particular species does not occur in Florida (the current range is Georgia, Alabama, Tennessee Virginia, and West Virginia [Radford *et al.*, 1968:994]). This suggests that either *V. prunifolium*'s range formerly included Florida, or that the match is superficial given that identifications based strictly on morphology can be prone to error or are sometimes

Table 7.3 Plant community associations for Page-Ladson arboreal taxa[1]

Taxon (+ = present; X = characteristic)	*Coastal strand*	*Salt marsh*	*Mangrove swamp*	*Sand pine scrub*	*Longleaf pine-turkey oak hills*	*Mixed hardwood, pine*	*Flatwoods (various)*	*Cutthroat seeps*	*Cabbage palm hammocks*	*Tropical hammocks*	*Oak hammocks*	*Upland hardwood hammocks*	*Wetland hardwood hammocks*	*Bottomland hardwoods*	*Swamp hardwoods*	*Cypress swamp and scrub cypress*	*Shrub bogs, bay swamps*	*Pitcher plant bogs*	*Sawgrass marsh*	*Freshwater marsh*	*Slough*
Acer sp., soft, cf. *A. rubrum*, red maple						+						+	X	+	X	X	+	+			
Acer sp., hard, cf. *A. saccharum*, sugar													+								
Berchemia scandens, rattan vine												+	+	+							
Betulaceae (*Alnus/Betula*, alder/birch)												X									
Carpinus caroliniana, ironwood						+						X	+	X							
Carya (*aquatica*), water hickory												+	X	+							
Carya (*glabra*), pignut hickory					+	X						X									
Cephalanthus occidentalis, buttonbush	+	X												+	X	+	+		+	+	
Coryleus (americana), hazelnut[2]																					
Cornus foemina, swamp dogwood													+	+	+						

Crataegus spp., hawthorn		+	+	X	+		+		+	X	X	+	+		+				
Diospyros virginiana, persimmon		+	+	X	+				+	+	+	+	+						
Fagus grandiflora, American beech				X						X	+								
Fraxinus (*caroliniana*), bottomland ash												X	+	+					
cf. *Gleditsia aquatica*, water locust													+						
Juglans nigra, black walnut				+															
Liquidambar styraciflua, sweetgum				+						+	X	X	+	+					
cf. Maclura pomifera, Osage orange^2																			
cf. *Malus angustifolia*, crab apple				+															
Morus rubra, red mulberry																			
cf. *Myrica* sp.,				+			+	+		+	+	+	+						
wax myrtle	+			+	X	X	X	+	+	+	X	+	+	X	+	X	+	+	+
cf. *Osmanthus* sp., wild olive		+		+						+									
Pinus sp., subsection *taeda*, pine	+	+	+	+	+	+		+		+	+	+	+	+	+	+			
Prunus sp., wild plum type	+		+	+	+					+									
Quercus sp., red/black group				+			+		+	+	+	+	+						
Quercus (*alba/michauxii*), white oaks				X						+	+	+							

(*Continued*)

Table 7.3 Plant community associations for Page-Ladson arboreal taxa[1]*—(Continued)*

Taxon (+ = present; X = characteristic)	*Coastal strand*	*Salt marsh*	*Mangrove swamp*	*Sand pine scrub*	*Longleaf pine-turkey oak hills*	*Mixed hardwood, pine*	*Flatwoods (various)*	*Cutthroat seeps*	*Cabbage palm hammocks*	*Tropical hammocks*	*Oak hammocks*	*Upland hardwood hammocks*	*Wetland hardwood hammocks*	*Bottomland hardwoods*	*Swamp hardwoods*	*Cypress swamp and scrub cypress*	*Shrub bogs, bay swamps*	*Pitcher plant bogs*	*Sawgrass marsh*	*Freshwater marsh*	*Slough*
Quercus lyrata, overcup oak														+							
Sabal palmetto, cabbage palm	X					+	+	+	X	+	+	+	X	+	+	+					
Salix (*caroliniana*), willow													+		+	X	+		+	+	
Taxodium sp., cypress/bald cypress													+	+	+	X					
cf. *Tilia* sp., basswood					+							+	+								
Ulmus (*americana*), American elm												+		X	+						
Viburnum (*prunifolium*), black haw[2]						+						+	+	+	+		+				
Vitis sp., wild grape	+			+	+	X	+		+	+	+	X	X	X	+		+				
Total taxa	6	1	0	6	6	19	7	3	6	5	6	20	20	23	20	9	8	3	3	3	1
Total characteristic taxa (only)	1	1	0	0	0	6	1	1	2	0	0	5	6	7	2	4	0	1	0	0	0

[1] Including lianas; based on USDA Soil Conservation Service (1981, revised 1989). *Twenty-six Ecological Communities of Florida*.

[2] *Coryleus* and *Maclura* do not exist in the modern flora of Florida; their present ranges include piedmont and mountains of Ga., Ala., Miss., Tenn., Ky., Va., W. Va.; *Coryleus* spp. and *Maclura pomifera* habitats: "rich woods" and "alluvial pastures or fencerows at widely scattered localities", respectively (Radford *et al*., 1968:367, 391). The identification of *Viburnum* provisionally to the species *V. prunifolium* is based on seed identifications; this particular species does not presently occur in Florida; however, other species do and it is possible that one of the native species is the correct identification; the habitat information above is based on that of the native taxa.

misleading, in which case the correct identification may be one of the native species, e.g. *V. acerifolium* (mapleleaf viburnum, bluff forests, central and western panhandle region) (Radford *et al.*, 1968:993–995; Wunderlin, 1998:584–585). Similarly, another potential range discrepancy concerns hazelnut, *Coryleus* spp., which is definitively identified, the individual specimens from this test unit as well as others from Test F (described below) being largely intact and very well preserved. This genus does not presently occur in Florida (the current range is Alabama, Georgia, Mississippi, Tennessee, Kentucky, Virginia, and West Virginia [Radford *et al.*, 1968:366–367]; and see Table 7.3), and so its presence at the site requires some explanation (discussed below).

The presence of at least two more arboreal taxa is tentatively inferred from a small cone-like scale (Betulaceae, *Alnus* sp. or *Betula* sp.) and robust thorns from either hawthorn or more probably locust (*Gleditsia* sp.). Lianas, trailing plants or climbers include rattan vine (*Berchemia scandens*), wild grape (*Vitis* sp.), wild gourd (*Cucurbita* sp., cf. *C. pepo*), and provisionally identified creeping cucumber (*Melothria* sp.). The presence of wild gourd, like hazelnut and possibly black haw, requires further consideration of the biogeographic dynamics, as discussed below, because it is evidently extinct from the modern flora of Florida, and at Page-Ladson its distribution appears to have been restricted to Zone D and earlier deposits.

Herbaceous taxa from FS 131 include a number of wetland or aquatic herbs: watershield (*Brasenia*) and coontail (*Ceratophyllum*) as aquatics, and sedge (*Carex*), sedge/nutgrass (*Cyperus*), smartweed/knotweed (*Polygonum*), bulrush (*Scirpus*), nutrush (*Scleria*), and unidentified sedge family (Cyperaceae), as damp-ground taxa. Pokeweed (*Phytolacca americana*) and perhaps the specimens assigned cf. Fabaceae are generally indicative of open, drier habitats.

Zone C (“Bolen level” “Bolen clay B” “the dirt” “zone C bottom”) samples from Test Unit C include six screen or *in situ* and two bulk sediment samples from three basic levels or sublayers (Tables 7.1 and 7.2). Samples from the deepest, i.e. Bolen level (“Bolen peat”, as in previously described Zone C), include FS 69 as well as FS 110 and 112 from north and south expansions of the unit, and are wood samples. The identifications are consistent with the Zone C samples from the 1985 excavation Units A and B, including oak and cypress wood, some of the former likewise with narrow growth increments, and individual specimens of both woods exhibited root wood anatomy (e.g. cypress “knee” [Table 7.1]) .

Situated above the “Bolen peat” was a level 2 “Clay B” that the excavators designated as two subunits, levels 2a and 2b (screen or *in situ* samples only [Table 7.1]). Identified arboreal taxa include some of the same as earlier indicated for the underlying Zone D and/or the 1985 Zone C deposits in addition to some unique taxa. From level 2b were identified ironwood, hickory (belonging to the true hickory wood anatomical group, e.g. pignut hickory), cypress, and wild grape, as well as maple (*Acer* sp.) of the soft maple anatomical group (e.g. red maple, *A. rubrum*), which represented a first record for this particular genus. From level 2a were identified white-type oak, willow, cypress, wild grape vine, and elm (*Ulmus* sp., cf. *U. americana*, American elm), the latter being another first and sole record. One additional wood specimen from Zone C level 2a appears to have been a wooden stake or shaft manufactured from a branch or (more likely) young stem/bole of hickory (true anatomical group, e.g. pignut hickory). More superficial Zones A and B were not sampled in excavation Unit C.

7.3.2.1 Summary and Conclusions for Unit C

The samples from this excavation provide considerable detail about the vegetation present during the formation of the strata designated Zones C and D due to the presence of abundant, well-preserved plant remains. Unfortunately comparable data are lacking for Zone E (the deepest peat deposits) or the more superficial deposits in this location. Nevertheless the information for the intervening Zones C and D make it clear that bottomland/swamp forest was present, much the same as was recognized from Test Units A and B described above. Three taxa exclusive to Zone D – hazelnut, wild gourd, and black haw – are particularly noteworthy because they do not exist as part of the modern flora of the state. It is possible that all three were typical components of the flora of this part of Florida prior to and during the time when the Zone D deposits formed. Indeed, there is an earlier record for the gourd genus from another location on the Aucilla River (Latvis-Simpson site, ca. 31,000 years before present [Newsom laboratory data]), and hazelnut pollen dating between 1.0 and 1.5 million years old was indentified from the Leisey Shell Pit near Tampa Bay (Rich and Newsom 1995). The subsequent disappearance of these plants from the area may be explained by climate change and the biogeographic flux and repositioning of plant communities that occurred in the transition from the Pleistocene to Holocene conditions. However, an alternative hypothesis is that the plants were present in this particular location either directly or indirectly as the result of megamammals that frequented the area during this period. In particular American mastodon may have been an influence resulting in the presence of the three taxa (and this almost certainly accounts for the superabundance of distinctive cypress twigs in these deposits; see Newsom and Mihlbachler, this volume).

Zone C samples also suggest external causes for the presence of certain plant specimens apart from natural tree rain, but in this case rather than mastodons, the samples from this unit/zone may provide further evidence of human activities. As was observed for Units A and B, the Zone C deposit in Test C again revealed the presence of carbonized woods and likewise, no seeds or other remains show signs of having been burned. Charcoal and charred wood from this test unit/level include maple, hickory, and cypress. In addition, one possible wooden artifact was recovered, the hickory stake/shaft from level 2a. It should be pointed out that additional specimens of culturally modified wood were recovered from test pits designated I and II that were excavated in 1988 and during brief work at the site in 1992. These are summarized at the end of Table 7.1, but include five adzed shaft-like roundwood segments made of cypress, two of which have shaped, pointed ends, and one adzed cypress wood chip (wood debitage). One of the stake/shaft specimens (number 5 under miscellaneous culturally modified wood, Table 7.1) was found *in situ* in vertical position in and penetrating beneath the Bolen levels; this specimen was radiocarbon dated (8,905+1–65

BP [AA–7454]). Finally, large hollow cypress trunk may superficially resemble a dugout canoe, though this possibility remains.

7.3.3 Test Units D′, E, and E′ (1987)

The samples analyzed from these units include screen, *in situ*, and bulk sediment samples (Tables 7.1 and 7.2; no samples from Unit D). These samples provide the most detailed information of all the test units and samples analyzed concerning the relatively deep peat stratum E ("cypress forest" "swamp forest clay"). Arboreal taxa identified from Tests E and E′ at this level (FS 77, 81, 84, 87) include maple (*Acer* sp.) of the hard maple wood anatomical group, which is unique to this unit/stratum, as well as ironwood, hickory, buttonbush, dogwood (e.g. swamp dogwood, *C. foemina/amomum*), hazelnut, hawthorn, beech, provisionally identified wax myrtle (*Myrica* sp., a unique record for the site), wild plum, oak, cypress, and robust thorn, e.g. *Gleditsia* sp., as in Zone D of excavation Unit C. The cypress remains include cone scales and wood; the latter includes a specimen of stem/branch with narrow growth rings, a fragment of carbonized wood (charcoal), a specimen of root/knee, and four segments of branch wood (2 exhibiting compression wood), one of which is charred or blackened (by fungal activity) down the length of one side.

Also identified were wild grape (one seed), and a number of wetland or aquatic herbs. Among these are watershield, coontail, water willow (*Decodon verticillatus*), spatterdock, bur-reed (*Sparganium* sp.), pondweed (*Potamogeton* sp.), and provisionally identified *Hydrolea corymbosa*, as aquatics, and Amaranthaceae, at least two species of sedge (*Carex* spp., Cyperaceae), smartweed/knotweed, and possible iris (cf. *Iris* sp.), as damp-ground taxa, additional herbaceous taxa blackberry (*Rubus* sp.) and (potentially) cf. Fabaceae.

The next superior level, Zone D, "lime sand sample, *Pleistocene strata*" (FS 73, Table 7.2) overall was very similar in composition to the deeper stratum E, but with the addition in this case of ash (*Fraxinus* sp., cf. *Carolina ash*, *F. caroliniana*) wood, and seeds from an unidentified grass (*Poaceae*), bulrush, and the black haw (*Viburnum* sp., cf. *V. prunifolium*).

7.3.3.1 Summary and Conclusions for Units D′, E, E′

These units and samples provide the greatest perspective on the deepest strata tested, specifically Zones D and E, which date to the late Pleistocene and transition with the Holocene. The Zone E "swamp forest" was indeed a period when rich bottomland and swamp forest were present, and same basic suite of taxa persisted into Zone D and beyond, based on the inventory of taxa from Zone C as revealed by samples from the other excavation units described above. The macrophytic remains from these units provide no definitive evidence of human activity. Wooden artifacts were lacking from these deposits and carbonized wood was limited to one possible specimen; however, the blackened surface in this case is very likely to have resulted from changes to the wood induced by wood-rotting fungi. None of the seeds or other plant remains was carbonized.

7.3.4 Test Units F and G (1991, 1997)

The 1991 excavations included a number of samples from Test F that were recovered as bulk sediment samples and which are described in another chapter (Newsom and Mihlbachler, this volume) due to their significance as part of dung-bearing deposits as described above. These strata of Test F generally define levels 16–22, “tan to gray silt and clay with abundant organics”; levels 23–26A, “mixture of light gray calcareous sand”; levels 26B–27, “whitish siliceous sand, mastodon skull with *Cucurbita* sp. seed”; level 27, “red-brown woody peat (full glacial, ca. 18,000 yr BP)”; they are roughly equivalent to the Zones D and E of the other excavation units. In addition, 22 screen samples were recovered and analyzed from the general dung-bearing strata during the 1997 excavations at Page-Ladson, specifically from Test units F-97-1, F-97-2, and G (Table 7.1), and these are the sources of the data presented here in this chapter.

The botanical composition of the screen samples strongly mirrors that described above for Zones D and E of the other test units, not to mention the bulk samples from the same deposits described in Chapter 10. Trees and shrubs commonly identified from among the samples include ironwood, hickory, hazelnut, hawthorn, beech, wild plum, oaks of at least two species, and cypress (which is superabundant in general in these levels; see Chapter 10). Provisionally identified sweetgum, wild olive, basswood (cf. *Tilia* sp., FS 203), southern crab apple (cf. *Malus* sp., FS 114), and Osage orange (cf. *Maclura pomifera*, FS 125) were recovered with individual samples, and the latter three taxa are unique to the Test F excavations. Osage orange, like hazelnut, does not currently occur naturally in Florida (present range is Georgia, Mississippi, Virginia, West Virginia [Radford *et al.*, 1968:391]). One persimmon seed and one provisionally identified holly (cf. *Ilex* sp.) seed were also recovered from Test F (in the additional bulk samples described in Chapter 10). Wild grape seeds, tendril fragments and sections of vine are frequent plant remains in the samples, as are wild gourd (*Cucurbita* sp.) seeds (see Chapter 10). Spatterdock and a damp-ground perennial, beakrush (*Rhynchospora* sp.) (also unique to Test F samples) were identified as part of the wetland component. Pokeweed (*Phytolacca*, FS 203) and cocklebur (*Xanthium* sp., several samples [Table 7.1]) are the only ones of the taxa from these samples that may be more indicative of drier and more open vegetation. They are particularly associated with disturbed habitats as generally weedy colonizers in succession dynamics. Nevertheless, in general these two taxa occur widely: in Florida pokeweed is found in mixed hardwood and pine forests, both upland and wetland hardwood hammocks, tropical hammocks, swamp hardwood forest, and freshwater marshes; cocklebur occurs in coastal strand vegetation, sand pine scrub, longleaf pine-turkey oak hills flora, mixed hardwood and pine forests, upland hardwood hammocks, oak hammocks, and bottomland hardwood forest (USDA Soil Conservation Service 1981, 1989). Specifically in terms of Page-Ladson where the occurrence of these two taxa is seemingly restricted to the effective Zone D deposits (Test Units F and G), the presence of both as well as Osage orange may have been strongly associated with the megafauna activity at the site as much as was pointed out for some of the other taxa described earlier (see Newsom and Mihlbachler, this volume).

7.3.4.1 Summary and Conclusions for Units F and G

The samples from these units represent more or less Zones D and E of the other excavations units, all attributed to the late Pleistocene. Bottomland/swamp forest taxa predominate in Tests F and G, mirroring the data from the other excavations. Megafauna activities in and around the site may have accounted for the presence of at least three of the taxa in the samples, including two herbs – pokeweed and cocklebur – and one tree, Osage orange. The latter in fact has long been hypothesized as having had an anachronistic seed dispersal relationship with the now extinct megafauna (see Newsom and Mihlbacher, this volume).

7.4 Discussion

Taken as a whole, the excavations and collective strata examined for their macrophytic composition provide compelling evidence for the presence of the bottomland hardwood ecological community, and related hydric–mesic hardwood forest associations (Table 7.3). Twenty-three of the woody arboreal taxa identified from the Page-Ladson deposits are typically associated with bottomland hardwood forest, and seven of these are characteristic of the plant community (7.3). Individual taxa from the samples also demonstrate strong associations with the swamp hardwood forest (20 taxa, 2 characteristic [Table 7.3]), an ecological community that in north Florida is closely linked with the bottomland hardwood forest association. This swamp community is found bordering rivers, including the Aucilla, and in basins that are either submerged or saturated during part of the year (USDA Soil Conservation Service 1981:112–114). Various species recorded from among the samples also occur and may be dominant in hydric or wetland hardwood hammocks, bluff and upland forest communities (hardwood hammocks), and mixed hardwood-and-pine forest associations (e.g. the longleaf pine-turkey oak community described in Section 7.1 of this chapter) found around the state, but taken as whole, they most likely derive in this case from local bottomland and swamp forests (Table 7.3).

The individual elements identified from among the Page-Ladson samples and deposits can be compared in terms of the forest strata described in Section 7.1, i.e. which reflect the gradient in elevation and drainage in the nearby Ochlockonee River valley, to illuminate similar spatial detail. The bluff rim vegetation may be indicated by the presence of the red/black-oak-type acorns and wood, if at least some of that material represents laurel oak (*Q. haemisphaerica*); however, they potentially also derive from another species such as water oak (*Q. nigra*), which is found in lower, wetter terrain. The second acorn morphotype – the relatively large specimens designed *Q. alba/michauxii* – potentially represents either or both white oak (*Q. alba*) of the upper slope vegetation or swamp chestnut oak (*Q. michauxii*) of the slope bottoms and floodplain. The lower slope vegetation comes into perspective very clearly and definitively with the presence of beech (*Fagus grandiflora*) in the samples. Moreover, at least six other tree taxa generally associated with the hardwood slope forests are recorded from Page-Ladson, pignut hickory (*C. glabra*) and sweetgum (*Liquidambar styraciflua*) were definitively identified, and wild olive (cf. *Osmanthus* sp., but possibly the tree *Franklinia* sp.) and basswood (*Tilia* spp.) were tentatively identified. In addition, the pine (Unit B, Zone C-upper) potentially represents spruce pine (*P. glabra*, being a member of the *taeda* anatomical group; however, individual pine species within the group are not separable by wood anatomy), and the hard maple (Test E, Zone E) may be the southern sugar maple (*Acer saccharum* [Panshin and de Zeeuw, 1980:603]), the only member of the hard maple anatomical group that occurs in Florida and which is also generally associated with the slope vegetation (Clewell, 1980; Wunderlin, 1989:415–416). The provisionally identified holly (cf. *Ilex* sp.) from Test F mentioned above may also have been part of this ecozone.

The lower-elevation floodplain vegetation is strongly indicated by the presence of nine taxa identified among the Page-Ladson samples. Water hickory (*C. aquatica*), overcup oak (*Q. lyrata*), soft-anatomical-group maple (e.g. red maple, *Acer rubrum*), ironwood (*Carpinus caroliniana*), American elm (*Ulmus americana*), Carolina ash (*F. caroliniana*), sweetgum, and possibly also diamond-leaf oak (*Q. laurifolia*), and/or water oak (*Q. nigra*), again considering the red/black acorn morphotype and wood type, all which occur in this habitat based on the Ochlockonee floristic survey mentioned earlier. This is also the general habitat for red mulberry (*Morus rubra*), which typically occurs in such alluvial woods and may grow also on the adjacent lower slopes (Radford *et al*., 1968:391).

The perpetually or frequently inundated floodplain depressions and backwater areas were undoubtedly the primarily locations for cypress trees (bald cypress, *Taxodium distichum*). The river swamp and bottomland forests are also the habitat for water locust (*Gleditsia aquatica*) (Radford *et al*., 1968:578). And we can infer that the riparian vegetation of the river banks was the primary habitat for additional species present in the deposits of the site: river birch (*Betula nigra*) – assuming that identification is correct – as well as willow (*Salix* sp.), buttonbush (*Cephalanthus occidentalis*), and the swamp dogwood, *Cornus foemina*). Hawthorn, *Crataegus* a spp., generally occurs in moist-wet forests, including the floodplain, swamp, and riparian forests (Radford *et al*., 1968:560–563). Wild rose (*Rosa palustris*), which is also associated with this habitat, was provisionally identified from some of the other Test F dung samples (see Newsom and Mihlbachler, this volume). The rambler (blackberry), lianas (rattan vine and wild grape) and vines (wild gourd and creeping cucumber) identified among the samples potentially grew virtually throughout the riparian, floodplain, and slope vegetation.

Although aquatic and damp-ground herbs were not a focus of this study, a number of wetland herbaceous taxa were identified from the samples. These serve to bring into focus the freshwater aquatic environments of the sinkhole/spring and eventual river system. The presence of virtually all of these taxa was verified beginning with the earliest Zone E deposits (e.g. FS 77 from Test E [Table 7.2]). Taxa from the shallow littoral zone near the water edge where such submersed aquatic and rooted emergent plants would have grown include: bur-reed (*Sparganium* sp., erect stout herb, muddy shores and shallow water), water willow (*Decodon verticillatus*, shrubby perennial, pools and marshes, stems spongy below water), watershield (*Brasenia schreberi,* floating leaves, ponds, and sluggish streams), spatterdock (*Nuphar lutea*, aquatic perennial, leaves submerged or emerged), coontail (*Ceratophyllum* sp., submersed aquatic herbs; pools, lakes, estuaries), cf. *Hydrolea corymbosa*, perennial aquatic herb, marshes, river bottoms, creek banks), and cf. pondweed (*Potamogeton* sp., perennial aquatic with submersed leaves). The wetland zone fringing the sinkhole or river would have supported the various damp-ground species identified in the samples, including smartweed/knotweed (*Polygonum* sp., dry-wet herbs, various settings), sedge (*Carex* spp., perennials, dry woods, bottomlands, bogs, etc.), nutgrass (*Cyperus* sp., damp ground annuals or perennials), beakrush (*Rhynchospora* sp., damp-ground perennial), bulrush (*Scirpus* sp., damp ground annuals or perennials), and nut-rush (*Scleria* sp., bogs, low woods, dry woods, savannahs).

Finally, we may have some suggestion of taxa potentially associated with the flatwoods vegetation of the Coastal Lowlands mentioned in Section 7.1, including the haw (if actually the species *V. nudum*, rather than the one that currently exists north of the area as discussed earlier) and possibly also the wild plum (*Prunus* sp.) and persimmon (*Diospyros virginiana*). However, plum and persimmon are typically early successional species, thus they may have been more generally present, particularly where the vegetation was disturbed (for example, resulting from the movements and activities of large animals such as mastodons, creating gaps in the vegetation and tree canopy) (check Table 7.3). As indicated earlier, disturbance situations creating openings in the forest potentially also account for the presence of cocklebur (*Xanthium* sp.) and pokeweed (*Phytolacca americana*) among the samples. Nevertheless, in all these cases mastodon browsing and consumption behaviors may have accounted for the plants' presence in the deposits, particularly given their primary or exclusive association with the dung-related deposits (and see Newsom and Mihlbachler, this volume).

Given all of the general correspondences in taxa, plant communities, and habitats mentioned above, one conclusion is that the general vegetation of the Aucilla drainage and bluff system during the overall period of site formation and active deposition was very similar in composition and general aspect to that today, but with the addition of a few elements no longer present in the region. Beyond this, the samples from the individual excavation units variously provide temporal data to try to discern something of the developmental dynamics of this flora in view of late Pleistocene climate change.

In general, as we have seen, the macrophytic plant assemblage is actually very similar throughout the deposits examined. Some of the variation evident in the late Pleistocene deposits (Zones D and E) – i.e. the abundance of wild gourd and cypress, along with the presence of hazelnut, Osage orange, and black haw – relative to later deposits may well have resulted from megafauna presence and under any circumstances does not change the overall picture of a rich deciduous forest environment. The predominantly bottomland forest community reflected by the plant samples seems to have remained relatively stable and unchanged during the temporal span of the deposits (Table 7.4). This conclusion is reached despite the fact that the pollen analysis by Hansen (this volume) provided evidence of environmental change, specifically a trend of arid to increasingly moist conditions in the transition from the Pleistocene to Holocene and recent period, but with temperature remaining relatively stable. The macrophytic remains indicate clearly that the dominant elements of the bottomland hardwood (oaks, hickories, beech, sweetgum, maple, ash, ironwood, elm, hawthorn) and swamp (cypress) communities were present during the entire period of the site deposits. This apparent discrepancy with the pollen data may be explained in part by the differences in scale and resolution between the two data sets (macro- and microbotanical sources) described earlier. Once established – evidently during some earlier period – the relative stability of the primary forest around the site is somewhat predictable and may be explained by the fact that the sinkhole/ravine and riparian environment were relatively protected. The area in and immediately around the site may have been a refuge for northern hardwoods and cypress swamp forest vegetation due to the ameliorating moisture and related microclimatic conditions present, thereby preserving some aspects of forest communities that probably originated during the Miocene (see discussion in Platt and Schwartz [1990] concerning the relict nature of hardwood forests in the panhandle region of Florida). Characteristics may hint at some correspondence with the moisture dynamics suggested by the pollen data: the presence of cabbage palm, red mulberry, and soft-group maple (almost certainly the red maple, *Acer rubrum*) by Zones B/C of the deposits may signal the onset of more humid and warm conditions, approaching those of the modern situation. I infer this because these taxa are also commonly associated with tropical hardwood hammock (see Table 7.3), whereas none of the other taxa are specifically listed for that plant community. The presence of these species may also signal the establishment and complete development of the flowing river system and wet floodplain environment versus the earlier sinkhole setting with its inferred lower water levels. Possibly the stressed growth exhibited in some of the wood samples from Zones C through E are indicative of the lower water levels and generally more arid conditions described by the pollen analysis.

Human activities in and around the basin river bottom are suggested by at least the (early/middle) Archaic period (“Bolen” era) by the presence of carbonized wood in Zone C and later deposits, and especially by the carved wooden items from Test Unit C and Test Pits I and II.

7.5 Conclusions

Whereas the pollen and related microbotanical data (Hansen, this volume) from Page-Ladson portray evidence of local–regional scale climate change from more arid to

Table 7.4 Temporal–spatial distribution of arboreal taxa from Page-Ladson

Test units	*A and B*	*A and B*	*C*	*A and B*	*C*	*A and B*	*C*	*A and B*	*C*	*D′, E, E′*	*F*	*A and B*	*D′, E, E′*
Zones/strata	*B*	*C-upper*	*C-upper 2a*	*C-middle*	*C-middle 2b*	*C-lower*	*C-lower*	*D*	*D*	*D*	*D*	*E*	*E*
Trees and shrubs													
Acer sp., soft, cf. *A. rubrum*, red maple					X								
Acer sp., hard, cf. *A. saccharum*, sugar													X
Betulaceae (*Alnus/Betula*, alder/birch)									X				
Carpinus caroliniana, ironwood					X				X	X	X		X
Carya sp., hickory (indeterminate group)		X								X	X		
Carya sp., true hickory anatomical group			X		X								
Carya (*aquatica*), water hickory	X			X									X
Carya (*glabra*), pignut hickory	X			X									
Cephalanthus occidentalis, buttonbush		X							X				X
Coryleus (americana), hazelnut									X	X	X		X
Cornus foemina, swamp dogwood									X				X
Crataegus spp., hawthorn									X	X	X		X
Diospyros virginiana, persimmon	X										X		
Fagus grandiflora, American beech	X	X							X		X		X

(*Continued*)

Table 7.4 *Temporal–spatial distribution of arboreal taxa from Page-Ladson*—(*Continued*)

Test units	*A and B*	*A and B*	*C*	*A and B*	*C*	*A and B*	*C*	*A and B*	*C*	*D′, E, E′*	*F*	*A and B*	*D′, E, E′*
Zones/strata	*B*	*C-upper*	*C-upper 2a*	*C-middle*	*C-middle 2b*	*C-lower*	*C-lower*	*D*	*D*	*D*	*D*	*E*	*E*
Fraxinus (*caroliniana*) bottomland ash		X								X			
cf. *Gleditsia aquatica*, water locust									X	X			X
Juglans nigra, black walnut[1]													
Liquidambar styraciflua, sweetgum		X		X					X		X		
cf. Maclura pomifera, Osage orange											X		
cf. *Malus angustifolia*, crab apple											X		
Morus rubra, red mulberry				X									
cf. *Myrica* sp., wax myrtle													X
cf. *Osmanthus* sp., wild olive		X									X		
Pinus sp., subsection *taeda,* pine		X											
Prunus sp., wild plum type		X									X		X
Quercus sp., oak (indeterminate group)		X		X			X		X	X	X		X
Quercus sp., red/black anatomical group		X				X		X				X	
Quercus sp., white anatomical group									X				
Quercus (*alba/michauxii*), white oaks	X	X	X								X		

Quercus (*laurifolia/nigra*), red/black oaks									X	
Quercus lyrata, overcup oak		X							X	
Sabal palmetto, cabbage palm	X	X								
Salix (*caroliniana*), willow			X				X			
Taxodium sp., cypress/bald cypress	X	X	X		X	X	X	X	X	X
cf. *Tilia* sp., basswood									X	
Ulmus (*americana*), American elm				X						
Viburnum (*prunifolium*), black haw							X	X		
Lianas, vines, ramblers										
Berchemia scandens, rattan vine							X			
Cucurbita sp. (cf. *C. pepo*), wild gourd							X		X	
cf. *Melothria* sp., creeping cucumber							X			
Rubus sp., blackberry		X						X		X
Vitis sp., wild grape		X	X		X		X	X	X	X
Notable herbs										
Phytolacca americana, pokeweed							X		X	
Nuphar lutea, spatterdock (waterlily)		X						X	X	X
Xanthium sp., cocklebur									X	

---

[1] Juglans, black walnut, identified from loose/fallen material in bottom of unit.

increasingly moist conditions, conversely the macrophytic remains demonstrate floristic continuity during the same span of time. This discrepancy is largely the result of the fact that pollen analytical data typically provide a regional climatic and vegetation signal, whereas plant macroremains – larger botanical organs and materials released, abscised or fallen from trees and other plants that generally fall and are deposited close to their source – highlight the local, microclimatic situation. In the relatively protected sinkhole/riverine environment, the macrophytic remains provide a long-term record of essentially unchanged, protected bottomland forest vegetation. Together the two data sets provide complementary information essential to a more complete understanding of the inherent floristic dynamics associated with the close of the Pleistocene epoch in north Florida and the southeast in general.

References

Clewell, A.F. 1980. The vegetation of Leon County, Florida. pp. 386–440, in The Leon County Bicentennial Survey Report: An Archaeological Survey of Selected Portions of Leon County, by L.D. Tesar. Bureau of Historic Sites and Properties, Division of Archives, History, and Records Management, *Miscellaneous Project Report Series Number 49, Section 1*. Florida Department of State, Tallahassee.

Elias, T.S. 1980. *The Complete Trees of North America: Field Guide and Natural History*. Van Nostrand Reinhold Company, New York.

Ewel, K.C. 1990. Swamps. *In Ecosyctems of Florida* edited by R.L. Myers and J.J. Ewel. University of Central Florida Press, Orlando.

Fernald, E.A. and D.J. Patton (editors). 1984. *Water Resources Atlas of Florida*. Florida State University and the Institute of Science and Public Affairs. U.S. Government Printing Office, Washington, D.C.

Godfrey, R.K. and J.W. Wooten. 1981. *Aquatic and Wetland Plants of Southeastern United States*. Two volumes. The University of Georgia Press, Athens.

Hitchcock, A.S. 1971. *Manual of the Grasses of the United States*. Two volumes. Dover Publications Inc., New York.

Landers, J.L. and A.S. Johnson. 1976. Bobwhite and Quail Food Habits in the Southeastern United States with a Seed Key to Important Foods. *Miscellaneous Publications, Tall Timbers Research Station*, Tallahassee, Florida.

Martin, A.C. and W.D. Barkley. 1961. *Seed Identification Manual*. University of California Press, Berkeley.

Nelson, G. 1994. *The Trees of Florida: A Reference and Field Guide*. Pineapple Press, Inc., Sarasota, Florida.

Nelson, G. 1996. *The Shrubs and Woody Vines of Florida: A Reference and Field Guide*. Pineapple Press, Inc., Sarasota, Florida.

Panshin, A.J. and C. deZeeuw. 1980. *Textbook of Wood Technology, 4th ed*. McGraw Hill, New York.

Platt, W.J. and M.W. Schwartz. 1990. Temperate Hardwood Forests. pp. 194, in *Ecosystems of Florida,* R. L. Myers and J. J. Ewel, eds. University of Central Florida Press, Orlando.

Radford, A.E., H.E. Ahles, and C.R. Bell. 1968. *Manual of the Vascular Flora of the Carolinas*. The University of North Carolina Press, Chapel Hill.

Record, S.J. and R.W. Hess 1942–1948. “Keys to American Woods”. In *Tropical Woods* 72:19–29 (1942), 73:23–42 (1943), 75:8–26 (1943), 76:32–47 (1944), 85:1–19 (1946), 94:29–52 (1948).

Rich, F.J. and L.A. Newsom. 1995. Preliminary palynological and macrobotanical report for the Leisey Shell Pitts, Hillsborough Country, Florida. *Bulletin of the Florida Museum of Natural History* 37 Pt. I(4):117–126.

United States Department of Agriculture, Soil Conservation Service. 1985. *Twenty-six Ecological Communities of Florida*. Gainesville, Florida.

United States Department of Agriculture, Soil Conservation Service. 1989. *Twenty-six Ecological Communities of Florida*. (Revised July 1989). Gainesville, Florida.

Urling, G.P. and R.B. Smith. 1953. An Anatomical Study of Twenty Lesser Known Woods of Florida. *Quarterly Journal of the Florida Academy of Sciences* 16(3):163–180.

Wheeler, E.A., R.G. Pearson, C.A. LaPasha, T. Zack, and W. Hatley. 1986. *Computer-Aided Wood Identification*. The North Carolina Agricultural Research Service, Bulletin 474. North Carolina State University, Raleigh.

Wunderlin, R.P. 1998. *Guide to the Vascular Plants of Central Florida*. University Press of Florida, Gainesville.

SECTION C: LATE PLEISTOCENE EVIDENCE

> "... we live in a zoologically impoverished world, from which all the hugest, and fiercest, and strangest forms have recently disappeared."
>
> **Alfred Russell Wallace.**

This central section of the book goes to the heart of the interactions between the First Floridians and the last mastodons. This section of the book is also the largest and most complex, consisting of seven rather diverse and sometimes technical chapters. The richest sediments in the Page-Ladson site come from Unit 3 near the bottom. They produce a wealth of evidence sampling three millennia from about 15,000 to 12,000 ^{14}C BP. When calibrated to calendar years, this interval reaches back about 14,000 or 15,000 years BP. The evidence in this section then places man in a rich context much earlier than the classic western Clovis sites. A restored scene from this part of the site was developed for the December, 2000 National Geographic Magazine and reappears in this volume, reprinted with permission.

Specific topics include two broad taxonomic chapters, one on Vertebrates and one on Molluscs, each divulging a wealth of terrestrial and freshwater species. The right tusk of a large male *Mammut americanum* (UF 150701) warrants two chapters. One introduces it and presents evidence that it was butchered and twisted out of its skull. The other provides a penetrating series of analyses revealing extraordinarily specific details of the last five years of its life. Another chapter features the vast body of *Mammut* stomach contents (digesta), revealing far more about their seasonal eating habits than any prior studies. Detailed studies of isotopes from the teeth of seven large herbivore species (including *Mammut and Mammuthus*) greatly illuminate their feeding ecology, their migratory patterns, and quite possibly their extinction. And finally the direct and indirect evidence of Paleoindian presence in the Page-Ladson site is detailed and the role of humans in the region is considered.

Each of these seven chapters makes valuable cutting-edge contributions. Yet the more remarkable feature of this section is the interplay of independent data sets, both explicit and implicit. For example mastodons are perceived differently yet importantly in each chapter, appearing as prey to hunters, source of ivory, modifiers of regional ecology, migratory herds, registers of drought cycles, and samplers of local vegetation. The large male that was butchered, perhaps for its tusks, was part of a migratory herd that traveled northward into granitic terrain, as evidenced by the strontium 87/86 ratios in their teeth. There it experienced a long but relatively poor growth season. Its return to Florida was rewarded by summer feasts, replete with gourds and fermenting grapes, as documented by digesta from the pond bottom. None of these multiple disciplines fails to carry an abundance of clues illuminating the regional environment inhabited by the first Floridians.

Chapter 8

Vertebrate Paleontology

S. DAVID WEBB and ERIKA SIMONS
Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.

8.1 Introduction

The accumulations of bones and teeth in the deep “holes” within the Aucilla River provided the initial impetus for most of the SCUBA collecting in that river. In the dark-water settings typical of that river, especially during summer months, most of the material recovered consisted of large land mammal elements. For example, in his study of *Bison* evolution, Robertson (in Webb, 1974) relied heavily on Aucilla River collections of *Bison antiquus* skulls as the most extensive in Florida.

It also became evident to both professional and amateur collectors that fully articulated skeletons were sometimes preserved in the river. Their occurrence was associated with incompletely eroded pockets of fine-grained, organic deposits encountered on the river bottom. The recovery of several mammoth and mastodon skeletons was reported by Webb (1976). The full skeleton of one large male *Mammuthus* now stands in the Florida Museum of Natural History next to a large male *Mammut* from another site in the Aucilla River.

In retrospect it is evident that these early collecting efforts were too narrowly focused on trophy hunting. The skeletons were disassociated from any faunal, floral,

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 215–246

or cultural context. And they were so efficiently recovered that they had limited stratigraphic or chronologic data. It is now evident that collectors in the Aucilla River ought to have distinguished at least the two major intervals of deposition, one in full glacial, and the other some 20,000 years later, in the late glacial. Of course, such additional rigor would have required far more investment of time and money, especially for field time and also for carbon dates. That is why two decades passed before a more rigorous scientific program to recover fossils in a broader multidisciplinary context could be mustered.

In the present chapter we set forth the principal results regarding fossil vertebrates from the late Pleistocene levels at the Page-Ladson site. The primary evidence is presented as a comprehensive list of vertebrate taxa. We do not include the early Holocene vertebrates, as they are considered in a later section of this book.

We also address three additional issues concerning these late Pleistocene vertebrates. One topic of vital importance is their paleoecology. This subject begins by separating the primarily aquatic fauna from the primarily terrestrial. We then briefly discuss each species (or next higher taxon) including its identification, ecology, and biogeography. We place special emphasis on the paleoecology of the terrestrial herbivores, especially their feeding habits.

Once we have established the ecological roles of the terrestrial herbivores, we can more clearly explore the possible interactions of the first Floridians with the terrestrial vertebrate fauna. A final discussion features the impact of Page-Ladson data on the question of extinction of the late Pleistocene megafauna in North America. These same issues are taken up in other, supplementary ways in several of the following chapters on the late Pleistocene.

8.2 Methods

8.2.1 Systematics Methods

We first sorted the taxa from each field season and cataloged them in the computerized system of the Florida Museum of Natural History collection of fossil vertebrates. This ultimately allowed us to produce lists of vertebrate taxa and their elements from any combination of late Pleistocene levels at the Page-Ladson site complex or elsewhere in the Aucilla River. We then developed a discussion of each individual taxon. The taxa are treated at whatever level seems practical, ranging from species up to genus, family or any higher systematic categories. Because the taxa sampled here are broadly divisible into either terrestrial or primarily aquatic species, we divided the discussion accordingly. In many species accounts we cite at least one catalog number as a voucher specimen, available in the Vertebrate Paleontology collections (with the prefix UF in reference to the University of Florida). In the same accounts we present relevant ecological data and discussions regarding probable habitat, feeding requirements, and biogeography.

8.2.2 Taphonomic Methods

To further understand the significance of the vertebrate fauna and its connection with local environments and human adaptations we developed a few taphonomic analyses. Taphonomy is a facet of paleoecology that attempts to penetrate the processes by which fossils accumulated from the time of their death to their final states of deposition and fossilization.

The first and simplest taphonomic study we made was to screen, sort, and weigh the different basic faunal components from the two most productive localities within our excavations. The two late Pleistocene localities that were most productive of fossil vertebrates were Levels 23 and 26 B in Test F. On October 30, 1992 toward the end of a very productive season, we took relatively large bulk samples from an area in which Levels 23 and 26 B both seemed unusually fossiliferous. The field number for the sample from Level 23 is FS 106 C. It weighed 3.04 kg after it was washed through 1/4 in. screen and dried. For Level 26 B the field number was FS 92.129 A and the bulk sample weighed 3.44 kg. In each case less than 10% of the bulk sample (fine sand and clay) washed through the screen. The material was then picked and sorted into four simple categories and weighed.

A second more detailed taphonomic study involved quantitative analyses of all aquatic vertebrates from Levels 23 and 26 B collected during the five productive seasons between June 1991 and October 1993. We featured the aquatic vertebrates because they were evidently the primary inhabitants of the sinkhole pond in which the entire fauna, including terrestrially derived specimens, was interred. We grouped the aquatic vertebrates coarsely into four taxonomic categories: fishes, amphibians, turtles, and snakes. We determined to omit alligators because they were quite common throughout the section, and their bulk would outweigh the rest of the material. MNI refers to the minimum number of individuals that would be required to account for the entire sample of any one taxon, inferred from the count of the most common element. All elements in each of the four categories were counted and weighed, and a final percentage based on element counts was calculated.

A third taphonomic study was initiated after we recognized that a major part of the peaty sands and silts of stratigraphic Unit 3 were digesta of *Mammut*. We were stimulated to try this experiment because we had become aware at the surface screen recovery station of strong “urine-like” smells associated with excavations in the digesta levels. The purpose of this third study was to discover what, if any, biochemical or cellular material of *Mammut* might remain within these anaerobic sediments. We submitted a number of freshly collected and cooled samples, taken from freshly cut excavation faces, in sterilized vials to Dr. Tim Gross at the U.S. Geological Survey’s Caribbean Research Center in Gainesville, Florida in 1995 for biochemical analysis. Besides Level 23 samples, the richest source of well-preserved fossils and fresh-looking digesta, we also submitted the highest apparent digesta sample from Level 7, and also a control sample from the basal red peat (non-digesta peat) from Level 27. We also submitted samples of digesta from Level 23 to Ms. Pam Humphrey of the Parasitology Lab in the University of Florida School of

Veterinary Medicine with the purpose of recovering parasites or other non-plant cellular material.

8.3 Results

Table 8.1 presents a full list of the vertebrate taxa recovered from all late Pleistocene levels of the Page-Ladson site complex. This taxonomic roster is divided into primarily aquatic and primarily terrestrial components. We proceed to a brief discussion of the ecology and other natural history notes for each taxon beginning with the primarily aquatic taxa.

8.3.1 Aquatic Fauna

The most primitive group of bony fishes represented are the family Lepisosteidae, garfishes noted osteologically for their heavy ganoid scales, opisthocoelus vertebral centra, and hard cranial parts (Wheeler and Jones, 1989:17). Extant species are found in eastern North America, Central America, and Cuba. Gars typically prefer quiet backwater areas, such as streams, swamps, lakes, reservoirs, and bayous with plenty of aquatic vegetation. They can tolerate a high level of salinity and may be found in waters that range from clear, to brackish, to marine (Williams, 1983:368–370). Possible species of gar at Page-Ladson Site include *Lepisosteus osseus* (long-nosed gar), *L. platyrhincus* (Florida gar), and *L. occulatus* (spotted gar).

The Bowfins, *Amia calva,* occur throughout the eastern half of North America. They prefer quiet, clear waters with little or no current, such as sluggish streams, swamps, and oxbow lakes, with vegetation (Williams, 1983:371–372). In the early spring bowfins spawn in shallow waters, where the male constructs a nest and protects the eggs until they hatch, and then the young until they are several weeks old (Williams, 1983:371–372).

Esox niger (chain pickerel) can obtain lengths up to 79 cm. They are found in clean, clear waters such as lakes, ponds, swamps, reservoirs, and stream pools, in areas of eastern United States and Canada, reaching as far north as Nova Scotia and Quebec, to the Atlantic and Gulf coasts of Florida (Williams, 1983:404). *E. niger* can live in waters with salinities to 22 ppm (Lee *et al.*, 1980:137). Another possible species present at Page-Ladson is *E. americanus* (redfin pickerel). This species is usually found in smaller lakes, ponds, and streams than *E. niger* and does not have the same affinity for brackish water.

There are five species in the genus *Ameiurus*. These Bullhead Catfish can be found in freshwater as far north as southeastern Saskatchewan and into central Eastern United States and south to Florida and Mexico. Williams (1983:469) notes that these fish have been “widely introduced outside native range”. They prefer a riverine habitat with moderate to swift current and a rock, gravel, or sand bottom. Bullheads are native to North

Table 8.1 Pleistocene vertebrate taxonomic list

Taxonomic name	*Common name*
Part A: primarily aquatic taxa	
Osteichthyes	Bony fishes class
Lepisosteidae	Garfish family
Lepisosteus sp.	Garfish
Amia calva	Bowfin or mudfish
Notemigonus chrysoleucas	Golden shiner
Catostomidae	Sucker family
Erimyzon sucetta	Lake chubsucker
Minytrema melanops	Spotted sucker
Ictaluridae	Freshwater catfish family
Ameiurus natalis	Yellow bullhead catfish
Ameiurus nebulosus	Brown bullhead catfish
Esox sp.	Pike fish
Centrarchidae	Sunfish and bass family
Lepomis sp.	Sunfish
Lepomis microlophus	Shellcracker or redeared sunfish
Micropterus sp.	Bass
Pomoxis sp.	Crappie
Sciaenops ocellatus	Red drum
Archosargus probatocephalus	Sheephead
Mugil sp.	Mullet
Amphibia	Amphibians class
Anura	Frog and toad order
Bufonidae	Toad family
Bufo sp.	Toad
Rana sp.	Southern leopard frog
Caudata	Salamanders
Amphiuma sp.	Amphiuma
Siren sp.	Siren
Reptilia	Reptiles class
Testudines	Turtle order
Chelydra serpentina	Snapping turtle
Kinosternidae[1]	Mud and musk turtle family
Kinosternon sp.	Mud turtle
Sternotherus sp.	Musk turtle
Emydidae	Cooter, slider, box turtle family
Deirochelys reticularia	Chicken turtle
Malaclemys terrapin	Diamondback terrapin
Pseudemys nelsoni	Florida red-bellied turtle
Pseudemys/Trachemys sp.	Pond turtle
Terrapene carolina putnami	Putnam's box turtle
Terrapene carolina	Eastern box turtle
Serpentes	Snake order
Crotalidae	Pit viper family
Agkistrodon sp.	Water moccasin
Natricinae	Water snake family
Nerodia sp.	Water snake

(*Continued*)

Table 8.1 Pleistocene vertebrate taxonomic list—(Continued)

Taxonomic name	*Common name*
Crocodilia	Crocodile and alligator order
Alligatoridae	Alligator family
Alligator mississippiensis	American alligator
Aves	Bird class
Anatinae	Ducks family
Ardea herodias	Great Blue Heron
Branta canadensis	Canada Goose
Podilymbus sp.	Grebe, near Pied-billed
Phalacrocorax sp.	Cormorant, near crested
Ciconia maltha[2]	Large, extinct stork
Part B: primarily terrestrial taxa	
Reptilia	Reptile class
Testudinidae	Tortoise family
Hesperotestudo crassiscutata[2]	Giant tortoise
Gopherus polyphemus	Pocket gopher
Crotalidae	Pit viper family
Crotalus sp.	Rattlesnake
Aves	Bird class
Vulturidae	Vulture and condor family
Gymnogyps sp.[2]	Condor
Meleagridae	Turkey family
Meleagris gallopavo	Wild turkey
Extinct eagle[2]	Large extinct eagle
Haliaeetus leucocephalus	Bald Eagle
Buteo linneatus	Red-shouldered hawk
Buteo jamaicensis	Red-tailed hawk
Zenaida macroura	Mourning dove
Mammalia	Mammals class
Marsupialia	Marsupial order
Didelphis virginiana	Virginia opossum
Edentata	Edentate order
Holmesina septentrionalis[2]	Giant armadillo or pampathere
Glyptotherium floridanum[1]	Glyptodont
Dasypus bellus[2]	Beautiful armadillo
Paramylodon harlani[2]	Harlan's ground sloth
Megalonyx jeffersoni[2]	Sloth
Carnivora	Carnivore order
Canis dirus[2]	Dire wolf
Canis familiaris	Domestic dog
Ursus americanus	Black bear
Lynx rufus	Bobcat
Leopardus amnicola[2]	Small extinct cat
Felis sp.	Indeterminate species of cat
Procyon lotor	Raccoon
Lutra canadensis	River otter
Lagomorpha	Hare and rabbit order
Sylvilagus floridanus	Cottontail rabbit
Sylvilagus palustris	Marsh rabbit

Rodentia	Rodent order
Sciurus niger	Fox squirrel
Castor canadensis	Beaver
Erethizon dorsatum[2]	Porcupine
Hydrochoerus sp.[2]	Capybara
Ondatra zibethicus[1]	Muskrat
Neofiber alleni	Round-tailed muskrat
Proboscidea	Elephant order
Mammut americanum[2]	American mastodon
Mammuthus columbi[2]	Columbian mammoth
Perissodactyla	Odd-toed ungulate order
Tapirus veroensis[2]	Vero tapir
Equus sp.[2]	Pleistocene horse
Artiodactyla	Even-toed ungulate order
Tayassuidae	Peccary family
Platygonus cumberlandensis[2]	Broad-headed peccary
Mylohyus fossilis	Long-nosed peccary
Camelidae	Camel and llama family
Hemiauchenia macrocephala[2]	Long-legged extinct llama
Palaeolama mirifica[2]	Short-legged extinct llama
Cervidae	Deer family
Odocoileus virginianus	White-tailed deer
Bovidae	Cattle family
Bison antiquus[2]	Extinct bison

[1] No longer living in Aucilla River.
[2] Extinct and/or extralimital in Florida in the late Pleistocene.

America and provide important food resources both now and presumably in the past (Wheeler and Jones, 1989:20). At Page-Ladson we have identified two species based on their dentaries. These are *A. natalis* (yellow bullhead) and *A. nebulosus* (brown bullhead).

Among the sunfish and bass group, family Centrarchidae, we consider three genera: *Lepomis*, *Micropterus*, and *Pomoxis*. There are seven species of *Lepomis*, all of which enjoy clear, calm waters with little or no current, some of which may flow over sand, gravel, or rock bottoms, and others with vegetation or other cover (Williams, 1983:548–557). One species *L. microlophus* has been identified from Page-Ladson based on its distinctive pharyngeal grinders. Of all the sunfish, *L. microlophus* has very thick pharyngeal grinders to aid in its diet of molluscs. Three species of *Micropterus* are found in Florida, the spotted bass (*M. punctulatus*), the largemouth bass (*M. salmoides*), and the Suwannee bass (*M. notius*). These are generally found in inland waters (Wheeler and Jones, 1989:23) and prefer clear to slightly turbid streams, ponds, lakes, reservoirs, and creek pools, with some type of vegetal covering (Williams, 1983:558–559). The most likely species at Page-Ladson would be *M. salmoides*. Its current distribution is statewide, whereas *M. punctulatus* is restricted to the western tip of the Florida panhandle and *M. notius* is endemic to the Suwannee River system. The latter species also prefers large springs and spring runs (Page and Burr, 1991:263–264). The black crappie (*Pomoxis nigromaculatus*) is found in many parts of the eastern United States. It prefers quiet, warm, clear streams, ponds, lakes, and reservoirs, and is less tolerant of silty and turbid waters than the white crappie (*Pomoxis annularis*), whose modern distribution does not reach into Florida (Page and Burr, 1991:260).

The Catostomidae or suckers include *Erimyzon sucetta* and *Minitrema melanops*. Most elements of catostomids from Page-Ladson may be referred to *E. sucetta*, lake chubsuckers. Some specimens could only be identified to family because they also resembled *Minitrema melanops*, the spotted sucker. The lake chubsucker prefers waters with little or no flow. On the other hand they require a vegetated sand or silt bottom with organic debris. The spotted sucker differs in preferring clear water over firm bottomed creeks and small rivers. They will also enter turbid creeks and overflow lakes and impoundments (Lee *et al*., 1980:399, 408).

Amphibians are abundantly represented at the Page-Ladson site with many identifiable elements of both frogs and salamanders.

The frogs are all large sized animals referable to *Rana* sp. Among the several species that occur today in Florida three appear the most likely comparisons for these large specimens. They are the pig frog (*R. grylio*), the bullfrog (*R. catesbiana*), and possibly the river frog (*R. hecksheri).* All of these species inhabit aquatic environments, usually swamps, ponds, sluggish area of streams, bogs, marshes, cypress bays, and can be found amid floating vegetation. They generally can be found near the water's edge or amidst vegetation that can be used for cover (Conant, 1975:338–350). *R. catesbeiana* and *R. grylio* have a larger Florida distribution than *R. hecksheri*. The latter does not occur in Jefferson or Taylor Counties today, but its range may have covered that area in the past (Conant, 1975).

The salamanders at this site belong to two genera, *Amphiuma* and *Siren*. Amphiumas and sirens can be differentiated osteologically by their vertebrae. The two-toed amphiuma (*Amphiuma means*), which is the most likely species of this genus to occur at Page-Ladson, lives in aquatic situations such as ditches, ponds, sloughs, swamps, streams, and rice fields (Conant, 1975:245). These amphibians can grow to be 46–76 cm in length, with a record of 116.2 cm (Conant, 1975:245). There is a smaller species from Florida, *A. pholeter* (one-toed amphiuma). It may reach a length of 32 cm and lives deep in the muddy sloughs off the sides of moderately sized streams.

Among the sirens the most likely identification for our material is the greater siren, *Siren lacertina*. It occurs in a number of shallow water environments such as streams with clear to turbid waters, ditches, weed-choked or muddy ponds, rice fields, and lakes (Conant, 1975:247). This species can grow to 51–76 cm, with a record of 97.8 cm (Conant, 1975:247). A smaller species, *S. intermedia* is also present in the Panhandle and shares a similar environment. This species reaches a length of 66 cm.

The most numerous bones of aquatic animals in our late Pleistocene collections are turtle bones and scutes. The Snapping Turtle, *Chelydra serpentina*, however, is quite rare in our samples. It gets its name from its aggressive behavior and inclination to bite and snap. Its range covers the area from southern Canada to the southern tip of Florida, and the Atlantic Ocean to the Rocky Mountains. These turtles live in fresh to brackish water environments and may bury themselves in mud in shallow waters. Unlike most other turtles, they do not bask. These are omnivorous creatures feeding on aquatic invertebrates, fish, reptiles, birds, mammals, and vegetation. They are often caught and used for stews and soups (Conant, 1975:37–38).

Among Mud and Musk turtles, family Kinosternidae, we have cf. *Kinosternon* sp. and *Sternotherus* sp. These turtles are known as “stinkpots” or “stinking-jims” because of the musky odor they secrete upon being captured. These small turtles are almost entirely aquatic, especially the musk turtles, only leaving the water during heavy rains or nesting season. They bask openly, but prefer to stay in shallow water with only a portion of the carapace exposed. The stinkpot (*Sternotherus odoratus*), loggerhead musk turtle (*S. minor*), and mud turtles (*Kinosternon bauri* and *K. subrubrum*) are found in Florida and the Southeastern United States, although not exclusively (Conant, 1975:363). Habitats range from swamps, ponds, lakes and rivers to ditches, and wet meadows. These two genera of turtles can be distinguished by comparing plastron elements or the nuchal bones from the carapace. *Kinosternon* has a hinge where the epiplastron and hyoplastron meet. The xiphiplastron is rounded in comparison to *Sternotherus*. *Sternotherus* has a squarish pectoral scute or xiphiplastron and does not have a hinge between the epiplastron and hyoplastron.

Among the family Emydidae, we identify six taxa of aquatic turtles. Among these Cooters and Sliders, we can recognize *Malaclemys terrapin*, *Pseudemys/Trachemys* sp., *Trachemys scripta*, *Pseudemys nelsoni*, and *Deirochelys reticularia*. The rarest of these in the Page-Ladson Site is the Diamondback terrapin, *Malaclemys terrapin*. It prefers brackish to salt water environments such as marshes, tidal flats, coastal marshes, estuaries and coastal streams where it feeds on fish, crustaceans, molluscs, and insects.

One species of *Pseudemys*, *P. nelsoni*, the red-bellied turtle, was identified from abundant material at the Page-Ladson site. It can be differentiated from other *Pseudemys* by its thick shell and the distinctive rugosity of its carapace and plastron. The thick shell of *P. nelsoni* helps it avoid or survive alligator predation. Habitat requirements of *P. nelsoni* are similar to those of other *Pseudemys*. Because of its thicker shell, however, it tends to coexist with alligators better than the other cooters.

Thick shells and alligator resistance also characterize *Trachemys scripta*, which is the most abundant of all the turtles at Page-Ladson. This turtle has a more highly sculptured carapace than *P. nelsoni*, but a thick smooth plastron. Several excellent pieces of carapace from Level 23 are cataloged as UF 15496–15499.

The Florida cooter, *Pseudemys floridana*, is a likely candidate to have lived at Page-Ladson, but cannot be clearly diagnosed from available material. This turtle is found in the Coastal Plain, living in permanent bodies of water such as ponds, lakes, swamps or marshes, and rivers (Conant, 1975:65).

The chicken turtle, *Deirochelys reticularia*, is generally found in still water environments such as ponds, marshes, sloughs, and ditches. It can be seen walking on land in the Coastal Plain from southeastern Virginia to eastern Texas (Conant, 1975:70). *D. reticularia* can be distinguished osteologically from other emydids by its distinct rugosity, thinner shell, wider neurals, the more distally set rib juncture with the costal bones, and elongated cervical vertebrae. The latter three characteristics reflect the animal’s “pharyngeal” feeding habits whereby the turtle can catch fast moving prey by shooting out its long neck and sucking in. This specialization had fully evolved by middle Pliocene (Jackson, 1978:42–50). The chicken turtle is not a common species at Page-Ladson.

The Florida softshell turtle, *Apalone ferox*, is also rare in the Page-Ladson fauna. Only a few specimens have been identified from this site. An excellent example from

Test F Level 23 is a nuchal cataloged as UF 146088. *Apalone ferox* is a common turtle throughout Florida in lakes marshes and ditches, and feeds on small fish, invertebrates, and small vertebrates.

Among the watersnakes, Natricinae, we recognize in moderate abundance *Nerodia* sp. Snakes of this genus are non-poisonous and live along the shores of freshwater rivers, streams, canals, lakes, and marshlands (Haast and Anderson, 1981:65). They feed on cold-blooded animals such as frogs, toads, salamanders, crayfish, fish, and each other (Haast and Anderson, 1981:65). This group does not include the Florida cottonmouth (*Agkistrodon piscivorus conanti*).

The American alligator, *Alligator mississippiensis*, occurs abundantly at virtually every late Pleistocene level in our excavations. Chalky-textured coprolites, almost surely from alligators, also occur in large numbers. A good example of a moderate-sized left mandible is UF 147378. The genus has lived in Florida since at least the early Miocene and perhaps as long as there have been freshwater habitats in the region. Alligators are found in Florida and the Gulf and Lower Atlantic Coastal Plain states (Conant, 1975:35). They live in rivers, swamps, lakes, bayous, marshes, and other bodies of fresh or even brackish water.

The ducks, Anatinae are moderate to large water birds. Ducks live in most areas of the world, migrating south in the winter months. About half of the bird bones from Page-Ladson represent ducks of various sizes, but few warrant exact identification. A number of species live in Florida at various times of the year for varying amounts of time (Stevenson, 1976). Their regional habitats differ throughout Florida, and only a limited number reside in the state.

There are five other kinds of aquatic birds in the late Pleistocene beds, most of them from Test F, Level 23. The most abundant of these is the Canada Goose, *Branta canadensis*, identified at Page-Ladson from three coracoids (e.g. UF 153703) and a partial furculum (UF 146175). *Podilymbus* sp. material closely resembles the living Pied-billed grebe, but is consistently slightly larger. An ulna (UF 92535) represents a species close to the Crested Cormorant, but is best left as a generic assignment, *Phalacrocorax* sp. Another complete right ulna (UF 63440) clearly belongs to a Great Blue Heron, *Ardea herodias*. And finally a right femur from Level 23 gives clear evidence of the large extinct stork, *Ciconia maltha*.

8.3.2 Terrestrial Fauna

In general, the larger vertebrates, especially ungulate mammals, are the most abundant representatives of the terrestrial fauna. For the most part, their remains appear to have been transported from adjacent banks into the pond where they became fossilized. Some smaller vertebrates such as toads, box turtles, birds, and rodents are important as ecological indicators of adjacent habitats.

The southern toad *Bufo terrestris* is moderately common at the Page-Ladson site. This toad reaches a length of nearly 10 cm, and its large bones are fairly durable. Its distribution includes all of Florida and is found in nearly all types of habitats from xeric to hydric (Conant, 1975). Another species possibly present is Fowler's Toad, *Bufo woodhowsei fowleri*. Its modern distribution in Florida is limited to the panhandle but it reaches Jefferson County. This toad is easily confused with the southern toad, in fact the two often hybridize. The habitat requirements are not as well known as for *B. terrestris*, except that it seems to prefer more sandy open areas (Conant, 1975).

A terrestrial representative of the Emydidae is *Terrapene carolina*, the Eastern box turtle. A nuchal bone from a *Terrapene* carapace found in Test F, Level 23 is UF 164592. Although the box turtles are generally terrestrial, they sometimes may be found in water. During hot and dry weather this species burrows beneath logs (Conant, 1975:49). Its range includes the Great Lakes region, eastern Texas, and the Eastern Coastal Plain, as well as the Gulf and Atlantic coastal regions. A large subspecies, *T. carolina putnami* occurs in the Florida Panhandle and is present at Page-Ladson.

The giant tortoise, *Hesperotestudo crassiscutata*, occurs as only a minor element at the Page-Ladson site, and is not as abundant in the Aucilla River sites generally as it is elsewhere in the Florida late Pleistocene. A large hypoplastron, UF 63438, represents this species at Page-Ladson.

Gopherus polyphemus, the gopher tortoise, occurs rarely at Page-Ladson. A thin left hypoplastron, UF 69516 is a good example of this surviving tortoise. This specimen was extensively gnawed by rodents around the edges. The gopher tortoise ranges from Florida around the Gulf of Mexico, through Texas, and into Mexico.

Terrestrial snakes are rare in the late Pleistocene at Page-Ladson. A large dorsal vertebra, UF 148400, from Test F, Level 26 B represents a rattlesnake, *Crotalus* species.

Among the birds at this site that are primarily terrestrial we recognize seven species. The California condor, *Gymnogyps californicus*, is indicated by a left cuneiform (UF 145279) from Test F, Level 23. The range of this species retracted to the west perhaps by way of the Gulf Coastal savanna corridor (Hulbert, 2001). It had retreated to Texas and the southwest by the early to middle Holocene. It survives today mainly by captive breeding programs but also in Ventura County, California.

The turkey, *Meleagris gallopavo*, is represented by five diagnostic late Pleistocene specimens at Page-Ladson, but is generally abundant in the late Pleistocene of Florida (Steadman, 1980). Although often associated with scrub and savanna, *Meleagris* do not venture far from freshwater sources where typically they must drink twice a day.

One of the four kinds of birds of prey is a large species of extinct eagle. Represented by a large carpometacarpus (UF 92591), it is not clear to which of several possible genera it should be referred. The bald eagle, *Haliaeetus leucocephalus*, left a diagnostic proximal phalanx (UF 103488) in the deepest strata of Page-Ladson. And there are two species of *Buteo* hawks, both *B. linneatus*, the red-shouldered, and *B. jamaicensis*, the red-tailed hawk.

The smallest element of a terrestrial bird recovered at Page-Ladson is a left coracoid (UF 144995) of *Zenaida macroura*, the mourning dove, from Test F, Level 23.

The only marsupial presently living in North America is *Didelphis virginiana* the Virginia opossum. It is best represented in the late Pleistocene at Page-Ladson by a left mandible with m2 (UF 175208) and a right mandible with m2–4 (UF 92532). Besides their distinctive omnivorous dentition, these mandibles bear the diagnostic dental formula with four molars and the marsupial feature of a strongly inflected angle. This species occurs in the eastern United States, except Maine, northern Michigan, and northern Minnesota. It ranges southwestward into Colorado and most of Texas, and also occurs in southeastern Arizona, and coastal California, Oregon, Washington, and southern British Columbia (Whitaker, 1980:599). Opossums can live in most environments except the most arid ones. They are strictly nocturnal and their omnivorous diet includes worms, berries, insects, frogs, and fruits (Whitaker, 1980:276). In Florida average home range sizes were 142 ha in males and 64 ha in females (Ryser, 1995).

Of the five species of Edentata at Page-Ladson all are now extinct. Instead of the living armadillo, *Dasypus novemcinctus*, we found a very limited sample of the larger extinct species *D. bellus*. In Test F Level 23 it is represented by a buckler scute (an osteoderm from one of the dorsal movable bands), UF 145126. During the latest Pleistocene this species ranged north as far as the Ozark Plateau in Missouri (Schubert and Graham, 2000).

Holmesina septentrionalis, the giant armadillo, is better represented, mainly by its large durable osteoderms (dermal scutes), for example UF 103569 and UF 175246. The third and largest shelled mammal was *Glyptotherium floridanum*. It is also represented, albeit rarely, by its thick rosette-like scutes. Its very tall cheek teeth and association with open-country habitats suggest that it was probably a grazer; on the other hand, Gillette and Ray (1981) point out that it regularly occurred near ponds and streams.

Two taxa of ground sloths occur in late Pleistocene deposits of the Aucilla River, namely *Megalonyx jeffersoni* and *Paramylodon harlani. Megalonyx* appears far more abundantly than *Paramylodon*, and this probably reflects the preference of the latter for more open country habitats (Hulbert, 2001). *Megalonyx* is represented by a left mandible with m3 (UF 151914) and a mandibular symphysis (UF 153783). The only diagnostic specimen of *Paramylodon* is a scapula (UF 63429).

Among rodents we recovered six species. The fox squirrel, *Sciurus niger*, is generally rarer in Florida than the Gray Squirrel, *Sciurus carolinensis*, but it is the only squirrel recognized at this site. The fox squirrel bones and teeth are easily distinguished from those of *S. carolinensis* by their larger size (Moore, 1957). Fox squirrels range northward and westward into the Dakotas, northeast Colorado, and eastern Texas; in the Eastern United States they stop short of New England, most of New Jersey, extreme western New York, and northeastern Pennsylvania (Whitaker, 1980:418). In the South *S. niger* inhabits live oak and mixed forests, cypress and mangrove swamps, and piney areas (Whitaker, 1997:593). It is the largest of the tree squirrels, and is easily tracked by the debris it may discard under a favorite feeding location such as a low branch, log, or stump (Whitaker, 1980:418).

The modern beaver, *Castor canadensis*, seems quite appropriate in the setting at Page-Ladson. It is moderately abundant there and at other sites in the late Pleistocene of the Aucilla River. A good voucher specimen is a right mandible, UF 150474.

Two genera of muskrats evidently coexisted, for they appear together in Unit 3 (Test F Level 23) in the late Pleistocene at the Page-Ladson site. The muskrat *Ondatra zibethicus* no longer lives in Florida, where the only similar form is the endemic, round-tailed muskrat *Neofiber alleni* (Lawrence, 1941). *Ondatra* is represented by a right mandible with m1–3 (UF 175212) and *Neofiber* by a left mandible with m1–3 (UF 150300). Neither is abundant at Page-Ladson. These two genera occur together at several sites in the Aucilla River, and *Ondatra* is usually the more abundant of the two. A much larger sample of *Ondatra zibethicus* from the Latvis-Simpson site was reported and treated statistically by Mihlbachler *et al*. (2002). These two muskrats are placed in distinct tribes by specialists. *Neofiber* is smaller, has completely unrooted cheek teeth, and tends to live more in ponds and swamps than the fully riverine settings typical of *Ondatra* (Lawrence, 1941).

Erethizon dorsatum, the porcupine, occurs in the Aucilla River at several sites including the Page-Ladson. It is represented by UF 92392, a right mandible with its incisor and p4–m3 from Test B. It presumably fed on bark of trees, especially conifers. These porcupines, although originally from South America before the Pleistocene, have spread far into north temperate woods, and no longer occur in Florida.

And finally *Hydrochoerus* species is represented only by a pelvis, UF 92484. These amphibious large herbivores occur widely in the Pleistocene of Florida, but retreated into the American tropics at about the end of the Pleistocene (Hulbert, 2001).

Today Florida supports two species of rabbits within the genus *Sylvilagus*. These are the eastern cottontail, *S. floridanus*, and the marsh rabbit, *S. palustris* (Stevenson, 1976:493–494). We were able to distinguish some of the material as the marsh rabbit, for example UF 92523, a right mandible with p3–m1 from Test B. This species lives today along the Atlantic and Gulf Coastal Plain from southeastern Virginia through Florida and southern Georgia to Mobile Bay, Alabama where it is found in bottomlands, swamps, lake borders, and coastal waterways. *Sylvilagus palustris* will take to water if threatened, submersing itself until only eyes and nose are exposed (Whitaker, 1980:349). It feeds on vegetation such as cane, grasses, bulbs, and leaves and twigs of deciduous trees.

It is probable that the Page-Ladson site also includes material of *Sylvilagus floridanus*, but the sample was not clearly diagnostic. The eastern cottontail ranges widely from southern Canada and west-central Vermont southward, to east of the Sierra Nevada Mountains, to Central America, the northern Gulf Coast, and the tip of the Florida mainland. As the most common rabbit in North America, it inhabits areas of brush, old fields, woods, and cultivated areas. It prefers thickets and brush piles (Whitaker, 1997:596).

Five families of carnivores are present at the Page-Ladson site. Canids are represented at the Page-Ladson site by two species, a large dire wolf, *Canis dirus*, and a smaller domesticated dog, *Canis familiaris*. An example of *Canis dirus* is UF 69576 a large edentulous jaw; it is also represented by half a dozen isolated teeth. Gillette (cited in Hulbert, 2001) reported that the largest known specimens of dire wolves in North America came from the Aucilla River.

Canis familiaris, the domesticated dog, is represented by UF 92391, a left maxillary with canine and P3/ to M1/ plus the alveoli for all of its teeth. The alveolar length for C to M2/ measures only about 70 mm. A critical specimen, for its stratigraphic record, is UF 147398, a right m/1 from Test F, Level 23, definitively indicating the presence of *Canis familiaris* in Unit 3. Other similar specimens occur in other sites along the Aucilla River. Another critical example is UF 18742 from Ladson Rise, a complete lower jaw with very heavy wear on its lower carnassial tooth, typical of domestic dogs, but unusual in the wild. The length of this tooth row, from canine past m/2, is about 82 mm.

Ursus americanus, the black bear, is represented by UF 69621, an excellent specimen of the right facial portion from the orbit to the rostrum including P4–M2, evidently a rather small female. A larger black bear is represented by its left mandible, UF 150475. Such animals are wide-ranging and omnivorous to frugivorous. Another late Pleistocene bear that occurs in other Aucilla River sites but is not yet known from Page-Ladson is *Tremarctos floridanus*, conspecific relative of the South American spectacled bear.

Raccoons, *Procyon lotor*, are the most abundant carnivore species in the Page-Ladson site. Key specimens include UF 69634 and 175215, both right mandibles. There are also a large number of radii and a baculum (UF 175228). The raccoons are omnivorous and range widely in many habitats, but prefer swamp forest and hammock especially near water (McKeever, 1959; Walker, 1995). They also greatly prefer rest sites in trees, using ground sites less than 10% of the time (Walker, 1995).

The remains of otters, *Lutra canadensis*, occur fairly abundantly in the Aucilla River late Pleistocene deposits. A complete right mandible is UF 146161. A well-preserved partial jaw comes from Test F, Level 23. An excellent palate, UF 153075, comes from the Pleistocene sediments near the confluence of the Wacissa River branch with the Half-Mile Rise of the Aucilla River. Clearly these otters required substantial bodies of water for their life as semiaquatic carnivores.

Two species of smaller cats occur at the Page-Ladson site, namely *Lynx rufus*, the bobcat, and *Leopardus amnicola*, an extinct cat known only from this region of Florida but closely related to such small species as the margay, *L. wiedii*, living in South America (Hulbert, 2001). Both cats were wide-ranging top carnivores. Larger forms such as *Panthera onca*, the jaguar, *P. atrox*, the extinct giant lion, and *Smilodon fatalis*, the extinct sabercat, surely ranged through the area, but do not occur in present collections.

The remaining ten species are large herbivorous mammals, all but one of which became extinct. Only the white-tailed deer, *Odocoileus virginianus*, did not disappear by the end of the Pleistocene.

At the Page-Ladson site, the American Mastodon, *Mammut americanum*, is the most abundant of these large herbivores. The other proboscidean from this site, *Mammuthus columbi*, is barely represented. In a census of proboscideans from all the Aucilla River sites, the ratio of *Mammut* to *Mammuthus* is about four to one, based upon dentigerous specimens in the Florida Museum of Natural History fossil vertebrate collections. This is about the same ratio as occurs in Michigan late Pleistocene sites (Fisher, 1984). Thus Page-Ladson represents an extremely biased sample in favor of *Mammut*. A specimen of a *Mammut* maxillary, UF 192226 with M2–M3, is illustrated in Fig. 8.1. Other specimens with possible evidence of butchering by Paleoindians are discussed below.

Tapirs are represented by the species *Tapirus veroensis*, a widespread species in the late Pleistocene of Florida. This species ranged north as far as New York and

Figure 8.1 *Mammut americanum* right M2–M3, UF 192226, crown view. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Pennsylvania and west as far as Texas and Nebraska (Hulbert, 2002). Clearly these animals were browsers as indicated by their living relatives in South America, as well as by their low-crowned dentition and the carbon isotopes preserved in their enamel. Their living relatives seek refuge in water and this may help explain their presence in many Aucilla River sites. At Page-Ladson a very well-preserved thoracic vertebra from Test F Level 23 has numerous small bite marks possibly of *Felis amnicola*. Another specimen, from the same level, UF 146666, is the deciduous upper canine of a very young individual. The youngest carbon-dated records of *Tapirus* in North America are recorded in the Aucilla River (Webb *et al*., 1998). A mandible of *Tapirus* from Page-Ladson is illustrated in Fig. 8.2.

Relatively few specimens of *Equus* have been recovered from the Page-Ladson site. A right jugal and maxillary, UF 151993, represents a large species. Hulbert (2001) notes that *Equus* ranged over much of North America during the Irvingtonian and Rancholabrean, becoming extinct by the end of the Pleistocene. The genus survives in nature only in the Old World.

Peccaries, family Tayassuidae, are sparsely represented by two genera and species, *Platygonus cumberlandensis* and *Mylohyus fossilis*. In general *Mylohyus* is commoner in Florida late Pleistocene sites than *Platygonus*, in contrast with the abundance of *Platygonus* in most sites in the High Plains (Guilday *et al*., 1971; Hulbert, 2001). At Page-Ladson one specimen of a *Mylohyus* lower molar, UF 26949, occurs in Test F, Level 23. It appears to have experienced partial dissolution by the stomach acids in an alligator's stomach. An unerupted lower molar of *Platygonus* is UF 154659.

Figure 8.2 *Tapirus veroensis* left mandible with p4–m3, crown view. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Camelidae are represented by two genera of llama-like forms in the late Pleistocene of Florida. They are *Hemiauchenia macrocephala*, a larger, longer legged form, and *Palaeolama mirifica*, a slightly smaller, much shorter-legged form. *Hemiauchenia* is represented mainly by UF 150443, a right mandible with well-worn dentition. *Palaeolama* is represented by many more jaws, including one, UF 92512, a juvenile with deciduous p/4 and erupting m/1. The ratio of *Palaeolama* to *Hemiauchenia*, based on dentigerous elements, is 17 to 1. The youngest carbon-dated record of *Palaeolama* in North America is that recorded in the Aucilla River (Webb *et al*., 1998). A *Palaeolama* jugal, from which the carbon sample was taken, along with the right upper jaw and its molars are illustrated in Figs. 8.3 and 8.4.

Ruminants in the Page-Ladson site are represented abundantly by *Odocoileus virginianus*, and are indistinguishable from the living white-tailed deer. In Test F Level 23 we recovered a frontal bone with a three-point antler attached, UF 146090. It is well preserved, but has weather checking and flaking on its dorsal (presumably upper) surface. All three tines also give evidence of carnivore gnawing while the bone was still fibrous.This species ranges from the southern half of Canada over most of the United States except parts of California and the Great Basin where the mule deer, *Odocoileus hemionus*, seems to displace it. These mammals can reach over 200 cm in length and the bucks can have an antler spread up to 90 cm and usually lack antlers (Whitaker, 1980:608). White-tailed deer generally inhabit bushy areas, woodlands, forest edges and thickets along streams, avoiding both extremes of either dense stands of conifers or wholly open places (Hall and Kelson, 1959:1007). They graze on green plants, including aquatic forms in the summer. In the fall they feed on acorns, beechnuts, and

Figure 8.3 *Palaeolama mirifica* right jugal bone and maxillary with M1–M3, UF 180214, crown view. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Figure 8.4 *Palaeolama mirifica* lateral view of same. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

other nuts and corn, while in the winter they browse on woody vegetation (Whitaker, 1980:609).

Bison antiquus, an extinct long-horned relative of modern *Bison bison*, is well represented in various sites in the Aucilla River and the adjacent Wacissa River, most notably at the kill site reported from the latter by Webb *et al*. (1984). At Page-Ladson it is poorly represented. In Level 23 a proximal left humerus (UF 146074) was broken while fresh, and appears to have been weakened by osteoporosis. In Level 22 a distal left humerus (UF 151914) also appears very porous, and may be part of the same specimen. This species is more widely known in western North America where it grades as a chronospecies into the modern *Bison bison*, and is associated with similar habitats of open or semiopen grasslands (Wheat, 1972; Wilson, 1978; Walker, 1981). It is very poorly represented at the Page-Ladson site. After the latest Pleistocene, *Bison antiquus* evidently vanished in Florida.

8.3.3 Taphonomy of Stratigraphic Unit 3

At the Page-Ladson site sediments of stratigraphic Unit 3 are the main source of the late Pleistocene vertebrate fauna reported here. Test F, Level 23 was by far the most productive source of both terrestrial and aquatic vertebrates reported above. The predominant sediments over a large area of excavation consisted of fine calcareous sand, often extensively interbedded or simply mixed with peat. In Chapter 10 by Newsom and Mihlbachler this peat is thoroughly analyzed and shown to be *Mammut* digesta.

In general we envision these deposits of stratigraphic Unit 3 as a shallow pond in the bottom of the Page-Ladson sinkhole. At times of heavy rain presumably the present upstream (northeast) side of the sink acted as a conduit for surface runoff to be funnelled into the pond. Most of the time, especially during dry periods, the sinkhole pond became an important source of water for animals and humans. Much of the sand was derived from the steep slopes of the sink by a variety of alluvial processes. Animal trampling probably contributed a major part of the clastic input, especially the coarser limestone fragments (Govers and Poesen, 1998). The field notes based on diverse observations repeatedly point to a pattern of clastic sediments coarsening to the south. This is consistent with the geometry of the site indicating the main input during high-water events as a sluice from the northeast in the area of Test II.

Most fossil vertebrate material reported here was derived from Test F and from Test C. Level 23 was the most fossiliferous stratum producing a majority of the studied material. The next largest contribution to the late Pleistocene fauna came from Level 26 B, a deeper stratum but one that is probably not much older. In the overall faunal analysis we have not separated these two principal samples. On the other hand, we note that there are important differences between these two samples, especially with regard to the material of *Mammut americanum*.

The results of the bulk sample analysis from Level 23 are given in Table 8.2. Unfortunately the results of the sample from Level 26 B were lost. Lab notes indicate similar results except that molluscs were less abundant than in Level 23 sample.

Table 8.2 Fossiliferous fractions of Test F, Level 23 bulk sample

Fraction	*Dry weight (g)*	*Percent of total*
1. Wood and seeds	8.7	16
2. Molluscs	3.1	6
3. Fish bones and teeth	4.7	8
4. Small bones (mostly turtle)	39.4	70

The second taphonomic study involved quantitative analyses of the aquatic vertebrates from Levels 23 and 26 B. The results are recorded in Table 8.3. MNI refers to the minimum number of individuals that would be required to account for the entire sample, inferred from the count of the most common element. The abundance and diversity of fishes, amphibians, turtles, and snakes were much the same in the two successive levels. The only difference revealed by this study was a moderate decrease in the percentage of fishes relative to that of turtles between the lower and the upper level. This relative decrease in the bones and scales of fishes parallels the decrease in the abundance of mollusc shells reported in the first study. Presumably this reflects some relative degradation in preservation of the smaller, more delicate elements in Level 26 B. The same effect is suggested by the considerably greater number of identifiable bird bones in Level 23 (about 6 to 1) as measured in the 1991 through 1993 collections.

These taphonomic analyses confirm what sedimentology and geomorphology had already indicated, namely that this was a sinkhole pond. The molluscs, consisting of many gastropods but also lamellibranchs, detailed in Chapter 9 by Auffenberg and others, indicate well-lit conditions with a luxuriant growth of algae and other aquatic plants. The sample is dominated by turtles also indicative of a productive pond with enough current to provide adequate ventilation.

Additional information about the taphonomy of the late Pleistocene vertebrate fauna comes from direct field observations. We often noted that larger bones in Level 23 had been partly displaced or broken downward into Level 26 B. Clustering of such displaced elements appeared to fit a large subcircular pattern, suggesting trampling by proboscidean feet. We conclude that the water was shallow, probably a meter or less deep, and that the sediments in the lower stratum, Level 26 B were still moderately soft. Another common observation was that Level 26 B, but not Level 23, frequently held large, partly deteriorated branches and logs of cypress and other forest trees. The

Table 8.3 Quantitative analyses of aquatic fauna from stratigraphic Unit 3

	Level 23				*Level 26 B*			
	MNI	*Grams*	*Count*	*Percent*	*MNI*	*Grams*	*Count*	*Percent*
Fishes	40	99.2	451	43	24	82.8	455	39
Amphibia	4	21.6	33	03	4	4.2	19	01
Turtles	27	834.5	543	52	48	841.2	686	58
Snakes	2	4.5	18	02	2	15.4	21	02

long bones and also a section of tusk from Level 26 B showed diverse signs of desiccation cracks. In general the bone is not as well preserved as in Level 23 and there are very few small elements. For example all of the identified avian elements in the vertebrate fauna come from Level 23.

Still another distinction of interest between Levels 23 and 26 B involved the nature of *Mammut* material. The lower level consistently produced material of juvenile *Mammut* whereas the upper level contained abundant adult specimens, including the large male tusk and the maxillary with second and third upper molars illustrated in Fig. 8.1. Several of the juvenile teeth are cited in Green and Hulbert (in press).

These taphonomic clues, taken together, suggest that Level 26 B represented a severe drought episode with a strong bias toward mortality of young mastodons. A similar coincidence of desiccated bones, evidence of trampling, and young elephant mortality is described by Conybeare and Haynes (1984) in Zimbabwe at a natural water source that had experienced a severe drought. Subsequently Level 23 accumulated during more normal times, where water in the Page-Ladson sinkhole remained available, but normal mortality patterns prevailed. Additionally at the upper level human predation patterns impinged more clearly on the natural processes of deposition, partly because of the better preservation of the bones, teeth, and tusks.

We have previously alluded to the remarkable wealth of peat-like deposits associated with the late Pleistocene strata at Page-Ladson and the conclusion that they probably represent digesta of *Mammut*. Additional unexpected paleontological results come from this same mass of mostly anaerobic digesta. Lab analyses by Dr. Gross produced definitive results for three corticosteroid products, namely estrogen, testosterone, and progesterone. The results for the seven samples are presented in Table 8.4. The null sample from Level 27 produced strong evidence of testosterone, but this hormone unaccompanied by a balanced set of two others alone is a common signature of a "plant hormone". The combination of all three corticosteroids seen in Levels 23 and 7, however, resembles, in the words of Dr. Gross, "a sample swept up from an elephant's cage". We also can report two epithelial cells recovered by the search for parasites by Pamela Humphrey. Presumably these cells belonged to *Mammut* and were swept from its esophagus through its digestive tract.

We have not pursued these biochemical and cellular data farther. It is possible that they might offer interesting avenues for further study of *Mammut* paleobiology. It is conceivable that DNA samples might be recovered from favorable cell preparations.

Table 8.4 Results of corticosteroid analyses of Mammut *digesta (in ppm)*

Sample #	*Test F Level*	*Estrogen*	*Testosterone*	*Progesterone*
1	23	3.63	0.44	8.76
2	23	2.44	0.33	5.78
3	23	4.02	0.56	4.38
4	23	3.49	0.64	7.27
5	23	11.98	1.65	5.52
6	7	12.31	1.98	15.12
7	27	0.52	9.41	0.18

If so phylogenetic questions about the relationships and divergence times between Mammutidae and Elephantidae could be addressed. For the present, however, this study on *Mammut* biochemistry and cellular material remains preliminary.

On the strength of these hormonal results we hoped also to provide samples cut and cooled from inside the alveolar region of a mastodon tusk. Our hope was to develop a method of determining the sex of an individual tusk under the special conditions of anaerobic preservation at the Page-Ladson site. At Dr. Gross' suggestion we first provided equivalent samples of a freshly exhumed tusk from the carcass of a large, male African elephant. Unfortunately none of the tusk samples produced credible results.

It is noteworthy that the relative abundance of herbivore species in the late Pleistocene deposits at Page-Ladson are out of balance from what one ordinarily expects in typical coastal plain assemblages. Quite simply the abundances of browsing species outnumber those of grazing species. The exact numbers unfortunately have not been calculated partly because the samples of most terrestrial forms are too small to warrant a quantitative approach. Nevertheless it is evident that *Mammut* is far more abundant than *Mammuthus*; that *Tapirus* is more common than *Equus*; that *Megalonyx* is more common than *Paramylodon*; and that *Palaeolama* is more numerous than *Hemiauchenia* or *Bison*. Specific data from stable isotopes of carbon sampled in the enamel of these taxa (except the sloths that have only dentine in their teeth) show that the commoner species are browsers and the rarer ones are grazers (see Chapter 13 by Hoppe and Koch). Clearly the sinkhole at Page-Ladson selectively drew mesic browsing species, most notably *Mammut*, *Tapirus*, and *Palaeolama*.

8.4 Discussion

8.4.1 Paleoindian Interactions

While some of the vertebrate remains from Page-Ladson shed light on possible interactions with the first Floridians, the vast majority of the fauna was evidently accumulated in a natural manner as discussed above. Taking into account all Aucilla River sites, there is sound evidence for interactions with the following seven large mammal species: *Equus* sp., *Tapirus veroensis*, *Bison antiquus*, *Palaeolama mirifica*, *Mammuthus columbi*, *Mammut americanum*, and *Canis familiaris*.

The use of *Equus* tibia and metatarsals as tools is fully set forth elsewhere, and the evidence does not come from Page-Ladson (Dunbar and Webb, 1996; Webb and Hemmings, in press). An ungual phalanx of a newborn foal from Test C, Level 23 (1995 excavation Fs 1.1) gives evidence of fresh cut marks at the proximal end mainly near the volar surface.

Limited evidence at Page-Ladson implicates human use of *Tapirus veroensis*. UF 146081, a left humerus has numerous shallow, fresh cut marks where presumably meat was removed from the shoulder region.

We have no evidence of human interactions with *Bison antiquus* at the Page-Ladson site, perhaps because it was outside of the normal range of that species, as indicated by its extreme rarity. The key evidence comes from the Wacissa River kill site described by Webb *et al*. (1984).

The late Pleistocene strata at Page-Ladson yield an abundance of *Mammut americanum* bones, teeth, including tusks, and digesta. The assemblage also yields considerable evidence of human killing and butchering, presented in Chapter 14 by Dunbar. A particularly clear example is a tall (anterior) thoracic spine (UF 27894) from the digesta deposits in Test C. This represents a young adult, with spine length of 44.5 cm and maximum width at base, 18.3 cm. The vertebra was broken while fresh, as indicated by fibrous green breaks at the top of the centrum above the zygapophyses. Presumably two strong poles were passed through the neural canal and using powerful leverage against the neural arch snapped it above the vertebral centrum. The dorsal tip of the spine is missing, possibly because the epiphysis had not fused in this young adult specimen. In addition there are obvious impact fractures and spalls at the upper expansion of the spine over an area of about 72 mm wide by 45 mm deep. And finally there are sets of fine longitudinal cuts along both sides of the neural arch (the lower shoulders of the spine), a region from which major cuts of meat would have been removed.

A very distinctive aspect of *Mammut* butchering in Aucilla River sites involves "peeling" marginal bone from the metapodials and phalanges. At Page-Ladson the best example is UF 103618, a second metacarpal with fine chipping and flaking around both proximal and distal ends. The most obvious activity is around the plantar edge of the distal articular surface. The largest single flake, about 3 cm^2, however, was removed from the proximal surface and extended into the upper articular surface. Obviously these activities were done after the bone was fully removed from adjacent bones and most of the adhering connective tissue. On the other hand, they were evidently done while the bone was fresh, possibly for the nutritious value in and around this relatively porous element. Similar activity involving a whole set of *Mammut* metapodials and phalanges from the Serbousek Site in the Little River section of the Aucilla River remains to be described.

Of special interest is the large tusk from Test F, Level 23 featured in Chapter 11 by David Webb and Chapter 12 by Fisher and Fox. We attempt to show that it was cut and twisted from the skull of a large male. A premaxillary fragment that closely fits that tusk was recovered within 1 m of the tusk in the same stratigraphic level. Then, quite possibly, the tusk was cached in the pond already heavily loaded with anaerobic digesta from other mastodons. This *Mammut* was evidently dispatched in the late summer or early fall adjacent to the Page-Ladson sinkhole pond.

The Aucilla River also produces the largest samples of worked ivory implements in the New World, most notably ivory shafts (sagaies) five or more centimeters long. One of these is from Page-Ladson, but many more are from Sloth Hole. Recent analyses have shown that these are made from *Mammut* tusks (Hemmings *et al*., 2004). Thus the utility of caching a large Mastodon tusk in anaerobic pond muck becomes clear.

Traditionally Paleoindian cultures in North America have been linked with hunting *Mammuthus columbi*. The most recent able advocate of this view is Haynes (1999, 2002). He closely connects the Paleolithic traditions of Eurasian hunting of *Mammuthus primigenius* with the classic Clovis associations involving *Mammuthus columbi*, for example at Blackwater Draw, New Mexico and Lehner, Arizona. He attributes the differences between large Eurasian and small North American mammoth kill sites principally to sociocultural differences, stressing the view that Paleoindian populations in the New World were smaller and more mobile than their Eurasian counterparts. The possible differences in habitat and behavior between the two species of mammoth are minimized. And no consideration is given to possible differences in habitat and behavior that might be involved in Mastodon kill sites (although they are included in the same list of 11 "stronger" and 8 "weaker" proboscidean kill sites for North America).

The present record of *Mammut* utilization at Page-Ladson and other sites in the Aucilla River adds to the evidence of *Mammut*-hunting tradition in eastern North America. The body of this tradition is still less prominently recognized than the western Clovis/*Mammuthus* tradition. Graham *et al.* (1981) presented a clear case for the Paleoindian/*Mammut* association at Kimmswick in Missouri; it was not only a kill site, but also probably a reduction site. In a series of studies Fisher (1984, 1987) completely advanced the modern study of *Mammut* procurement by Paleoindians. He investigated several sound examples of butchery and caching in the Great Lakes Region, while also presenting a number of cases of natural deaths. Hiscock in New York, Burning Tree and Paleo Crossing in Ohio are further examples of substantial case studies of *Mammut* butchery by Paleoindians in eastern North America (Laub *et al.*, 1988; Fisher *et al.*, 1991). The Manis site in Washington shows that *Mammut* kill sites are not restricted to eastern North America. The association of *Homo sapiens* and *Mammut americanum* is more probably keyed to the ecology of this browser found mainly in or near mesic forests, rather than to any particular geographic region. FAUNMAP (1994) gives 206 major localities including many in California and Washington. It is worthy of note that *Mammut* is also recorded at Lehner in Arizona but not as prey of Paleoindians. Much of eastern North America supported mesic forests composed of mixed conifers and deciduous trees that served as the preferred browsing habitat of *Mammut*. In general, but not exclusively, this contrasts with the predominance of grazing habitats in the midcontinent and far west where *Mammuthus* was more abundant and more generally hunted.

Underwater excavations in north Florida rivers, especially the Aucilla River, have produced nine ivory tool types (Hemmings *et al.*, 2004). Preliminary analyses of six long shafts ("sagaies" in the French terminology applied to similar Paleolithic tools) demonstrate that these tools were made from tusks of *Mammut*. Also an atlatl hook from the Ichetucknee River is made from a *Mammut* lower tusk (Hemmings *et al.*, 2004). Thus, there is strong evidence of a *Mammut*-based "ivory industry" in Florida. Presumably the same or similar traditions extended to other places where *Mammut* was hunted. Such ivory tools are recoverable in Florida rivers because of the excellent anaerobic wet-site preservation that occurs therein.

Radiocarbon dates at Page-Ladson place the *Mammut*-Paleoindian association as much as a millennium earlier than the classic *Mammuthus*-Paleoindian association in classic Clovis sites in the western United States (see Chapter 4 by David Webb and Dunbar). This raises the possibility that proboscidean hunting in North America first appeared in the east with *Mammut* as its target. If so the classic western model of Clovis-*Mammuthus* hunters is a later adaptation.

This alternative hypothesis about the sequence of proboscidean hunting traditions in North America also has implications about the geography of Paleoindian dispersal. If *Mammut* kill sites continue to yield older dates than classic western Clovis sites such as Blackwater Draw and Lehner, then the prey-base sequence would tend to align itself with the alternative hypothesis that the first Americans arrived from Europe by way of the north Atlantic (Bradley and Stanford, 2004).

The importance of *Canis familiaris* as part of a Paleoindian hunting strategy has not received sufficient attention. Such reticence is unusual in the broad and thoughtful coverage of such authors as Haynes (2002) and Meltzer (2004). The reason probably stems from uncertainties as to when dogs entered North America. Their presence at Page-Ladson and Sloth Hole in close association with early Paleoindian cultural remains may be one of the most important results of the Aucilla River excavations. Previously the oldest securely identified specimens came from Danger Cave in Utah (Grayson, 1988), but these were associated with early Holocene dates.

A major practical problem complicating identification of *Canis familiaris* is its close resemblance to *C. latrans*, the coyote. Anything less than a complete mandible or maxillary, or preferably a large statistical sample, will arouse doubt within the most competent investigator. At Dust Cave in Alabama, for example, in the early Holocene level (Zone T 1) Morey (1994) identified five specimens, some with two teeth in their jaws, all possibly from one individual, merely as *Canis* species. Even this much material fell ambiguously within the possible ranges of three different canids, not only *C. familiaris* but also *C. latrans* and even *C. rufus*. Occasionally a favorable feature, diagnostic of some domestic dogs, will simplify the task of identification. For example the severely crowded premolars in a maxillary permitted Walker (1981) to identify *C. familiaris* in the fauna from Vore Bison Jump even while that fauna also included both *C. lupus* and *C. latrans*.

An important result of FAUNMAP (1994), the mapping project that documents late Quaternary distributions of North American mammals, is to show that there are very few records attributed to *C. latrans* in eastern North America. In contrast legitimate records of *C. latrans* are mapped in many sites from central Texas and from Arkansas westward. Farther east there are very few latest Pleistocene citations of *C. latrans*, the largest number being five from Florida. One way to read this pattern is to consider the possibility that these few scattered citations represent misidentified *C. familiaris*, thus supporting the view of Nowak (1974) that *C. latrans* was a western species that did not insinuate itself eastward until historic times.

In the late Pleistocene of Florida each example of *C. latrans* presented by FAUNMAP (1994) comes from a very late Pleistocene site closely associated with Paleoindian cultural material, including one from the Aucilla River. Another is from Seminole Field near St. Petersburg, a well-known Paleoindian and late Pleistocene faunal complex. The largest of these Florida late Pleistocene samples, representing either *C. latrans* or *C. familiaris*, comes from Devil's Den, Florida. Martin and Webb (1974) considered the problem and gave the decision in favor of the dogs. In the latest Pleistocene Cutler Hammock fauna from south Florida, Emslie and Morgan (1995) and Morgan (2003) recognized both *Canis dirus* and *C. latrans* or *C. familiaris*. The presence of humans in the same cave site, as well as the morphology of the available jaws, suggests to us that dogs, not coyotes, were present at Cutler Hammock.

Given the present evidence, we hypothesize that most of the late Pleistocene small *Canis* in Florida and eastern North America was associated with Paleoindians in a hunting context. The western evidence will continue to be more difficult to deal with simply because there may generally be more coyote material in most faunal assemblages.

Clearly this hypothesis that *Canis familiaris* is usually the small canid present in late Pleistocene faunas of Florida and perhaps eastern North America is preliminary and requires testing with better samples. If future evidence continues to support this possibility, then it becomes appropriate to discuss how *Canis familiaris* may have been utilized by Paleoindian hunters. Certainly the ability of domesticated dogs to track, stalk, and turn prey, as part of a coordinated hunting campagin, would have been invaluable. Inclusion of *C. familiaris* adds one more indication that Paleoindians came to the New World with a highly sophisticated repertoire of hunting tools and tactics.

8.4.2 Megafaunal Extinctions

We may begin by considering the disappearance of some of the vertebrate fauna purely on the evidence available in the Aucilla River sites. For the sake of local empiricism this requires us, for the moment, to ignore the widespread debate on the extinctions issue.

It is immediately apparent from these stratigraphically ordered samples that many of the most prominent terrestrial vertebrate species disappeared between the latest Pleistocene and early Holocene strata, that is below Unit 5 in the terminology set forth in Chapter 3 by Kendrick. A small but fresh-looking fragment of proboscidean tusk in Test F, Level 11, in roughly the middle of the gray clay sequence of Unit 4, was the youngest evidence of an extinct large herbivore in that excavation. It did not appear to be reworked, but that possibility cannot be wholly ruled out even in that relatively low-energy deposit.

More generally we find the last abundant and diverse evidence of large herbivores in the more productive sands and silt of Unit 3, often in the peat-like sediments that we identify as *Mammut* digesta. The last appearances there, extracted from Table 8.1, include the giant tortoise, *Hesperotestudo crassiscutata*, five genera of edentates, and nine genera of large terrestrial herbivores. In addition to these 15 large herbivores, two carnivores, *Canis dirus* and *Leopardus amnicola*, also made their last appearances in the late Pleistocene at Page-Ladson. As noted above, four other large, rare carnivores, *Smilodon fatalis*, *Panthera onca*, *Panthera atrox*, and *Tremarctos floridanus*, surely lived in the area and became extinct at about the same time. Several large scavenging birds also became extinct at this same time. Presumably the losses of predators and scavengers can be directly traced to the drastic reduction in herbivore abundance and diversity.

Among the terrestrial vertebrates that vanished from the Page-Ladson sequence at the end of the Pleistocene, approximately half have close relatives surviving in the American tropics. The exact number of tropical survivors depends on the degree of relationship that one wishes to count. For example all the five genera of edentates from Page-Ladson have South American relatives, but only one, the genus *Dasypus*, can claim congeneric survivors. The next nearest claim among edentates is that of *Megalonyx*, which has a closely related genus in *Choloepus*, the two-toed tree sloth. Among edentates the number of closely related Neotropical surviving genera is thus two.

Among carnivores the small cat, *Leopardus amnicola*, has congeneric, and perhaps even conspecific, relatives that survive widely in the American tropics. The same is true of *Panthera onca*, the jaguar, and *Tremarctos floridanus*; although neither is known from Page-Ladson, both surely lived in the region as demonstrated by their occurrence in several nearby sites of similar age. The capybara, genus *Hydrochoerus*, also occurs in late Pleistocene sites in the Aucilla River and elsewhere in Florida, but subsequently withdrew into South America. *Tapirus veroensis* has very closely related species living in lowland and upland regions of South America. Both tayassuid genera and also both extinct genera of llamas have sibling genera living in the Neotropical Realm (i.e. Central and/or South America). Thus the number of herbivores and carnivores from Page-Ladson with congeneric survivors in the Neotropical Realm is four. If one counts sibling genera as well, the number doubles. If one adds the two edentates, the Neotropical survivors of late Pleistocene extinctions at Page-Ladson number ten. Thus about half of those terrestrial taxa that became extinct might equally well be considered to have retreated into the tropics.

Three other terrestrial species disappeared from Florida after the latest Pleistocene, and must be considered in this discussion of extinctions and extirpations. The fates of *Ondatra zibethicus* and *Erethizon dorsatum* must have some bearing on these issues. After the late Pleistocene they both disappeared from Florida, retracting their ranges to the north, no farther south than central Georgia. The porcupine relies heavily on tree bark, especially of conifers, as a major constituent of its diet, but this does not seem to help explain its disappearance from Florida. The previous coexistence of *Ondatra zibethicus* with *Neofiber alleni* has been well documented, not only at Page-Ladson, but also in several late Pleistocene river sites in north Florida. After the Pleistocene, however, its body size became smaller, and its range shrank northward (Mihlbachler *et al.*, 2002), while *Neofiber alleni*, the smaller of the two species of muskrats, persisted as a Florida endemic. Such enlarged ranges (beyond present distributions), especially in rodents, are characteristic of many “disharmonious” faunas of the late Pleistocene. The causal explanation generally offered for such effects involves narrowing ecological tolerances in more restrictive Holocene environments (Webb *et al.*, 2004).

The third species that retreated after the late Pleistocene is the condor, *Gymnogyps californicus*, which retracted its range westward. Presumably the cause of its decline involved the loss of an abundance of megafaunal carcasses on which to scavenge. The retreat continued through the Holocene until it became extinct everywhere except in coastal California.

And finally it is worth considering what terrestrial herbivores persevered in this region without succumbing to extinction. The largest of these is *Odocoileus virginianus*. It appears to have become far more abundant in the early Holocene than it was earlier. This would surely be expected if it pre-empted some of the ecospace vacated by more than a dozen other large herbivores. Similarly, after the latest Pleistocene deer must have become the primary large prey item in the human economy. This predictable focus by early Archaic culture is supported by an abundance of evidence on the Bolen Surface at Page-Ladson.

Unlike western North America, *Bison* in Florida and perhaps generally in the east, had vanished along with other late Pleistocene megafauna. At present the only evidence of human utilization in the Aucilla River region is the *Bison antiquus* kill site on the Wacissa River, dated at about 11,000 ^{14}C BP (Webb *et al*., 1984).

Turning now to the broader context of North American Pleistocene studies, it is evident that the two prevailing hypotheses regarding the possible causes of latest Pleistocene megafaunal extinctions are climatic change and human impacts. The importance of the Page-Ladson data, besides documenting another substantial site, is that they are among the most complete in southeastern United States, thus providing crucial information from a region with few multidisciplinary sites. The late Pleistocene vertebrate records at Page-Ladson occur within a context that provides considerable evidence of changing environments and Paleoindian procurement activity. They thus offer potentially balanced local insights into the extinction question.

The obvious question then becomes whether the pattern of vertebrate extinctions in the southeastern United States adds to or modifies that from other regions. The answer is “yes, incrementally”. Of course the debate between climatic causes and Paleoindian “blitzkrieg” remains unresolved. Webb *et al*. (2004) and Meltzer (2004) present a pair of reviews of the extinction question in North America. A fundamental problem in this arena is that the impact of humans is so rare and so subtle in the late Pleistocene of North America that it is very difficult to interpret, much less to quantify in biologically meaningful terms. This shortcoming weakens both sides of the debate. Skeptics as well as “blitzkrieg believers” continue to argue at great length about a rather limited set of relevant data (Thomas, 1971; Lyman, 1984; Haynes, 2002). The problem can be overcome in a satisfactory manner only by greatly augmenting the relevant excavations.

In an earlier report from the Aucilla River Prehistory Project we noted that the radiocarbon dates from Unit 3, as applied to *Palaeolama* and *Tapirus*, were the youngest known in North America for those two genera (Webb *et al*., 1998). The Page-Ladson data constrain the terminal dates of the missing megafauna to something between about 12,400 and 10,000 ^{14}C BP. Although the timing of the Aucilla River extinctions appears to be a millennium older, one must allow considerable leeway for missing records, especially because the next higher strata, the gray clays of Unit 4, are not very productive of fossil vertebrates. Thus the Page-Ladson extinction data may be approximately synchronous with the majority of other last appearances in North America, that is approximately 11,000 ^{14}C BP, very near the end of the latest Pleistocene.

The fact that about half of the extinct taxa from Page-Ladson have close generic, if not conspecific, Neotropical surviving relatives, strongly implicates climatic change as a major effect. The herbivores among these extralimital survivors, including sloths, tapirs, peccaries, and llamas, require productive browse on a year-round basis. Possibly the seasonally dry and unproductive climates that encroached on Florida, beginning with Meltwater Pulse 1A, can be cited as the primary cause of a retreat by these species to lower latitudes. Explaining the southward range shift of the other carnivores may be more complex, but in essence they were followers of the herbivores. It is certainly clear that jaguars rely heavily on peccaries as their primary prey. Spectacled bears, on the other hand, may have been more like the browsing herbivores in their requirements for continuous year-long supply of nutritious browse and fruit. This pattern of Neotropical retreat has strong climatic implications for the late Pleistocene extinctions.

Page-Ladson along with several other sites from the Aucilla and the adjacent Wacissa River provide clear evidence of human impact on the late Pleistocene species that became extinct. It is intriguing to note that the apparent human impact is more intense for five of the species that did not have Neotropical surviving relatives. These species are *Mammut americanum*, *Mammuthus columbi*, *Bison antiquus*, *Equus* species, and *Hesperotestudo crassiscutata*. The three herbivores that fall in both categories, having closely related Neotropical survivors and showing evidence of human impact, are *Megalonyx jeffersoni*, *Tapirus veroensis*, and *Palaeolama mirifica*; but these impacts appear to be rare (Hemmings *et al*., 2004). A major problem, as noted above, is that the impact of humans is so rare and so subtle in the late Pleistocene of North America that it is very difficult to interpret, much less to quantify in biologically meaningful terms. This shortcoming does not actually support the skeptics who are quick to discount light evidence of “cut marks”. There is a countervailing case that the skeptics have ignored evidence of Paleoindian hunting in half or more of the 36 genera of North American megafauna that became extinct at about the end of the Pleistocene. On the other hand, a few minor cuts on a few bones of one species do not fully warrant conviction of Paleoindians as its executioners. Several years ago Fisher (1984) wisely observed that we must be wary both of Type I (false positive) and of Type II (false negative) evidence in this very subtle detective work. Much work is still needed.

A most intriguing modification of the human impact hypothesis is the keystone species argument presented by Owen-Smith (1989). Based on his own experiences in African ungulate communities, he suggested that the reduction and ultimate demise of one proboscidean species might produce a cascade of detrimental ecological changes depriving other herbivores in the same ecosystem of essential resources. Such a hypothesis is credible especially if applied to coadapted sets of grazing species which depend heavily on the keystone species such as an elephant to open (by terraforming) and maintain the grazable landscape. This concept has not been applied in any detail in the late Pleistocene of North America, but it certainly warrants it. It might apply equally well to the Paleoindian/*Mammuthus* tradition in the west or to the Paleoindian/*Mammut* tradition in the east.

8.5 Conclusions

The Page-Ladson site gives evidence of about three dozen aquatic and about three dozen terrestrial vertebrates in the late Pleistocene strata, especially Unit 3. The aquatic species are all primarily inhabitants of freshwater, mainly representing quiet water or even swampy conditions, not unlike many settings in Florida today. Nearly half of the terrestrial sample, however, had become extinct or at least extralimital by the latest Pleistocene. Much of the discussion, therefore, focuses on the paleoecology and extinction of the larger terrestrial fauna, or so-called megafauna.

With regard to the extinction question, there is strong evidence within the Page-Ladson terrestrial fauna that about half of the terminal taxa had close relatives that survive in the American tropics. This evidence of southward survival tends to suggest that environmental change may have been a primary cause of extinction of these taxa in Florida, especially since many of them require year-round production of nutritious browse. On the other hand, there is strong direct evidence in the Aucilla and Wacissa Rivers of late Pleistocene hunting and butchering by Paleoindians of at least *Mammut*, *Mammuthus*, *Bison*, *Palaeolama*, and *Equus*. Thus the causes of extinctions probably included both climatic change, notable sudden cooling and drying episodes such as Meltwater Pulse 1A, and impacts by Paleoindians especially predation on *Mammut* both for its food value and for its ivory, bone, and other raw materials.

8.6 Acknowledgments

We have received valuable help from many friends and colleagues. We thank Drs. Dan Fisher, Dave Steadman, Russ Graham, and Richard Hulbert for advice on vertebrate faunas including various identifications. Dr. Frank Stehli volunteered his services on many matters including analyses of bulk samples. We appreciate the quantitative analyses of aquatic vertebrates carried out by Tanya Peres. We thank Pamela Humphrey of the Parasitology Lab at the Veterinary School of the University of Florida, Gainesville, for sampling the *Mammut* digesta for parasites and cells. And finally we are deeply grateful to Dr. Tim Gross of the U.S. Geological Survey in Gainesville, Florida for carrying out biochemical analyses of *Mammut* digesta in his laboratory.

References

Bradley, B. and D. Stanford. 2004. The North Atlantic Ice-edge corridor: a possible Paleolithic route to the New World. *World Archaeology* 36:459–478.

Conant, R. 1975. *Field Guide to Reptiles and Amphibians of Eastern and Central North America*. Houghton Mifflin, Boston.

Conybeare, A. and G. Haynes. 1984. Observations on elephant mortality and bones in Water Holes. *Quaternary Research* 22:189–200.

Dunbar, J. S. and S. D. Webb. 1996. Bone and ivory tools from submerged Paleoindian sites in Florida, pp. 331–353. *In* D. G. Anderson and K. E. Sassaman (eds.) *The Paleoindian and Early Archaic Southeast*. The University Press of Alabama, Tuscaloosa, Alabama.

Emslie, S. D. and G. S. Morgan. 1995. Taphonomy of a late Pleistocene Carnivore Den, Dade County, Florida. *In* D. W. Steadman and J. I. Mead (eds.) *Late Quaternary Environments and Deep History: A Tribute to Paul S. Martin* . Scientific Papers, vol. III. The Mammoth Site of Hot Springs, South Dakota.

FAUNMAP Working Group. 1994. A database documenting late Quaternary distributions of mammal species in the United States. Illinois State Museum Scientific Papers, 25.

Fisher, D. C. 1984. Taphonomic analysis of late Pleistocene mastodon occurrences: evidence of butchery by North American Paleo-Indians. *Paleobiology* 10:338–357.

Fisher, D. C. 1987. Mastodont procurement by Paleoindians of the Great Lakes Region: Hunting or scavenging, pp. 309–421. *In* M. H. Nitecki and D. V. Nitecki (eds.) *Evolution of Human Hunting*. Plenum Press, New York.

Fisher, D. C., B. Lepper and P. Hooge. 1991. Taphonomic analysis of the Burning Tree Mastodont. *Current Research in the Pleistocene* 8:88–91.

Gillette, D. and C. E. Ray. 1981. Gloptodonts of North America. *Smithsonian Contributions to Paleobiology* 40:1–255.

Govers, G. and J. Poesen. 1998. Field experiments on the transport of rock fragments by animal trampling on steep slopes. *Geomorphology* 23:193–203.

Graham, R. W., C. V., Haynes, D. L. Johnson and M. Kay. 1981. Kimmswick: a Clovis-Mastodon association in eastern Missouri. *Science* 213:1115–1117.

Grayson, D. K. 1988. Danger cave, last supper cave and hanging rock shelter: the faunas, American Museum of Natural History. *Anthropological Papers* 66:1–205.

Green, J. L. and R. C. Hulbert. In press. The juvenile dentition of *Mammut americanum* (Mammalia, Proboscidea). *Journal of Vertebrate Paleontology*.

Guilday, J. E., H. W. Hamilton and A. D. McCrady. 1971. The Welsh Cave Peccaries (*Platygonus*) and associated Fauna, Kentucky Pleistocene. *Annals of the Carnegie Museum* 43:249–320.

Haast, W. E. and R. Anderson. 1981. *Complete Guide to Snakes of Florida*. Phoenix, Miami, Florida.

Hall, E. R. and K. R. Kelson. 1959. *The Mammals of North America*, 2 vols. Ronald, New York.

Haynes, G. 1999. The role of Mammoths in rapid Clovis dispersal, pp. 9—38. *In* G. Haynes, J. Klimowicz and J. Reumer (eds.) *Mammoths and the Mammoth Fauna: Studies of an Extinct Ecosystem*, DEINSEA – Annual of Natural History Museum Rotterdam, the Netherlands.

Haynes, G. 2002. *The Early Settlement of North America: The Clovis Era*. Cambridge University Press, pp. 1–355.

Hemmings, C. A., J. S. Dunbar and S. D. Webb. 2004. Florida's Early Paleoindian Bone and Ivory Tools, pp. 88–92. *In* B. Lepper and R. Bonnichsen (eds.) *New Perspectives on the First Americans*. Texas A&M University Press, College Station, Texas.

Hulbert, R. C., Jr. 2001. *The Fossil Vertebrates of Florida*, 350 pp. University Press of Florida, Gainesville.

Hulbert, R. C., Jr. 2002. *Tapirus veroensis* Sellards 1918, Fossil Species of Florida No. 2:1–14.

Jackson, D. R. 1978. Evolution and Fossil Record of the Chicken Turtle *Deirochelys*, with a Re-evaluation of the Genus. *Tulane Studies in Zoology and Botany* 20 (1–2).

Laub, R. S., N. G. Miller and D. W. Steadman (eds.) 1988. Late Pleistocene and early Holocene paleoecology and archaeology of the eastern Great Lakes Region. *Bulletin of the Buffalo Society of Natural History 33.*

Lawrence, B. 1941. The muskrat in Florida. *Proceedings of the New England Zoological Club* 19:17–19.

Lee, D. S., C. Gilbert, C. H. Hocan, R. E. Jenkins, D. E. McAllister and J. R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. Pub. # 1980–12, N. Carolina Biological Survey, North Carolina State Museum of Natural History.

Lyman, L. R. 1984. Archaeofaunas and Butchery Sites: A taphonomic perspective, pp. 249–337. *In* M. B. Schiffer (ed.) *Advances in Archaeological Method and Theory*, vol. 10. Academic Press, San Diego.

Martin, R. A. and S. D. Webb. 1974. Late Pleistocene mammals from the Devil's Den fauna, Levy County, pp. 114–145. *In* S. D. Webb (ed.) *Pleistocene Mammals of Florida*. The University Press of Florida, Gainesville.

McKeever, S. 1959. Relative abundance of twelve southeastern mammals in six vegetative types. *American Midland Naturalist* 62:222–226.

Meltzer, D. J. 2004. Peopling of North America. *Developments in Quaternary Science* 1:538–563.

Mihlbachler, M. C., C. A. Hemmings and S. D. Webb. 2002. Morphological chronoclines among late Pleistocene muskrats (*Ondatra zibethicus*: Muridae, Rodentia) from northern Florida. *Quaternary Research* 58:289–295.

Morgan, G. S. 2003. Late Rancholabrean mammals from southernmost Florida, and the Neotropical influence in Florida Pleistocene faunas, pp. 15–38. *In* R. J. Emry (ed.) *Cenozoic Mammals of Land and Sea: Tributes to the Career of Clayton E. Ray*, Smithsonian Contributions to Paleobiology, no. 93. Smithsonian Institute, Washington, D.C.

Moore, J. C. 1957. The natural history of the fox squirrel, *Sciurus niger shermani. Bulletin of The American Museum of Natural History*. 113:1–71.

Morey, D. F. 1994. *Canis* remains from Dust Cave. *Journal of Alabama Archaeology* 40:163–172.

Nowak, R. M. 1974. North American Quaternary *Canis* Monograph of Museum of Natural History, University of Kansas 6:1–154.

Owen-Smith, N. 1989. Pleistocene extinctions: the pivotal role of megaherbivores. *Paleobiology* 13:351–362.

Page, L. M. and B. M. Burr. 1991. *A Field Guide to Freshwater Fishes North America North of Mexico*. Houghton Mifflin Company, Boston.

Ryser, J. 1995. Activity, movement and home range of Virginia opossum (*Didelphis virginiana*) in Florida. *Bulletin of the Florida Museum of Natural History* 38:177–194.

Schubert, B. W. and R. W. Graham. 2000. Terminal Pleistocene armadillo (*Dasypus*) remains from the Ozark Plateau, Missouri, USA. *PaleoBios* 20:1–6.

Steadman, D. W. 1980. A review of the osteology and paleontology of Turkeys (Aves: Meleagrinae). Natural History Museum of Los Angeles County, *Contributions in Science* 330:131–207.

Stevenson, H. M. 1976. *Vertebrates of Florida*. The University Press of Florida, Gainesville, Florida.

Thomas, D. H. 1971. On distinguishing natural from cultural bone in archaeological sites. *American Antiquity* 36(3):366–371.

Walker, D. N. 1981. Early Holocene vertebrate fauna, pp. 274–394. *In* G. C. Frison and D. J. Stanford (eds.) *The Agate Basin Site: A Record of the Paleoindian Occupation of the Northwestern High Plains*. Academic Press, New York.

Walker, S. 1995. Habitat Use by Raccoons (*Procyon lotor*) in a Sandhill–Wetland Mosaic of North-Central Florida. *Bulletin of the Florida Museum of Natural History*. 38:245–260.

Webb, S. D. (ed.) 1974. *Pleistocene Mammals of Florida*. The University Press of Florida, Gainesville.

Webb, S. D. 1976. Underwater paleontology of Florida's rivers. *National Geographic Society Research Reports*. 1968 Projects:479–481.

Webb, S. D., J. T. Milanich, R. Alexon and J. S. Dunbar. 1984. An extinct *Bison* kill site, Jefferson County, Florida. *American Antiquity* 49:384–392.

Webb, S. D., C. A. Hemmings and M. P. Muniz. 1998. New Radiocarbon dates for vero tapir and stout-legged llama from Florida. *Current Research in the Pleistocene* 15:127–128.

Webb, S. D., R. W. Graham, A. D. Barnosky, C. J. Bell, R. Franz, E. A. Hadly, E. L. Lundelius, Jr., H. G. McDonald, R. A. Martin, H. A. Semken, Jr. and D. W. Steadman, 2004. Vertebrate paleontology. *Developments in Quaternary Science* 1:519–538.

Wheat, J. B. 1972. The Olsen-Chubbuck Site: A Paleo-Indian *Bison* Kill. Society for *American Archaeology Memoir 26*.

Wheeler, A. and A. K. G. Jones 1989. *Fishes*. Cambridge University Press, New York.

Whitaker, J. O., Jr. 1980. *The Audubon Society Field Guide to North American Mammals*. Alfred A. Knopf, Inc., New York.

Williams, J. D. 1983. Freshwater fishes. *National Audubon Society Field Guide to North American Fishes, Whales, and Dolphins*. Alfred A Knopf, Inc., New York.

Wilson, M. 1978. Archaeological kill site populations and the Holocene evolution of the genus *Bison. In* L. Davis and M. Wilson (eds.) *Bison* Procurement and Utilization. *Plains Anthropologist Memoir* 14:9–23.

Chapter 9

Non-marine Mollusca

KURT AUFFENBERG, IRVY R. QUITMYER, JAMES
D. WILLIAMS and DOUGLAS S. JONES
Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.

9.1 Introduction

The non-marine mollusks of the late Pleistocene–Holocene boundary are virtually unstudied in Florida. Previous surveys of the fossil mollusk faunas of Florida have emphasized marine taxa of the middle to late Tertiary. Clearly, this is an artifact of the numerous marine exposures throughout much of the state, as well as the research interests of earlier workers. As a result, the serendipitous occurrences of non-marine taxa in these sediments were reported upon as ancillary sidebars to the main thrust of the research. Unfortunately, abundant alluvial deposits, where younger fossil non-marine mollusks would be expected, have received very little attention. Fossil freshwater mollusk beds, which commonly occur in much of the state, remain poorly studied, while terrestrial mollusk fossils from the late Pleistocene–Holocene boundary have been very rarely collected. Therefore, little is known of the distribution of the non-marine fossil mollusks in Florida. Additionally, potential climatic and environmental information that may be gleaned from the remains of these organisms is wanting.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 247–261

Non-marine mollusks can be highly responsive to changes in local environmental conditions, such as seasonality, amount of precipitation, water chemistry and quality, soil type, relative humidity and temperature. Additionally, many species have a limited distribution and/or are often restricted to certain, often highly specialized, habitats. Presence of a taxon or suite of taxa in the fossil record is perceived as evidence indicative of a particular climatic regime and/or set of environmental factors. Analyses of former assemblages have provided insight into the past, which are in most cases entirely congruent with those garnered by more traditional methodology, such as the study of vertebrate remains. For these reasons, non-marine mollusks, particularly terrestrial species, are being utilized with more frequency to reconstruct paleoclimates and paleoenvironments by an increasing number of researchers (see Evans, 1972 for uses in archaeology; Roth and Emberton, 1994; Karrow, *et al*., 1996).

The Page-Ladson (8JE591), Aucilla River, Jefferson County, northwestern Florida site provided an ideal setting to study the non-marine mollusks occurring in the area over the last approximately 12,500 years. Throughout history, this part of the Aucilla River formed a low energy environment where flow rate was slow to non-existent and sedimentation gradual. Studies of the sediments and ^{14}C dates show that the Page/Ladson sediments were sequentially accumulated with little or no disturbance to the superimposed layers. As a result, organic preservation is excellent.

In the following report, we present a summary of the non-marine mollusks collected at the Page-Ladson site. The material collected from this site represents one of the most diverse fossil non-marine mollusk faunas ever documented in North America. The broad diversity has allowed a relatively detailed reconstruction of the local paleoclimate and paleoenvironment. This material also reveals that a once diverse freshwater mollusk fauna was extirpated from the Aucilla River drainage within the last 9,950 years to yield the present depauperate fauna. Possible causes for this local extinction event are presented as well as a discussion dealing with the apparent lack of recolonization by the relatively diverse freshwater mollusk faunas occurring in the drainages to the east and west of the Aucilla River.

9.2 Methods

The mollusks identified in this study were stratigraphically excavated from the underwater sediments of Test F of the Page-Ladson site (see Latvis and Quitmyer, Chapter 1 this volume) during field seasons from 1991 to 1993. Some of the materials listed in Table 9.1 were collected (post 1993) by members of the Aucilla River Prehistory group other than the authors. The initial Page-Ladson research design did not include the identification and analysis of molluscan remains because their presence in such abundance was not anticipated. Once recognized, we were obligated to extend our analysis to these taxa.

Table 9.1 *Molluscan fauna identified from the Page-Ladson site (8JE591). Species marked by an "X" represent those sampled in 1991–1993 by the authors; those marked by an "*" represent species sampled post-1993 by other researchers. Assignments of Physidae from Taylor (2003) in part*

		9,950+/−70	*10,870+/−100*	*11,240+/−90*	*11,460+/−50*			*11,790+/−50*				*12,260+/−60*		*12,310+/−50*			*12,290+/−60*	*12,385+/−100*				*12,370+/−90*			*12,940+/−70*				*12,570+/−100*
Taxon	*L2a*	*L2b*	*L3*	*L4*	*L5*	*L6*	*L7*	*L8*	*L9*	*L10*	*L11*	*L12*	*L13*	*L14*	*L15*	*L16*	*L17*	*L18*	*L19*	*L20–22*	*L20*	*L20B*	*L21*	*L22*	*L23*	*L24*	*L25*	*L26A*	*L26B*
BIVALVIA																													
Musculium sp.																									X				
Pisidium sp.																									X				
Toxolasma paulus																									*				
GASTROPODA																													
Oligyra orbiculata	Unknown level																												
Pomacea paludosa												X				X	X	X		X					X				
Elimia floridensis		*																											
Campeloma geniculum		*																											
Viviparus georgianus		X,*					X	X	X	X	X	X	X		X					X			X	X	X	X	X	X	X,*
Amnicola dalli dalli																									X				*
Aphaostracon hypohyalina	Unknown level																												
Spilochlamys conica		*																				X		X	X				*
Haitia sp.		*																				X			X	X	X		*
Haitia cubensis																									X				
Haitia hendersoni		*							X															X	X		X		
Haitia cf. *hendersoni*		*						X					X										X			X			*
Haitia heterostropha heterostropha		*					X	X	X			X						X	X					X	X		X		*
Haitia heterostropha pomila		*							X								X			X					X				*
Laevapex diaphanus																									X				*
Gyraulus parvus																						X			X	X			
Micromenetus dilatatus avus																						X			X				*
Micromenetus alabamensis																													*
Planorbella duryi		*					X	X	X	X		X		X	X	X	X	X	X	X				X	X		X		
Planorbella trivolvis intertextum		*																	X										*
Planorbula armigera wheatleyi																	X		X						X	X	X		*
Fossaria cubensis																									X				*

(*Continued*)

Table 9.1 *Molluscan fauna identified from the Page-Ladson site (8JE591). Species marked by an "X" represent those sampled in 1991–1993 by the authors; those marked by an "*" represent species sampled post-1993 by other researchers. Assignments of Physidae from Taylor (2003) in part*—(*Continued*)

		9,950+/–70	*10,870+/–100*	*11,240+/–90*	*11,460+/–50*			*11,790+/–50*				*12,260+/–60*		*12,310+/–50*			*12,290+/–60*	*12,385+/–100*				*12,370+/–90*			*12,940+/–70*				*12,570+/–100*
Taxon	*L2a*	*L2b*	*L3*	*L4*	*L5*	*L6*	*L7*	*L8*	*L9*	*L10*	*L11*	*L12*	*L13*	*L14*	*L15*	*L16*	*L17*	*L18*	*L19*	*L20–22*	*L20*	*L20B*	*L21*	*L22*	*L23*	*L24*	*L25*	*L26A*	*L26B*
Fossaria modicella																									X				*
Pseudosuccinea columella		*																									X		
Gastrocopta armifera																									X				
Gastrocopta pentodon																									X				*
Pupisoma macneilli																									X				
Pupoides sp.																									X				*
Pupoides albilabris																						X			X				*
Vertigo ovata																									X				
Strobilops aenea																									X				
Helicodiscus parallelus																													
Euglandina rosea		*														X				X				X	X				
Euconulus sp.																										X			
Glyphyalinia umbilicata																								X					*
Ventridens sp.		*																	X										
Hawaiia minuscula																									X				*
Mesomphix globosus																		X											
Mesomphix cf. *pilsbryi*																								X					
Daedalochila cf. *subclausa*		*					X	X					X				X	X	X	X				X	X	X	X		
Polygyra septemvolva															X	X	X	X	X					X	X			X	
Mesodon thyroides																			X					X					
Triodopsis hopetonensis		*											X		X					X				X	X	X			*
Level	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	20	20B	21	22	23	24	25	26A	26b
Number of taxa	0	16	0	0	0	0	4	5	5	2	1	4	4	1	4	4	6	6	8	7	0	5	2	11	32	8	8	2	20

Samples were excavated by hand with the aid of a hydraulic dredge (see Latvis and Quitmyer, this volume) where the dredge effluent was passing onto a screening platform equipped with 1/4 in. (6.35 mm) gauge hardware cloth screen. Some of the specimens were recovered from four one-liter bulk samples taken with a one-liter box core device from each level of Test F. All samples were transported to the Florida Museum of Natural History where material collected from the dredge screen was allowed to air dry and then sorted by hand. The bulk samples were sieved through a nested series of geological screens with gauges measuring 1/8 in. (3.18 mm) and 1/16 in. (1.58 mm). These sieved samples were hand sorted wet so as to assure the preservation of the attendant botanical material. The sorted molluscan samples were then allowed to air dry.

The Page-Ladson mollusks were identified to the lowest possible taxonomic level by Kurt Auffenberg, Irvy R. Quitmyer, James D. Williams, and Douglas S. Jones. The identifications were facilitated by direct comparison with the modern comparative collections of the Florida Museum of Natural History and with the aid of generous specimen loans provided by Harry G. Lee, Jacksonville, Florida. All of the fossil mollusks identified in this study are housed in the stratigraphic collections of the Division of Invertebrate Paleontology, Florida Museum of Natural History.

9.3 Results

The systematic sampling and sorting techniques employed throughout the investigation (see Latvis and Quitmyer, Chapter 1, this volume) allowed the collection of mollusk specimens ranging in size from 1.5 to 50 mm, as well as the accurate dating of the layers of riverine sediments. Many hundreds of specimens consisting of 46 species and subspecies of non-marine mollusks were collected (Table 9.1) during the extensive investigation of this site in the eastern portion of the Florida panhandle. Preservation is superb in all taxa except the freshwater bivalves, which were often represented by fragmentary material.

The land snail assemblage collected at the Page-Ladson site (Table 9.1) is very similar in composition to the fauna of today, with only two anomalies; *Gastrocopta armifera* and *Mesomphix* cf. *pilsbryi* are not known from the area today (Hubricht, 1985). This suggests that parameters, such as forest type (i.e. hardwoods versus conifers), soils, precipitation, relative humidity, temperature, were also comparable and the terrestrial habitat of the Aucilla River watershed has not undergone substantial changes in the past 12,000 years.

In contrast, the freshwater mollusk fauna has drastically changed over this period of time. The fossil freshwater mollusk assemblage collected at the Page-Ladson site is very similar to that expected in a northwest Florida coastal river system of today. However, the freshwater mollusk fauna occurring today at Page-Ladson, and the Aucilla River at-large, is extremely depauparate in comparison to neighboring river systems, indicating that a once diverse assemblage has been extirpated.

9.4 Discussion

9.4.1 Origin of Specimens

Three hypotheses are proposed for the origin of these fossil mollusk specimens. These shells (1) were water-transported to the site from upstream localities, (2) are the remains of individuals living in the immediate vicinity of the site, or (3) were deposited by a combination of both transported and *in situ* individuals. The analysis of the molluscan fauna presented below does nothing to confirm or disprove any of these possible scenarios. Other contributions in this volume offer compelling arguments that the site was an isolated body of water not connected to the present-day Aucilla River, a perspective with which we have no data to refute. However, the mere presence of fossil non-marine mollusks at the site does not necessarily indicate that these species actually lived there.

Non-marine mollusks are easily transported downstream, particularly during periods of high water and floods. Living individuals can be flushed from their habitats during floods. Land snails are generally intolerant of long periods of submergence and often drown before floodwaters recede. Buoyancy of dead land snails may be increased by trapped gasses (a byproduct of tissue decomposition) inside the whorls. This often results in the shells being carried long distances. For example, collections made in southern Texas of water-transported specimens have resulted in several erroneous locality records due to shells being carried far from their points of origin in Mexico and deposited along the Texas bank of the Rio Grande River (Hubricht, 1985). Drift samples taken from along rivers are now considered virtually useless, in fact, misleading, while those collected from riverine sediments are regarded as suspect and should be analyzed with caution. Freshwater snails and bivalves are also transported downstream after death. Shells found at the Aucilla site could have been carried through the deep underground river passages or washed overland through the elaborate mosaic of intermittent wetlands connecting the numerous sinkholes in the area, but probably not in the observed numbers with such remarkable preservation. Despite not being able to state with total certainty that all of the mollusk fossils originated at Page-Ladson, they surely were derived from the Aucilla watershed.

Other investigators in this volume provide insights into the origin and history of the middle Aucilla River during the last glacial interval (~18,000 YBP). Since we have been unable to locate documentation of subsidence and/or uplifting in this part of Florida over the past ~18,000 years, it is assumed that changes in the watershed are primarily attributable to either regressions or transgressions of the sea. Relative to present day sea level, the Gulf of Mexico reached its Pleistocene nadir of around 120 m about 18,000 years ago (see Donoghue, Chapter 2, this volume), with a concomitant lowering of the freshwater aquifer. As a result, the spring-fed Wacissa River may not have developed until ~5,000 YBP. Such a configuration would preclude the river transport of non-marine mollusks from upstream localities.

The present Aucilla drainage can be divided into four sections: (1) coastal zone, (2) karst region, (3) Wacissa River, and (4) the upper section. The coastal zone extends from the Gulf of Mexico north to Nuttall Rise (near the Page-Ladson site) and is characterized by a broad floodplain with cypress and hardwood swamps, and coastal salt marshes. The section from Nuttall Rise north and east runs through an extensive karst region and is characterized by the entire river channel disappearing into sinkholes, flowing through deep underground passages, only to reappear at the surface further downstream. The Wacissa River is a large, spring-fed tributary originating near the town of Wacissa, Jefferson County, and entering the main river channel as a series of braided streams just north of Nuttall Rise. The upper section of the Aucilla (north of the karst region) drains the extensive swamps and lowlands between the Oklockonee and Suwannee drainages of northern Florida and southern Georgia.

Palynological evidence (see Chapters 6 and 7, this volume) indicates that the forest around the site has not changed substantially over the last 12,000 years. Much of the flora living in the area today also occurs in Pleistocene samples. Since the now heavily forested site harbors a moderately diverse assemblage of land snails, it can be postulated that a similar forest type in the past would have a comparable land snail fauna. Certainly, shells would be washed into the site from the immediate vicinity during periods of high precipitation and flooding.

9.4.2 Land Snails

The terrestrial mollusks found at the Aucilla River site comprise a diverse array in size and phylogeny (Table 9.1). The fauna is very similar to that presently found in the area (Hubricht, 1985). Major shifts in the land snail faunal composition through the time period embraced by these deposits are not apparent, leading us to believe that climatic change was minimal (but see below). Palynological evidence from northern Florida indicates periodic local alternations between hardwood and conifer forests. These shifts in dominant floral composition were caused by climatic shifts during the Late Quaternary, resulting in warmer temperatures, increased precipitation and higher sea levels (Platt and Schwartz, 1990). In the lower levels of the site, particularly 22–23, the assemblage is indicative of the presence of a primarily hardwood forest, although a mixture of hardwoods and conifers may have been present. None of the species are necessarily confined to forests consisting solely of hardwoods. The diversity in the lower levels, as well as the habitat preferences of the fewer species present in the upper levels, does not indicate a purely coniferous forest either. Unlike the Appalachian conifer forests, the land snail fauna is extremely depauperate in the pinelands of the southern coastal plain. All of the species present at the Page-Ladson site are often found in forests comprised of a mixture of hardwoods and conifers growing on sandy, moderately well-drained soils. In Florida, this environment often occurs in floodplains, such as that of the Aucilla River. The presence of *Pupoides albilabris*, *Gastrocopta armifera*, and perhaps *Daedalochila* cf. *subclausa*, which are often found in more open situations than most of the other species found at the site, suggests the existence of nearby grassy glens, perhaps surrounding springs, seeps or bogs.

The number of land snail species collected varies greatly between levels, with the highest diversity noted in levels 22 and 23 ($N = 15$). The lowest diversity is observed in the upper levels (7–14) ($N = 2$). There are several potential reasons for these differences: (1) an actual reduction in diversity through time, (2) differing sample volume, during the course of the study, (3) specimen preservation through time was affected by changes in water chemistry, and (4) differential deposition through time and/or exact site of sample collection.

A reduction in land snail diversity at the site would most likely be caused by a major alteration of the local habitat. Palynological evidence (see Chapters 6 and 7, this volume) does not indicate that such a change occurred. However, two species, *Gastrocopta armifera* and *Mesomphix* cf. *pilsbryi* (Table 9.1), now confined to localities further to the northwest, do indeed disappear from the record in levels 23 and 22, respectively. Since neither species occupies a specialized microhabitat and both are widely distributed to the north, these disappearances probably indicate range reductions brought about by a warming trend rather than major environmental change. These warmer climates also may have affected the floristic composition of the area, but apparently did not cause alterations of the microhabitats utilized by non-specialized, ground-dwelling land snails.

The faunal assemblage was not systematically collected as it came from other research activities on going at the site. However, this assemblage addresses the fundamental question of what species existed at the site through time. For example, large volume samples were excavated from level 23 for other research purposes, while the faunal samples from levels 7 to 14 came from much smaller volumes. This greater bulk of sieved matrix from level 23 clearly increased the opportunity of collecting rarer species and those less commonly preserved.

Reduced dissolved calcium in water increases the leaching of these ions from mollusk shells (Stites *et al*., 1995). This shell dissolution process diminishes the possibility that a shell would become adequately preserved to allow collection and proper identification. However, the high preservation quality of the specimens from throughout the sampled layers, even the later layers with lower molluscan diversity, attests that excessive postmortem dissolution did not occur. Additionally, the freshwater mollusk shells do not have eroded apices, etc., indicating that dissolved calcium levels were probably high even when the animals were living.

Because the samples were taken from progressively lower stratigraphic levels we assume that the samples reflect different environmental conditions (differential deposition) that existed during deposition. In addition, physical attributes of the site may have changed through time leading to differential deposition of fossils. At this time we do not have evidence to confirm or refute this speculation.

The presence of *Gastrocopta armifera* and specimens tentatively identified as *Mesomphix* cf. *pilsbryi* at Page-Ladson is interesting. *G. armifera* is widespread throughout central and eastern United States, but in Florida, this calciphile of sunny, grassy areas and open forests (Hubricht, 1985) is known only from the limestone region of Jackson County, near Marianna (Pilsbry, 1948), about 90 miles (144 km) northwest of the study area. It is rarely encountered on the coastal plain in other parts of its range (Hubricht, 1985). *Mesomphix* cf. *pilsbryi* is known from inland localities in Alabama, Georgia, and South Carolina, as well as Jackson County and northern Walton County, Florida. It occurs in floodplains and upland forests, but is not known from the coastal plain (Hubricht, 1985). Since the preferred habitats (forest, leaf litter, surficial limestone) of these species are still extant at the Aucilla site, perhaps the only viable explanation for their disappearance from the area is the warming trend that apparently occurred during this time period. For these two species, the general climatic amelioration following the final glacial episode resulted in a range restriction to the north.

The distributions of *Gastrocopta armifera* and *Mesomphix* cf. *pilsbryi* may also be governed by elevation. Neither species are known from the coastal plain in southeastern United States so their occurrence at a site presently only 2 m above sea level is perplexing. However, Donoghue (Chapter 2, this volume) reports that the earliest Floridians would have found the coast at approximately the modern 40–60 m isobath. This would have placed the Page-Ladson site at an approximate 40–60 m elevation around 12,000 YBP. Interestingly, the elevation of Marianna, Jackson County, Florida where both species are known to occur today, is at an elevation of approximately 40 m.

9.4.3 Freshwater Mussels

Remains of freshwater mussels, family Unionidae, consist of a single right valve, about 37 mm in length (the extreme posterior portion of valve is broken off) and hinge plate fragments of several valves, consisting of the umbo, pseudocardinal teeth, and a small portion of adjacent shell. All unionid material is identified as *Toxolasma* (formerly *Carunculina*) *paulus* (Lea, 1840). Assignment of the single valve to *T. paulus* is based on the oval outline of the shell, evenly rounded posterior ridge, moderately thick pseudocardinal teeth, and the umbo sculpture. Identification of the fragments is based on the relatively intact distinctive umbo sculpture, which consists of thick concentric ridges that become thickened, somewhat knobby, and curve dorsally on the posterior ridge. Gulf Coast species of *Toxolasma* are sexually dimorphic, mature females are broadly truncate posteriorly compared to males which are evenly rounded. Based on the rounded posterior end of the intact right valve, it appears to be a male.

Taxonomy of the genus *Toxolasma* in the eastern Gulf drainages is not fully understood. Clench and Turner (1956) recognized *Toxolasma paulus* as valid while some authors (Johnson, 1972; Burch, 1975; Heard, 1979) have considered it to be a synonym of *T. parvus* (Barnes, 1823). *Toxolasma paulus* is currently recognized (Turgeon *et al.*, 1998) and its distribution extends from the Apalachicola Basin of Alabama, Florida, and Georgia, eastward to the St Johns River, Florida (Brim Box and Williams, 2000). However, it is not currently known to inhabit the smaller coastal drainages between the Ochlockonee and Steinhatchee rivers.

Very little is known about the ecology and biology of *Toxolasma paulus*. It is known to occur in a variety of habitats, ranging from large rivers to small creeks with slow to moderate current and in ponds, lakes, and reservoirs. It is typically found in substrates consisting of sand or sandy mud and is most often found in shallow water near shore on sloping bottoms where it follows the rise and fall of the water level. *Toxolasma paulus*, like most species of unionids, requires a host, usually fish, for its parasitic larval stage (glochidia) for successful reproduction. The glochidial host is not known for *T. paulus* but other species of *Toxolasma* are known to utilize fishes of the sunfish family Centrarchidae (e.g. *Lepomis gulosus*, Warmouth and *L. macrochirus*, Bluegill) as glochidial host (Watters, 1994). The Aucilla River and adjacent coastal rivers and creeks are known to have diverse centrarchid fauna.

9.4.4 Freshwater Snails

Viviparus georgianus (Lea, 1834) is an ovoviviparous freshwater operculate snail occurring from the lake region of central Florida north to Illinois and Indiana, mainly in the Mississippi River drainage. It has dramatically expanded its range north to southern Canada since 1867 (Clench, 1962; Burch, 1989). Several names have been proposed for forms found in the southeastern United States, particularly in the lake region of peninsular Florida (Clench, 1962) that have been treated historically as synonyms or subspecies of the nominate form. Recent genetic and morphometric studies (Katoh and Foltz, 1994) have shown that populations occurring in the Florida panhandle are specifically distinct from those of the peninsula. Unfortunately, it remains unknown whether the peninsular populations are conspecific with that of the Altamaha River at Darien, Georgia, the type locality for *V. georgianus* (Katoh and Foltz, 1994). The southeastern populations are appropriately referred to as the "*Viviparus georgianus* species complex" until other populations from throughout the range are studied. They concluded that in Florida *V. goodrichi* Archer, 1933 occurs west of the Aucilla River, in the Choctawhachee and Apalachicola River drainages, while *V. limi* Pilsbry, 1918 is restricted to the Ochlockonee River. These drainages are west of the Aucilla River. In this report, we follow Katoh and Foltz (1994) by referring populations in the Suwannee River, which is east of the Aucilla drainage, to *V. georgianus* (Lea, 1834).

All of the viviparid shells collected from throughout the Page-Ladson sediments are best assigned to *Viviparus georgianus* (Lea, 1834). Comparative shell morphology and variation of the Aucilla River fossils are most similar to that observed in living populations from the Suwannee River, although shells were not quantitatively analyzed. The Aucilla specimens do not exhibit the diagnostic shell shapes and sizes of *V. goodrichi* or *V. limi* as characterized by Katoh and Foltz (1994).

Viviparus georgianus is presently distributed in peninsular Florida from the Econfina River to the St. Mary's River on the northeast coast and south to Lake Okeechobee. Living *V. georgianus* have not been recorded from the Aucilla River drainage, including the spring-fed Wacissa River, despite extensive sampling (Clench and Turner, 1956; FLMNH collections; personal observation). *V. georgianus* is a common component of most lotic habitats in northern peninsular Florida. It is inconceivable that this large, conspicuous species would be overlooked by biologists that have sampled the Aucilla River over the past 50 years.

Viviparus georgianus is present in virtually every level at the Page-Ladson site. This indicates that the species, although now absent from the Aucilla River drainage, occurred at the Page-Ladson site from at least 12,570 to 9,950 YBP (Table 9.1). Recent excavations at the Latvis Simpson Site (8JE 1500) about 2 km downstream from Page-Ladson yielded *V. georgianus* from layers dating to ~32,000 YBP, based on three dates (Mihlbachler *et al*., 2002). Its absence from the Aucilla River drainage today is particularly perplexing given that the species occurs in the Econfina River (FLMNH collections) less than 10 miles (26 km) to the east.

The otherwise diverse Hydrobiidae is poorly represented in the Aucilla River watershed. To our knowledge only two species, *Amnicola dalli dalli* (Pilsbry and Beecher, 1892) and *Spilochlamys conica* Thompson, 1968 have been recorded from the drainage, both confined to the spring-fed Wacissa River (Thompson, 1968; FLMNH collections). *S. conica* has been recorded from Wakulla County southeast to the Waccasassa River drainage in Levy County. It is usually confined to aquatic habitats associated with freshwater springs. *Amnicola d. dalli* is ecologically restricted to spring and spring run habitats from Wakulla County east and south to various spring systems in the St. Johns River drainage (Thompson, 1968). It is to be expected that both species would be present in the spring-fed Wacissa River, and absent in the Aucilla River upstream from the confluence with the Wacissa. The apparent absence of these species in the vicinity of the Page-Ladson site today cannot be readily explained. However, hydrobiids are often overlooked due to their small size and the specialized collecting techniques necessary to procure specimens. Therefore, the lack of records for these two species in the Aucilla may be an artifact of collecting and not represent a real hiatus in their distributions. A series of specimens without provenience from the Page-Ladson site in the FLMNH malacology collections was identified by Fred G. Thompson as *Aphaostracon hypohyalina* Thompson, 1968. We did not encounter this species in the material from the Page-Ladson site. *Aphaostracon hypohyalina* is presently confined to spring habitats in the Suwannee River drainage and Blue Springs in Levy County in north central peninsular Florida (Thompson, 1968). Its former presence in the Aucilla drainage is noteworthy and coincides closely with the reduced distributions observed in other freshwater taxa. The widespread brackish to freshwater species, *Littoridinops monroensis* (Frauenfeld, 1863), has not been recorded from the Aucilla River or its tributaries (Thompson, 1968), although it must surely occur in the salt marshes along the Gulf Coast. Specimens collected from an undated fossil layer of freshwater mollusks in the Wacissa River, near Goose Pasture were identified by Fred G. Thompson as *L. monroensis* (R. Means, personal communication, October, 1999). We did not encounter this species in the fossil material from the Page-Ladson site, but its occurrence would not be overly surprising.

Planorbula armigera wheatleyi (Lea, 1858) is represented in several layers at the Page-Ladson site (Table 9.1). This species is presently confined to the Chipola River system of southeastern Alabama and northwest Florida (Thompson, 1984; Burch, 1989). Its apparent extirpation from the Aucilla River drainage represents a range contraction to the northwest of approximately 80 miles (128 km).

9.4.5 Extirpation of the Freshwater Fauna

The coast and inland regions of the northern and eastern Gulf of Mexico are extremely susceptible to tropical storms and hurricanes and the remarkable surges that often accompany these events. Warm water temperatures and shallow water depths are conducive to the development and/or sustentation of tropical storms in the Gulf of Mexico. The Florida coast extending from the Aucilla River drainage to just north of Tampa Bay (ca. 300 km) has been characterized as a low-energy, storm-dominated shoreline due to its susceptibility to storm-driven tidal surges. Barrier islands are absent from this stretch of coastline, sand is scarce and sediments overlying the limestone bedrock seafloor are generally thin (Goodbred *et al.*, 1998). Additionally, inland elevations of <10 m above sea level are prevalent in the area. The effects of storm surges, which may exceed 5–6 m, often extend inland for several kilometers. Evidently, the physiographic parameters defining this susceptibility (warm, shallow offshore environment, low inland topography) have been extant along the northern and western coasts of Florida for at least several thousand years.

Goodbred *et al.* (1998) discuss sedimentological evidence which indicates the Waccasassa River embayment (158 km SE of the Aucilla River) was impacted by a storm surge(s) at some point after the regional rapid rise in sea level at about 1800 YBP. Although similar studies have not been conducted in the Aucilla River embayment, it is not unreasonable to assume that the coastal region in the Aucilla area has also been periodically impacted by storm surges. Such events have the potential to extirpate local populations of freshwater mollusks.

One missing part of the fossil record is that time from 9,950 YBP to the present. The fossil evidence is clear that a diverse freshwater fauna existed at the Page-Ladson site at 9,950 YBP and contemporary collections indicate that this condition no longer exists. Based on Goodbred *et al.* (1998) findings at the nearby Waccasassa River embayment and the content of the Page-Ladson molluscan fauna at 9,950 YBP, we believe that storm surges adversely affected the local freshwater mollusk fauna some time after 9,950 YBP. What we do not know is when the rising sea level of the Holocene neared the Page-Ladson site to the point where such events would have direct impacts on the local biota.

9.4.6 The Extant Freshwater Mollusks of the Aucilla River

The present fauna of the Aucilla River drainage appears enigmatic when compared to other river systems of the Florida panhandle and the northern peninsula. This is particularly true for the freshwater mollusks. Although the river has been sampled, at least at highway bridges, by several competent biologists over the last 50 years, we have been able to locate very few records of mollusks from the entire Aucilla River drainage. Most of these sparse records are from the Wacissa River, a large spring-fed tributary. Molluscan taxa otherwise widespread in Florida and contiguous areas of Georgia and Alabama (i.e. *Viviparus*, *Campeloma*, *Lioplax*, *Pomacea*, *Elimia*, several genera of Hydrobiidae, *Planorbella*, and genera of Unionidae, *Elliptio, Uniomerus,* and *Villosa*) are apparently lacking from the main Aucilla River channel and its tributaries, except the Wacissa. The absence of freshwater gastropods in several south central Georgia streams (Thompson and Hershler, 1991) and the upper Aucilla River drainage (upstream from the confluence with the Wacissa River) is probably related to water chemistry caused by local geology. The rarity of *Elimia* in the fossil record at the Page-Ladson site (Table 9.1) is noteworthy. Since *Elimia* is ecologically confined in Florida to creeks, rivers, and a few lake systems (central Florida), it is indeed tempting to use this absence as corroboration that the Page-Ladson site was a small, isolated body of water. However, the genus is also lacking at the Page-Ladson site of today, as well as the entire Aucilla drainage, except in the spring-fed Wacissa River (FLMNH collections). The possibility that this species cannot survive travel through the river's subterranean passages between the confluence of the Wacissa River and Nuttall Rise may explain its absence from the fossil site today, but does nothing to explain its apparent absence from the Aucilla drainage upstream from the Wacissa.

9.5 Conclusions

The Page-Ladson site provides an ideal setting to study the non-marine mollusks that have existed in the area during the last approximately 12,500 years. Fossils are abundant and organic preservation is excellent. In this report, we record 20 species of terrestrial snails and 26 freshwater taxa ($N = 46$) occurring in the 24 sampled levels that span about 2,600 years (12,570 – 9,950 YBP).

The terrestrial snail fauna is comparable to that found in the area today, except for two anomalies. *Gastrocopta armifera* and *Mesomphix* cf. *pilsbryi* disappeared from the site sometime after 12,970Y BP. These two species are known today from localities in Jackson County, Florida and are widely distributed in southern Alabama and Georgia today, indicating a range reduction of about 90 miles (144 km), probably caused by the warming trend known to have occurred during the late Pleistocene.

The present freshwater mollusk fauna of the Aucilla River drainage is extremely depauperate when compared to those of other coastal river systems in the Florida panhandle. However, excavations at the Page-Ladson site document a diverse freshwater mollusk fauna existed there until some time after 9,950YBP. One possible explanation is that the rising sea levels in the late Pleistocene allowed tropical storm surges to impact this formerly inland body of water extirpating the local freshwater mollusk fauna. Repopulation of this portion of the present-day Aucilla River has not occurred due to the subterranean features upstream from the site and the dearth of freshwater mollusks upstream from the confluence of the Wacissa and Aucilla rivers.

The land snail fauna indicates a paleoenvironment at the Page-Ladson site of mixed forest (hardwoods and conifers) with some areas being open, perhaps grassy. The diverse freshwater mollusk fauna suggests varied microhabitats (i.e. hard and soft substrates) in shallow water (<3 m) with submerged and perhaps emergent vegetation.

References

Brim Box, J. and Williams, J. D. 2000. Unionid mollusks of the Apalachicola Basin in Alabama, Florida, and Georgia. *Bulletin of the Alabama Museum of Natural History*, 21:1–143.

Burch, J. B. 1975. *Freshwater Unionacean Clams (Mollusca: Pelecypoda) of North America*. Malacological Publications, Hamburg, MI, i–xviii, 1–204.

Burch, J. B. 1989. *North American Freshwater Snails*. Malacological Publications, Hamburg, MI, i–viii, 1–365.

Clench, W. J. 1962. A catalogue of the Viviparidae of North America with notes on the distribution of *Viviparus georgianus* Lea. *Occasional Papers on Mollusks*, 2(27):261–287.

Clench, W. J. and R. D. Turner. 1956. Freshwater mollusks of Alabama, Georgia, and Florida from the Escambia to the Suwannee River. *Bulletin of the Florida State Museum, Biological Sciences*, 1(3):97–239.

Evans, J. G. 1972. *Land Snails in Archaeology*. Seminar Press, London, 417 pp.

Goodbred, S. L., E. E. Wright, and A. C. Hine. 1998. Sea-level change and storm-surge deposition in a late Holocene Florida salt marsh. *Journal of Sedimentary Research*, 68(2):240–252.

Heard, W. H. 1979. Identification manual of the freshwater clams of Florida. State of Florida Department of Environmental Regulation. *Technical Series*, 4(2):1–83.

Hubricht, L. 1985. The distributions of the native land mollusks of the Eastern United States. *Fieldiana, Zoology, New Series*, 24:i–viii, 1–191.

Johnson, R. I. 1972. The Unionidae (Mollusca: Bivalvia) of peninsular Florida. *Bulletin of the Florida State Museum, Biological Sciences*, 16(4):181–249.

Karrow, P. F., G. S. Morgan, R. W. Portell, E. Simons, and K. Auffenberg. 1996. Middle Pleistocene (early Rancholebrean) vertebrates and associated marine and non-marine invertebrates from Oldsmar, Pinellas County, Florida, pp. 97–133. In: *Palaeoecology and Palaeoenvironments of Late Cenozoic Mammals, Tributes to the Career of C. S. (Rufus) Churcher,* K. M. Stewart and K. L. Seymour (Eds.). University of Toronto, 675 pp.

Katoh, M. and D. W. Foltz. 1994. Genetic subdivision and morphological variation in a freshwater snail species complex formerly referred to as *Viviparus georgianus* (Lea). *Biological Journal of the Linnean Society*, 53:73–90.

Mihlbachler, M. C. C. A. Hemmings, and S. D. Webb. 2002. Morphological chronoclines among Late Pleistocene muskrats (*Ondatra zibethicus*: Muridae, Rodentia) from Northern Florida. *Quaternary Research*, 58:289–295.

Pilsbry, H. A. 1948. Land Mollusca of North America, Excluding Mexico. *Monographs of the Academy of Natural Sciences of Philadelphia*, no. 3, 2(2), pt.2i:–xlvii, 521–1113.

Platt, W. J. and M. K. Schwartz. 1990. Temperate hardwood forests, pp. 194–229. In: *Ecosystems of Florida.* R. L. Myers and Ewel (Eds.). University of Central Florida Press, Orlando, i–xviii, 765 pp.

Roth, B. and K. C. Emberton. 1994. "(Extralimital) land mollusks" (Gastropoda) From the Deep River Formation, Montana: evidence for mesic medial Tertiary climate. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 145:93–106.

Stites, D. L., A. C. Benke, and D. M. Gillespie. 1995. Population dynamics, growth, and production of the Asiatic clam, *Corbicula fluminea*, in a blackwater river. *Canadian Journal of Fisheries and Aquatic Sciences*, 52:425–437.

Thompson, F. G. 1968. *The Aquatic Snails of the Family Hydrobiidae of Peninsular Florida*. University of Florida Press, Gainesville, i–vii, 1–268.

Thompson, F. G. 1984. *The Freshwater Snails of Florida: A Manual for Identification*. University Presses of Florida, Gainesville, i–ix, 1–94.

Thompson, F. G. and R. Hershler. 1991. Two new hydrobiid snails (Amnicolinae) from Florida and Georgia, with a discussion of the biogeography of freshwater gastropods of south Georgia streams. *Malacological Review*, 24:55–72.

Turgeon, D. D., J. F. Quinn, Jr., A. E. Bogan, E. V. Coan, F. G. Hochberg, W. G. Lyons, P. M. Mikkelsen, R. J. Neves, C. F. E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F. G. Thompson, M. Vecchione, and J. D. Williams. 1998. *Common and Scientific Names of Aquatic Invertebrates from the United States and Canada: Mollusks* (2nd edition). American Fisheries Society Special Publication 26, Bethesda, Maryland, 526 pp.

Taylor, D. W. 2003. Introduction to Physidae (Gastropoda:Hygrophil): biogeography, classification, morphology. *Revista Biologia Tropical*, 51(Supplement 1):1–287.

Watters, G. T. 1994. An annotated bibliography of the reproduction and propagation of the Unionoidea (Primarily of North America). *Ohio Biological Survey Miscellaneous Contributions*, no. 1, 158 pp.

Chapter 10

Mastodons (*Mammut americanum*) Diet Foraging Patterns Based on Analysis of Dung Deposits

LEE A. NEWSOM[1] and MATTHEW C. MIHLBACHLER[2]
[1]Department of Anthropology, Pennsylvania State University, University Park, Pennsylvania, PA 16802, USA.
[2]Department of Vertebrate Paleontology, American Museum of Natural History, 79th and Central Park West, New York, NY 10024, USA.

10.1 Introduction

Wet sites in Florida are widely known for their exceptional preservation of organic materials, including diverse plant remains, collagen-rich bone, and brain and other animal soft tissues (Cushing, 1897; Clausen *et al.*, 1979; Beriault *et al.*, 1981; Wharton *et al.*, 1981; Purdy, 1987a,b; Doran and Dickel, 1988; Dunbar *et al.*, 1989;

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 263–331

Doran, 2002; see Purdy, 1991). An extensive record of late Pleistocene and early Holocene biota is preserved in the wet sinkhole deposits submerged below the modern channel of the Aucilla River in northern Florida at the Page-Ladson site (8JE581). During the late Pleistocene, when water levels were lower and the local climate more arid (Brown and Cohen, 1985; Watts and Hansen, 1988; Grimm *et al*., 1993), the karstic river channels of North Florida contained much less water and the deeper sinkholes formed shallow spring-fed ponds that accumulated organic sediments. The sinkhole ponds and adjacent terrain became a refuge where wetland and more mesic vegetation survived Pleistocene climatic changes and variability, providing important habitat and water resources for a host of fauna, including large Pleistocene herbivores.

Good evidence for this exists at the Page-Ladson site where the skeletal remains of both extinct and extant species of herbivores and other animals have been discovered along with intact deposits of late Wisconsin plant material, some of which we conclude represents the preserved fecal remains of herbivores that used the sinkhole as a watering hole and wallow during the latest Pleistocene. Based on the analyses reported in this chapter, the bulk of this material has been identified as the dung of *Mammut americanum*, the extinct American mastodon. Here we describe the composition of these dung deposits and the overall significance to mastodon foraging and behavioral ecology, including which plant taxa were selected or preferred as browse, what specific plant parts were consumed, the extent of damage large herbivores may have caused to plants in the foraging process, and what plants may have benefited from mastodon seed dispersal. The research has broader implications concerning how mastodons potentially influenced the ecology, structure, and evolution of woody plant communities in southeastern North America through their foraging activities. When compared to extant herbivore dung and known mastodon dung and stomach contents from other regions, the Page-Ladson dung reveals insights into the possible seasonal and regional fluctuations in the diet and migratory patterns of North American mastodons.

10.1.1 Mastodon Paleoecology

American mastodon skeletal remains have been found throughout North America, but are considerably more numerous from the forested eastern half of the continent (Gross, 1951; Dreimanis, 1968; Haynes, 1991; Saunders, 1996). The animals are inferred to have been primarily adapted to browse on woody vegetation (Graham and Lundelius, 1984; Dudley, 1987; Haynes, 1991; Saunders, 1996) and are thought to have been ecologically distinct from contemporary proboscideans, the Colombian mammoth (*Mammuthus columbi*), which is inferred to have grazed primarily in the cool steppes and grasslands (primarily the western half of the continent), and the gomphothere (*Cuvieronius oligobunis*), that was evidently a mixed-feeder in tropical and subtropical environments (Janzen and Martin, 1982; Haynes, 1991; Sánchez *et al*., 2004; Webb, 1992).

Browsing dietary behavior for mastodons is suggested by their relatively low-crowned molars that consist of parallel rows of stout cusps that would have functioned effectively in clipping or crushing twigs, leaves, stems, and other tough woody plant tissues, but would not have been optimal for grinding abrasive foods, such as grasses (as were, in contrast, the high-crowned teeth of mammoth species) (Haynes, 1991). Moreover, dental microwear analysis and carbon isotope studies of proboscidean dental tissues from Florida, including specimens recovered from numerous Aucilla River localities such as Page-Ladson, further indicate a C3 (i.e. woody/forest vegetation) browsing diet for the mastodon and a C4 (i.e. herbaceous vegetation, particularly grasses) grazing diet for the Columbian mammoth (Koch *et al.*, 1998; Green *et al.*, 2003, 2005; Hoppe and Koch, this volume). However, a study of opal phytoliths thought to be from tooth calculus from Kansas mastodons (Gobetz and Bozarth, 2001) indicates they ingested grasses, at least in that region, and to the extent that the crystalline structures are securely associated with the teeth and not strictly part of the background vegetation.

Additional evidence for the overall habitat preferences and foraging patterns of American mastodon comes from the frequent associations of pollen and plant macroremains with mastodon finds, consequently linking them with hydric to mesic wooded environments (Oltz and Kapp, 1963; Stoutamire and Benninghoff, 1964; Dreimanis, 1967, 1968; Whitehead *et al.*, 1982; King and Saunders, 1984; Garland and Cogswell, 1985; Jackson *et al.*, 1986; Shoshani *et al.*, 1989; Haynes, 1991). Paleobotanical evidence from the upper Midwest and northeastern region consistently supports a strong association of mastodon with wetland plant communities: woody (typically conifer-dominated) bogs or swamps, ponds, marshes, and periglacial lake environments, based on the presence of spruce, other conifers, and various freshwater aquatics found directly with mastodon remains (Dreimanis, 1968; Hayes, 1991). Similarly, mastodons have been linked to hardwood swamps and riparian wetlands in the Olympic peninsula of Washington (Gustafson *et al.*, 1979) and in the Ohio Valley (Lepper *et al.*, 1991) based on identifications of sedges, grasses, the thorny rambler blackberry (*Rubus* sp.), shrubs such as buffalo berry (*Shepherdia* sp.), and willow trees (*Salix* sp.) with mastodon remains. Otherwise, open, mixed coniferous and deciduous woodland or deciduous forests were part of the range of mastodons throughout the eastern United States (Haynes, 1991; Delcourt and Delcourt, 1993) and were probably also important habitats exploited by them. Together these lines of evidence support the generalized model of woodland-dwelling browsers for mastodons, especially in the northeastern portions of North America.

A hypothetical niche for mastodons focused on forested wetlands may be partly fortuitous, wetlands in general being exceptional preservation environments relative to open dry terrestrial settings. Nevertheless, the relatively high plant species richness and diversity that generally characterizes forested wetlands (Calhoun, 1999), with their array of woody and herbaceous forms, as well as the refugia factor alluded to earlier, would have represented relatively abundant mixed browse potentially very attractive to mastodons. Combined with the ready availability of freshwater (Webb, 1992; Haynes, 2002), wooded wetland environments would have afforded suitable habitats for mastodons.

While the specific habitat and inferred dietary elements of mastodons inhabiting the late Pleistocene boreal and northern mixed deciduous forest biomes are reasonably well documented, these details are less well established for mastodons ranging into southeastern forests and coastal plain environments. Well over a 100 years ago, Koch (1841) excavated and reported a mastodon skeleton in southern Missouri, describing an unusual mixture of apparently associated plant remains, including large quantities of cypress (*Taxodium* sp.) cones, wood and bark, as well as “tropical swamp moss” (perhaps Spanish moss, *Tillandsia* sp. [?]), native cane (very likely *Arundinaria* sp.), and several petioles (leaf bases) of “palmetto” (presumably *Serenoa* sp. or *Sabal* spp., Palmae). Currently, southern Missouri and adjacent southern-most Illinois primarily in the vicinity of the Mississippi River valley form the northern limit of the Coastal Plain Province and its “southeastern regional flora” (Thorne, 1993), including cypress swamp (but lacking Spanish moss and palm species). If this vegetation was growing at the site (Koch also observed tree stumps, though the species are not mentioned), then it provides a record of the historical range of the southeastern regional flora, though at such a time period given the generally cooler, dryer conditions of the late Pleistocene, this is difficult to rectify; the presence of the moss and palmetto is especially difficult to explain, assuming the identifications were accurate. If alternatively, some of this material was in fact consumed by the mastodon, then the northern extent of the forest association could have existed and the browsing activity have taken place further to the south of the bone bed where the mastodon was recovered. We mention this account not so much to ponder historical forest biogeography in the late Pleistocene – something well documented by palynology and other research – but as a potential precedence for mastodon browsing on cypress trees and associated vegetation, considering the ubiquitous presence of cypress cone scales in the Page-Ladson samples, as described below, as well initial thoughts about their migratory patterns. The dung remains from the Page-Ladson site add further evidence of the preferred habitats and foraging behaviors of the American mastodon, with aspects reflective of the distinctive floristic patterns of the Southeast region.

10.1.2 Page-Ladson Dung-bearing Deposits and Previous Research on Mastodon Dung

The Page-Ladson site is a sinkhole depression submerged below the main channel of the Aucilla River. During the Pleistocene, the site existed as a deep, isolated freshwater spring (cenote) surrounded by well-drained limestone terrain supporting bluff forest vegetation. Under the more arid conditions of late Pleistocene Florida (Watts and Hansen, 1988; Hansen, this volume), such sinkhole ponds were an important source of fresh water for terrestrial fauna. Sediments filling this sinkhole have been partially eroded by moving water since the terminal Pleistocene rise in water levels and the initiation or reactivation of a riparian system, but much of the western edge of the sinkhole contains intact sediments that preserve a record of the late Pleistocene and early Holocene environmental history of the area.

Excavation units that penetrate deeply enough into the relic sinkhole deposits reach a discontinuous, late Pleistocene reddish-brown peat stratum. Near the center of the sinkhole the oldest of such sediments were encountered, woody peat that produced a radiocarbon date of 18,430 +/– 220 B.P. (Webb and Dunbar, 1989; Dunbar, this volume). Calcareous sand lenses that are 0.5–1.0 m in thickness overlie and intergrade with the red-brown peat. One *Cucurbita* sp. (cf. *C. pepo*, gourd/squash) seed recovered from within the eye orbit of a mastodon skull found embedded in the red-brown peat was dated by the accelerator method to 12,570 +/– 100 B.P. (AA-8759) (Newsom *et al.*, 1993).

The calcareous deposits are capped in several locations by a highly organic sandy clay/marl stratum (Levels 16–26, 1991 excavations, and similar strata). Some pockets of this distinctive organic-rich deposit occur also within the underlying calcarenites, and, similarly, as isolated pockets of material overlying the primary organic clay/marl concentration of Level 20B in the Test F excavations of 1991. Dense gray to brown clays lie above the deposit and may have protected the organic stratum from the erosion and subsequent contamination of river water (Kendrick, this volume). The highly organic deposits are very distinctive due to their unusually course texture, which is a consequence of a superabundance of relatively consolidated masses of woody fiber, twigs, and small stems, many appearing to have been cut or clipped at both ends. The ubiquitous woody plant debris is rather uniformly sized and they overwhelmingly form the bulk of these strata, comprising upwards of 95% of the volume and item counts of individual samples. Laboratory analysis of a representative sample (FS 131) of the organic debris from excavations in 1988 revealed that the lengths of the wood/twig fragments were strongly modal at 9–10 mm and they exhibited very consistent diameters, as described below. Moreover, the overall texture and composition of the material contrasted markedly with the underlying peat, other sediment samples from the site, and with peat or other organic-rich samples from various other wet sites in Florida (e.g. Newsom, 1987, 1994, 2002; Newsom and Scarry, 2006) suggesting a distinctive origin for the organic layer at Page-Ladson. Ultimately, the dense concentration of fine woody debris, their general uniformity, and the chopped or clipped appearance of so much of the material prompted Webb and Newsom (1991) to interpret this material as partially digested gut contents or dung of *Mammut americanum*, the American mastodon. The unique characteristics of the material were hypothesized to have resulted from mastication by these extinct proboscideans, and the woody-organic deposits in general as having been formed by the deposition of large volumes of mastodon dung.

These organic-rich deposits were originally encountered in 1988, when the first samples were retrieved for analysis. At the time, Aucilla River researchers colloquially dubbed the distinctive layer and similar concentrations as the “straw mat” because its color and texture resembled that of straw. Besides the abundant fine wood debris, thorns, seeds, nutshells, and other plant materials occur in the deposit. Sand, limestone pebbles, and animal remains (vertebrates and invertebrates) representing local terrestrial and aquatic fauna comprise the non-botanical components of the “straw-mat” deposit. Among the large herbivorous mammals that could have contributed such organic plant material in the form of dung, *Mammut* is best represented at the site, while remains of *Equus*, *Odocoileus*, *Paleolama, Tapirus*, *Megalonyx*, and *Mammuthus* (Webb, 1998, this volume) have also been identified within these deposits.

Subsequent excavations at Page-Ladson revealed that the strata containing heavy concentrations of dung-like organic deposits covered extensive portions of the site. The excavations in 1991 uncovered at least 29 horizontal square meters of the dung-like deposits in Test C and Test F, with a thickness of up to 1.5 m and extending from Levels 16 through 20B of Test F, together now designated as stratigraphic unit 3 (Kendrick, this volume), and deeper into Levels 22 through 26, based on our sample analyses. The full extent of the deposits is unknown, but is undoubtedly greater than any of the excavations have revealed; we estimate they may originally have been hundreds of cubic meters in volume, filling a large portion of the entire sinkhole basin. Of the many radiocarbon dates from Page-Ladson (Webb and Dunbar, this volume), at least nine were derived directly from dung sample constituents (Table 10.1). These dates adhere to a relatively short period ranging from about 12,550 to 12,350 B.P., possibly indicating a relatively rapid rate of deposition over a period approximately 200 years.

The individual twigs and other fine woody debris that comprise the bulk of this material span shades of tan to brown and generally lack bark, though fine bark

Table 10.1 Radiocarbon dates from Page-Ladson dung layers

#	*Date*	*Excavation and unit*	*Lab I.D.*	*Type*	*Material*	*FS*
1	12,375 +/– 75	Test C Unit 3	AA-7453	AMS	*Cephalanthus* (buttonbush) twig	88-131
2	12,545 +/– 80	Test C Unit 3	AA-7452	AMS	*Vitis* (grape) seed	88-131
3	12,385 +/– 100	Test F 91 Unit 3 = Level 18	AA-008760	AMS	*Carya* (hickory) nutshell	91.21
4	12,370 +/– 90	Test F 91 Unit 3 = Level 20b	AA-11048	AMS	*Vitis* (grape) seed	91.24
5	12,570 +/– 100	Test F 91 Unit 3 = Level 26b	AA-8759	AMS	*Cucurbita* (wild gourd) seed	91.32
6	12, 940 +/– 70	Test F 93 Unit 3 = Level 23 – FS,	Beta-118586	AMS	Digesta and sediment fill taken from tusk cavity	93.16
7	12,480 +/– 100	Test C Unit 3 – Test F 97-1 Unit 3	Beta-116493	AMS	*Quercus* (oak) acorn	97-1-10C
8	12,390 +/– 50	Test F 97-1 Unit 3	Beta-112236	AMS	*Paleollama* jugal	97-1-11C
9	12,400 +/– 110	Test F 97-1 Unit 3	Beta-116497	AMS	*Quercus* (oak) acorn	97-1-51C
10	12,420 +/– 130	Test F 97-1 Unit 3	Beta-116500	AMS	Wood	97-1-163
11	12,460 +/– 100	Test F 97-1 Unit 3	Beta-116499	AMS	Wood	97-1-162

fragments are variously present throughout the sediments. Larger fragments of wood, e.g. broken segments of branches or stems ca. 1 cm and greater in diameter, are infrequent among these samples and when present suggest naturally abscised material from trees or shrubs that presumably grew on the perimeter and over the sinkhole pond.

The concurrence and intermingling of abundant fine woody debris and calcareous sandy clay/marl of the apparent dung layer is unique among the stratigraphic units of Page-Ladson. One possible alternative explanation for this deposit would be size sorting by river current. However, there is no apparent orientation of wood specimens that would be indicative of current action. Likewise, fossils contained within the dung appeared to be floating in their matrix and were oriented in no particular direction. Furthermore, it seems unlikely that the abundant fine woody debris, fossils, sand grains, and limestone pebbles would be deposited together in a strong river current, which would have separated the lighter wood fragments and other plant debris from the sand and pebbles. During excavations we noted that when the dung deposits were exposed to the modern river current they eroded at a visible pace as the inorganic particles leached out of the walls of the units and the twigs and other plant remains floated free and drifted downstream. Based on this observation, we consider it highly improbable that this stratigraphic layer was deposited in and formed by moving water.

Rather, the individual plant constituents of the deposits are highly suggestive of uniform mastication, as observed in the initial study of FS 131 mentioned above. Reiterating, most of the wood fragments and twigs appear to have been cut or broken at both ends; some of the longer fragments are partially frayed and appear to have been pinched and bent, while other specimens appear torn or thoroughly shredded. These unusual and conspicuous morphologies differ from wood debris typically associated with woody peat and seem most consistent with mastication by a large animal. Furthermore, the descriptions of mastodon intestinal remains from other localities, particularly those recovered from within the confines of individual skeletons (Warren, 1855; Garland and Cogswell, 1985; Lepper *et al.*, 1991; Laub *et al.*, 1994), conform so closely to our observations of the Page-Ladson woody debris that there is little question that these remains were ingested by large herbivores. For instance, botanical material found immediately around the bones of a mastodon excavated in 1817 from near Goshen New York was described as "a mass of coarse vegetable fibers said to resemble chopped straw; perhaps the remains of the last meal" (Hartnagel and Bishop, 1922). Likewise, a mass of broken branches and twigs (hemlock, *Tsuga* sp.) estimated to have been about five to six bushels in volume was found in the shape of a convoluted cylinder evidently preserving the original shape of the intestine beneath the pelvis of the Warren mastodon from New York (Dreimanis, 1968; Warren, 1855; Haynes, 1991:89–90). According to Warren (1855:199) the plant mass extended in a straight column roughly 10 cm in diameter through the pelvic orifice, "The largest twigs, in their wet and swollen state, were from one-fourth to three-eighths of an inch in diameter, and from an inch to an inch and a half in length. They presented no appearance of being ground during mastication, but rather as though crushed through a vice. Some pieces of twigs were entire; those which separated, parted in the direction of their longitudinal fibres".

A similar mass of woody plant fiber, likely also representing stomach contents, was found among the ribs of the Cambridge mastodon skeleton discovered near Hackettstown, New Jersey. Maxwell (1844, in Warren, 1885:108) described the plant debris as "resembling coarse chopped straw, mixed with fragments of stick". Later, Asa Gray (1948, in Laub *et al.*, 1994:141), a famous American botanist, examined the plant debris and described it as "earthy material, filled with finely broken fragments of branches of trees" and which "evidently consisted of branchlets of one, two, and three years old, broken, quite uniformly, into bits of half an inch or so in length, with only, now, and then, traces of bark remaining on the wood". In yet another example, Cheney (1872:178) described probable gut contents from a mastodon skeleton from Jamestown New York: "in proximity to the visceral cavity of the larger skeleton, a mass of undigested food, some eight or nine bushels in quantity, and consisting of slightly decayed twigs, of two or three inches in length, identified as cone-bearing species, similar to our pines and firs...". More recently, Bryan *et al.* (1978:1277, Fig. 10.4) reported "a concentrated mass of small wood twig fragments which were notably sheared at both ends as if masticated" from a *Haplomastodon* kill site in Taima-taima, Venezuela. Garland and Cogswell (1985) reported a large quantity of chopped bark-less twigs, 20–40 mm long that they interpreted to be stomach contents of the Powers mastodon from Decatur, Michigan. Finally, Lepper *et al.* (1991) described an elongate mass of intestinal contents from the "Burning Tree mastodon", Licking County, Ohio, that is reminiscent of the convoluted mass of plant remains found with the Warren mastodon (Warren, 1885). The compact cylindrical mass of plant materials differed markedly in botanical composition from the surrounding peat and contained twigs with a mean length of 20 mm (sd = 6 mm, $n = 14$). Similarly, Laub *et al.* (1994, Fig. 10.2) described and analyzed a large number of woody twigs believed to represent dung associated with the Hiscock mastodon, discovered in a spring deposit from western New York state. These recently described sites and the associated botanical remains are discussed in greater detail below.

We have concluded that the woody plant debris from the Page-Ladson dung deposits, i.e. the sediments composed primarily of "clipped" naked twigs, conforms closely to prior descriptions of mastodon dung and stomach contents, and is very likely also of mastodon origin. In succeeding sections we endeavor to demonstrate this more conclusively. Nevertheless, we note that it is possible that smaller amounts of feces deriving from the other browsing herbivores – *Equus*, *Tapirus*, *Paleollama*, *Odocoileus*, *Megalonyx*, and *Mammuthus* – represented at the site also may be present. Therefore, in our analyses, we broadened our comparison to include dung from modern representatives of some of these fauna in an attempt to account for the possibility that these other ancient herbivores could have deposited dung that also became incorporated in the deposits of the same sinkhole.

Finally, aside from the characteristic woody plant debris, some additional details of the strata further highlight the distinctiveness of the dung deposits, lending additional support to the suggestion that mastodons were the primary agent behind the deposition of these materials. As we indicated above, thin discontinuous lenses of nearly pure sand and pebbles are interbedded within the thickest sections of dung deposit, and a thicker lens of calcareous sand underlies the main dung layer. During the underwater excavations, we observed that sand visibly leached through the compacted twigs when the material was moved or disturbed. Because minor disturbances caused such rapid vertical sorting, it is possible that large herbivores such as proboscideans wading or wallowing in a shallow water environment could have caused the sand lensing. Haynes (1991) described a similar phenomenon of sand lensing intermingled with trampled elephant dung in shallow water seeps in Africa that were frequented by elephants. The disturbed condition of the reddish woody peat that lies directly below the dung layer is perhaps more evident that proboscideans waded and wallowed here. The contact of the dung strata (and calcareous sandy deposits) with the lower peat is highly irregular and the upper 30 cm of the peat appears to have some of the chopped twigs mixed within. Logs and large branches located in the dung stratum and upper portions of the peat are often found in lengths less than 1 m and some were found in a nearly horizontal position. The weight of mastodons wading in shallow water is sufficient to have caused substantial mixing of the soft underlying wet peat and superior deposits containing dung, and to damage or break large fallen logs and branch sections and to reorient them, driving them into deeper deposits. Finally, a few small, isolated spherical pockets of the unusual straw-like plant material were found within the lower red peat. These pockets are similar in size to a dung bolus of African elephants, suggesting that they could represent the dungs of single individuals.

10.2 Methods of Analysis

10.2.1 Sampling Strategy and Recovery Procedures

Following the recovery and analysis of the first dung sample during the 1988 field season, we endeavored to focus a large part of our subsequent efforts on the recovery and analysis of additional samples from this unique deposit. Our basic objectives were to clarify the contents and nature of the deposits to more definitively verify or perhaps refute the proboscidean connection, and if correct, to discern some of the details of mastodon zoogeography and foraging behaviors. Therefore, in 1991 and 1997 additional samples from the dung deposits were collected from test units excavated by teams of underwater archaeologists (see Latvis and Quitmyer, this volume). We employed an extensive sampling strategy during the 1991 field season: four bulk samples were taken from the floor of each 20 cm level, specifically one sample from each quadrant. Bulk samples were extracted from the wall profiles of completed test units during subsequent work at the site in 1997. Additional plant specimens were drawn from the excavation screens in 1997. In terms of the bulk samples, the divers recovered approximately 1–3 l of sediment, sealing them in ziplock bags while underwater.

Our subsequent research on these samples was designed around three primary approaches: (1) the basic separation, classification, and quantification of sample constituents into categories including wood, bark, seeds, nutshell, and miscellaneous materials; (2) a wood particle-size analysis, incorporating a comparative analysis of dung from modern herbivores; and (3) a complete description and analysis of the overall botanical composition of individual samples, identifying the various taxa comprising each sample and recording details of the condition of individual specimens, including collecting morphometric data from seed and fruit specimens. Given the unusual conditions of excavating below water, it was impossible to prevent exposure of the samples to river water; thus, the presence of modern seed contaminants in the samples is a possibility, albeit a remote one. Though Aucilla River water is stained with tanic acid, the silt load is minimal and the water is free of suspended macroscopic particles. Therefore, concerning plant macroremains, the subject of this research, we regard contamination from the river itself as insignificant.

The paleobotanical constituents of the samples were entirely waterlogged and generally in a partially degraded state of preservation; only in more superficial levels were occasional carbonized specimens discovered and in no instance were plant remains found mineralized. The samples, therefore, were kept continuously moist during all stages of handling, processing and analysis to avoid the destructive effects of drying (resulting in checking, shriveling, and disintegration of the plant remains). Exposure to air and light sometimes turns the material from its original tan or straw color to a slightly darker brown but does not hinder identification, which relies on other morphological features and anatomical details. In the following sections, we begin by outlining the procedures followed to conduct the particle-size analysis. This particular facet of the research emphasized the woody constituents of samples, specifically those wood specimens representing terminal growth, i.e. twigs, or similarly sized particles, which as we have indicated are the most voluminous class of plant material comprising the dung strata. This is followed by a description of the methods employed in the general paleobotanical study, then the results of our analyses.

10.2.2 Wood Morphological Analysis and Modern Dung Comparative Study

While the most common, basic method of identifying the unknown dung remains of a particular animal is by the size and shape of the dung bolus, the fact that the Page-Ladson dung material was found in the form of a generalized stratigraphic deposit precluded this kind of analysis. However, analyzing the plant composition as well as comparing the particle-size distribution of the individual particles comprising the dung has the potential to illuminate the ultimate faunal source of the material. This follows along the lines of modern dung studies (several of which are described below), considering the types and diversity of plant materials, the amount of low-quality woody browse versus more nutritious items, and the potential size of the animal that consumed the materials. This method to varying degrees has been successfully used in other Pleistocene dung analyses to distinguish proboscideans dung from that of smaller herbivores (Mead *et al.*, 1986; Laub *et al.*, 1994). Therefore, aside from the basic plant identifications one approach we used to try and determine more closely from which species of herbivore the dung originated was to divide the Page-Ladson dung samples into their constituent particles, cataloguing all items and collecting metric data from the woody component as well as particular plant reproductive structures (seeds, fruits, etc.).

For the direct comparison with modern dung samples, we emphasized the individual twig-like elements to document the range of sizes and diameters of the material, presumably representing the bulk low-quality forage. As indicated, the preliminary study of this type on the original dung sample FS 131 revealed that the lengths of the wood/twig fragments were strongly modal at 9–10 mm (range 39.5–3.3 mm), with diameters ranging from around 6.5 to 1.5 mm (n = 784) (Webb and Newsom, 1991). The consistent sizes of the fragments and species composition (primarily the presence of seeds of *Phytolacca americana*, pokeweed, a woody herb found in dryer open settings) suggested an origin apart from strictly environmental deposition derived from the sinkhole/bottomland, i.e. rather, mastication and dung deposition by a large herbivore. In the follow-up study, we extended the morphometric analysis to include additional samples from the 1991 and 1997 excavations as described in the following sections. In addition, to facilitate the direct comparison of our data with that from known animals – beyond what was gleaned from the published literature, as described below – Mihlbachler collected and analyzed comparative samples of dung from several large herbivores. These modern dung samples included specimens from African elephants (*Loxodonta africana*) collected from Amboseli Park, Kenya, and another region in northeastern Kenya. Indian elephant (*Elephas maximus*), tapir (*Tapirus indicus*), and llama (*Lama glama*) dung samples were collected from local Florida zoos, while a horse (*Equus*) dung sample came from a farm in central Florida. In addition, Newsom collected and processed samples of white-tailed deer (*Odocoileus virginianus*; two dung piles) as well as black bear (*Ursus americanus*; five samples from two locations) dung, the latter as an omnivore simply for comparison. The deer and African elephant samples consisted of natural woody browse from local moist and dry scrub forest associations, and the bear dung came from the same deciduous forest habitat as the deer, while the zoo and farm specimens consisted mostly of hay with occasional fruit matter, e.g. bits of orange peel.

Four Page-Ladson sediment samples, including three recovered directly from the most heavily dung-concentrated stratum (FS 17C, FS 28C, FS 163C) and one for comparison from the underlying peat (FS 24C), were selected for the second stage of quantitative–morphometric analysis. Initially, these and the modern dung samples were wet sieved with gently running water through a graduated screening system consisting of 4, 2, 1, and 0.42 mm mesh sizes, the same as employed for other paleobotanical samples from the site. The percentages of total sample volume of the resulting subsamples from each sieve from both the Page-Ladson samples and the modern dung samples were calculated. Then, after observing that the 4 mm sieve fraction collected most of the woody debris in the paleontological samples, the material in this fraction was emphasized for the next stage in the morphometric study.

It became immediately apparent in the first stage of sample processing that tapir, llama, horse, deer, and bear dung differed considerably and were generally inconsistent with the Page-Ladson samples from the dung-concentrated stratum and were excluded from further consideration. Ultimately only elephant dung consisting of woody browse was considered in this second stage of analysis. The lengths and diameters of wood specimens from portions of the 2 and 4 mm fractions of the Page-Ladson samples (FS 24C, FS 28C), and the *Loxodonta* samples were recorded to directly compare Page-Ladson material with the woody constituents in the dung of modern browsing elephants. Any twigs and other wood fragments in the paleontological samples that did not conform to the general morphology suggestive of mastication, i.e. were not visibly fractured or sheared or that were still fully sheathed in bark, were excluded from measurement. However, the contents of the 2 and 4 mm fractions of the original sample (FS 131) were measured in their entirety. For each sample, over 300 woody particles (twigs) were measured, with the exception of FS 24C, the sample from red-brown peat, which contained fewer items that seemed to have undergone mastication. It was not feasible to continue measuring smaller particles in the smaller fractions due to the prohibitive number of specimens at this size level. At any rate, we were primarily interested in the size distribution of the larger particles within the samples. Measurement was discontinued when the 2 and 4 mm fractions had been depleted of specimens ≥4 mm in length. Note that the number of specimens measured for length and diameter is not always equal from sample to sample (Tables 10.2 and 10.3) because the diameter data were collected on a different occasion and different portions of the total samples were measured.

Table 10.2 Mean twig length and standard deviation for measured samples of woody twig fragments from proboscidean dung samples

Sample	*Mean*	*Mode*	*SD*	*Min*	*Max*	*N*
FS 28C	10.3	8	4.7	3	35	612
FS 131	10.7	9	5.4	1	99	788
FS 24C	12.6	12	8.5	4	89	209
Loxodonta (Amboseli)	10.3	7	5.9	2	50	672
Loxodonta (North Kenya)	12.4	9	6.6	5	56	329

Table 10.3 Mean twig diameter and standard deviation for measured samples of woody twig fragments from proboscidean dung samples

Sample	*Mean*	*Mode*	*SD*	*Min*	*Max*	*N*
FS 28C	2.0	1	1.2	1	9	672
FS 131	2.3	2	1.1	1	10	793
FS 24C	2.6	3	1.2	1	12	210
Loxodonta (Amboseli)	1.5	1	0.7	1	6	507
Loxodonta (North Kenya)	1.6	1	0.9	1	7	329

10.2.3 Paleobotanical Analysis

Samples used for the detailed paleobotanical study derive from all three field seasons (Table 10.4). The assemblage includes five samples from the 1988 excavation units C, D′, and E. Four of these samples were recovered as bulk sediment samples with volumes ranging between 550 and 5000 ml, and one sample was a collection of seeds from the general excavation water screens. All fractions (4, 2, 1, and 0.42 mm [Table 10.4]; see below) from these original bulk sediment samples were completely processed and analyzed. Eleven samples derive from the 1991 excavations of unit F. These were bulk sediment samples (1400–3300 ml [Table 10.4]) from different quadrants of the excavation unit levels, as indicated above; the second integer of the FS number (e.g. 24.1) indicates from which specific quadrant the sample originated (i.e. 0.1, 0.2, 0.3, 0.4 correspond to the northeast, southeast, southwest, and northwest quadrants, respectively). Analyses of these samples included two that were completely sorted and analyzed (all four sieve fractions), three that encompassed materials in the 4 and 2 mm sieve fractions, and six that focused exclusively on the 4 mm fraction (Table 10.4). Finally, 35 samples from the 1997 units 97-1, 97-2, and G were included in the analysis; all these samples represent 4 mm sieve fractions.

In the laboratory, the volumes of the samples were recorded, after which they were gently washed through a series of nested geological sieves with mesh sizes 4, 2, 1, and 0.42 mm. This partitions the sample constituents into groups of similarly sized particles to facilitate analysis and identification. Sample characterization and analysis proceeded by examining the materials from the subfractions in glass petri dishes, sorting them under magnifications ranging from 4× to 30× into various botanical and other material categories (bone, fish scales, lithic).

The basic procedure entailed placing an emphasis on the two larger sieve fractions (4 and 2 mm), these being the subfractions that contain most or all dung-related materials, as opposed to very small seeds and other items in the 1 and 0.42 mm fractions, many or most of which are likely to represent the ancient aquatic and emergent vegetation (i.e. less likely to be directly related to mastodon foraging). However, the primary reason for the different levels of analysis described above was to compensate for the considerable time and effort that would be required to process all the samples through each subfraction, given the exceptional preservation of plant tissues and other organic remains from such a site that typically results in quite voluminous quantities of material. Therefore, the 4 mm, and in some cases also the 2 mm, fractions were completely sorted and all constituents identified, while any finer fractions analyzed were sorted only for identifiable seeds, with the 0.42 mm component subsampled 10% by volume, searched for identifiable seeds, and not further analyzed. This strategy for the laboratory analysis allowed for both intensive and extensive coverage, providing an "in depth" perspective in some cases with as broad an overall coverage as possible of the sample assemblage as a whole. Hence, as indicated above, a set of six samples were completely analyzed (i.e. all sieve fractions, as indicated above), another three samples encompassed the 4 and 2 mm fractions, and analysis

Table 10.4 Page-Ladson megafauna dung sample inventory

FS	*Provenience*	*Volume*	*Sort*
119	Unit C, “lime sand”	2000	4
131	Unit C, “straw mat”	4000	4
73	Unit D′, upper lime sand	550	4
77	Unit E, lower peat “forest”	1000	4
84	Unit E, lower peat “forest”	scr	–
17.4	Unit F-91, Level 14	3100	1
20.3	Unit F-91, Level 17	1700	2
22.2	Unit F-91, Level 19	1400	1
24.2	Unit F-91, Level 20	2000	1
25.4	Unit F-91, Level 21	3300	2
26.4	Unit F-91, Level 22	2800	4
28.2	Unit F-91, Level 23	2350	1
29.4	Unit F-91, Level 24	3100	2
31.2	Unit F-91, Level 26A	1500	1
31.3	Unit F-91, Level 26A	1450	1
32.2	Unit F-91, Level 26B	2200	4
8C	Unit F-97-1/SE e.t.	scr	–
22C	No unit desig.	scr	–
29C	Unit F-97-1	scr	–
45C	Unit F-97-1	scr	–
50C	Unit F-97-1	scr	–
58C	Unit F-97-1	scr	–
79C	Unit F-97-1/SC	scr	–
86C	Unit F-97-1	scr	–
90C	Unit F-97-1/NC	scr	–
92C	Unit F-97-1/NE	scr	–
94C	Unit F-97-1/NC	scr	–
102	Unit F-97-1/SE	scr	–
128C	Unit F-97-1/NC	scr	–
129C	Unit F-97-1/NW	scr	–
132C	Unit F-97-1/SC	scr	–
135C	Unit F-97-1/NW	scr	–
136C	Unit F-97-1/SC	scr	–
179C	Unit F-97-1/SE	scr	–
194C	Unit F-97-1/NE	scr	–
196C	Unit F-97-1	scr	–
198C	Unit F-97-1	scr	–
200C	Unit F-97-1	scr	–
203	Unit F-97-1/NE	scr	–
78C	Unit F-97-2/NE	scr	–
82C	Unit F-97-2/NE	scr	–
83C	Unit F-97-2-NC AREA	scr	–
100C	Unit F-97-2/SE	scr	–
110C	Unit F-97-2/NE	scr	–
114C	Unit F-97-2/SE	scr	–
115C	Unit F-97-2/NE	scr	–
125C	Unit F-97-2	scr	–
183C	Unit F-97-2/SE	scr	–
184C	Unit F-97-2/SE	scr	–
187	Unit F-97-2/SC	scr	–
73C	Unit G, Level 2	scr	–

of 42 additional samples emphasized the 4 mm sieve fractions (necessarily including those from the excavation screens).

All plant materials were separated into basic categories of wood, bark, seeds, nuts, fruits, leaf, and miscellaneous, then counted, and identified to the lowest taxon possible. Seed and nut/fruit identifications were made based on morphological characteristics, using published identification guides and relevant floras, as well as by reference to modern comparative specimens. In addition, details such as whether specimens were whole, fragmentary, crushed, or otherwise showed any potential signs of mastication and having passed through a digestive tract were recorded. Individual wood specimens were also examined for evidence of chewing/digestion. Select specimens of wood in each dung sample were thin-sectioned for anatomical analysis and observation of the growth increments. The sections were mounted in glycerin solution on glass microscope slides for identification by compound microscopy (100×–1200×) according to the anatomical structure with reference to published keys, anatomical data, and comparative specimens.

10.3 Results of Page-Ladson Dung Analyses

We begin with the results of the basic particle-size and comparative dung analyses, and discuss the significance in terms of candidate dung depositors. This is followed by the results of the overall paleobotanical research, including specific observations that distinguish the dung-bearing deposit (Fig 10.1), providing indications of mastodon diets and foraging patterns. In closing sections of this chapter, we consider how our data compared with the model provided by the "ruminant-rodent-elephant" seed dispersal syndrome and ideas about anachronistic associations between particular plants and their extinct megafaunal seed dispersers.

10.3.1 Particle-size Analysis and Modern Dung Comparisons

The particle composition analysis revealed a difference between samples from the dung-concentrated layer (Fig. 10.2a) and the one from the underlying red-brown peat deposit (Fig. 10.2b). The dung-concentrated samples – FS 17C, FS 28C, and FS 163C – showed no great differences in the relative volumes of the subfractions collected in each mesh size from the sieving series. The red-brown peat (FS 24C) sample was distinguished from the dung-stratum samples by having relatively lesser quantities of large-sized organic particles, essentially because it contains a lesser concentration of the material (primarily clipped twigs) that we postulate to be from large herbivore dung. Moreover, the paleobotanical content of the peat (and other samples from other strata) contrasts strongly with the dung-concentrated layers, providing greater perspective on the distinctive nature of the these deposits relative to other sediments and organic debris from Page-Ladson that contain little or no apparent large herbivore dung (Newsom, this volume).

Figure 10.1 Diver excavating by trowel in Level 23 removes a relatively coherent bolus of digesta from a massive deposit of similar material. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Next, comparing the size distribution of the Page-Ladson dung particles (Fig. 10.2a) with the modern dung samples (Fig. 10.2c–h) allowed us to infer which Pleistocene herbivores were probably not significant contributors to the dung deposit. As indicated above, the remains of a number of large herbivores occur at Page-Ladson including *Equus*, *Paleolama*, *Odocoileus*, *Tapirus*, *Megalonyx*, *Mammut*, and *Mammuthus*. The comparative analysis revealed that horse and llama (Fig. 10.2d,f) dung have a much higher proportion of small particles than the Page-Ladson dung, thus immediately ruled out were *Equus* and *Paleolama*. Similarly, the white-tailed deer (*Odocoileus virginianus*) and bear dung were ruled out for the same reason. An analysis of the dung of *Nothrotheriops*, a Pleistocene ground sloth, from Bechan Cave (Mead *et al.*, 1986), indicates that the dung is similar to that of horses. Therefore, *Megalonyx* dung is also unlikely. Interestingly, the particle-size distribution of tapir dung (Fig. 10.2g) was found to be similar to the Page-Ladson dung (Fig. 10.2a), although it demonstrated a higher volume of smaller particles. Moreover, living tapirs generally consume the green shoots, leaves, and terminal growth of low growing herbs and shrubs (see below as to tapir foraging behavior and diet), and since the Page-Ladson woody materials are predominantly from cypress trees, an animal with a taller reach is suggested. Except perhaps for juvenile trees and shrubs, virtually all of the plant material in the Page-Ladson samples would be well beyond the reach of tapirs,

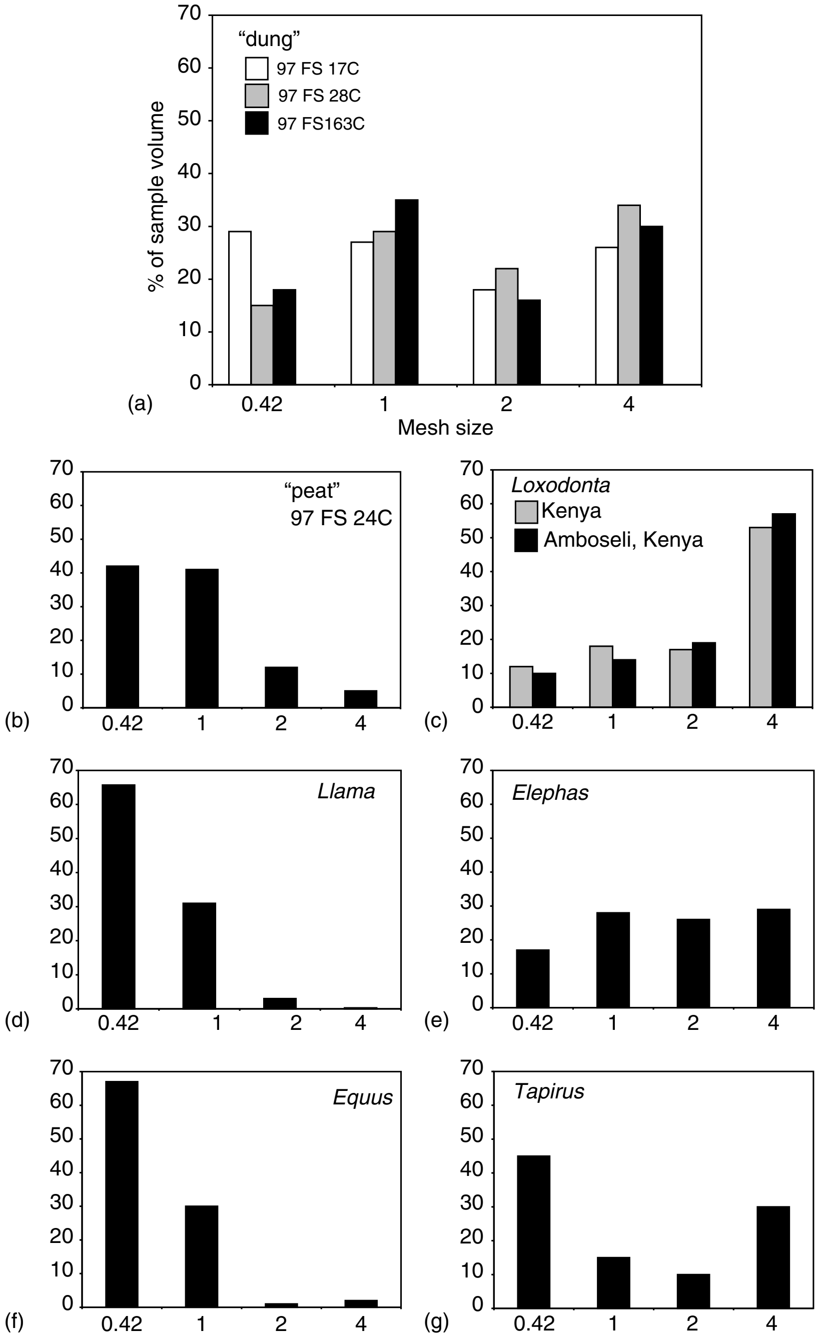


Figure 10.2 Particle-size analysis of dung samples.

and though cones, acorns, other nuts and fruits theoretically could be consumed by tapirs when first fallen to the ground, the apparently green state (seemingly consumed while still on the tree) of many specimens in the dung samples as described below again implies that tapirs as a source of the dung are unlikely.

In contrast, the material-size distribution of the Page-Ladson dung samples proved most like the living elephant dung. Both African elephant dung samples consistently had the largest sized particles of all the samples (Fig. 10.2c). The Indian elephant sample had greater quantities of material in the smaller sieve fractions (Fig. 10.2e). In fact, if based simply on the direct sample subfraction volumes, the Page-Ladson dung samples proved most similar to the Indian elephant dung. However, if we could have extracted the sand from our samples – which created a bias in the raw volumetric data by artificially inflating and weighting the material somewhat toward the smaller fractions – the sieve size distribution would have conformed more closely with the African elephant. The sand is of course extraneous to any food remains. In any case, these estimates suggest that the Page-Ladson dung is likely to be proboscidean in origin compared with other possible animal sources.

Analysis of the particle sizes of extinct mammoth dung from Bechan Cave in Utah (Mead *et al*., 1986) and mastodon dung from the Hiscock site in New York state (Laub *et al*., 1994) also indicated that extinct proboscideans produced dung particles that are similar in size to that of living elephants and again, distinctly larger than the dung produced by smaller herbivores. And while the particle-size distribution does not allow one to distinguish mammoth from mastodon, nevertheless mammoths of Florida have been demonstrated to have grazed almost completely on C4 grasses while mastodons were indicated to have consumed primarily C3 vegetation (Koch *et al*., 1998; Hoppe and Koch, this volume). Seemingly, the overwhelmingly woody nature of the material and the general paucity or lack of grass or other non-conifer photosynthetic tissues (see below) would seem to preclude mammoth in favor of a conclusion that the dung is the result of mastodon browsing activities.

The metric data from individual wood/twig specimens recovered from the dung samples offer a stronger, more direct comparison with the dung of browsing African elephants. The means of all of the samples are similar ranging from 10.3 to 12.6. However, the mean values are a somewhat misleading summary statistic, because the data do not adhere to a normal distribution curve. The modal twig length (ranging between 8–and 9 mm) of the samples taken from layers of heavily concentrated dung (FS 28C and FS 131) is similar to the modal lengths of the elephant dung samples (ranging between 7–and 9 mm). The modal twig length of the sample from the less dung-concentrated red peat layer (FS 24C) was higher at 12 mm. The histograms plotting these data (Fig. 10.3) show a remarkably similar bimodal pattern. Each displays a peak at around 8–10 mm (except FS 24C, where the modal value is 12) and, a smaller peak at 16 mm (Fig. 10.3d). Maximum twig length exceeds 40 mm in all of the samples except FS 28C where the maximum is 36 mm. Overall, the pattern of wood/twig lengths of the Page-Ladson material adheres closely to the pattern seen in the dung of samples of browsing African elephants.

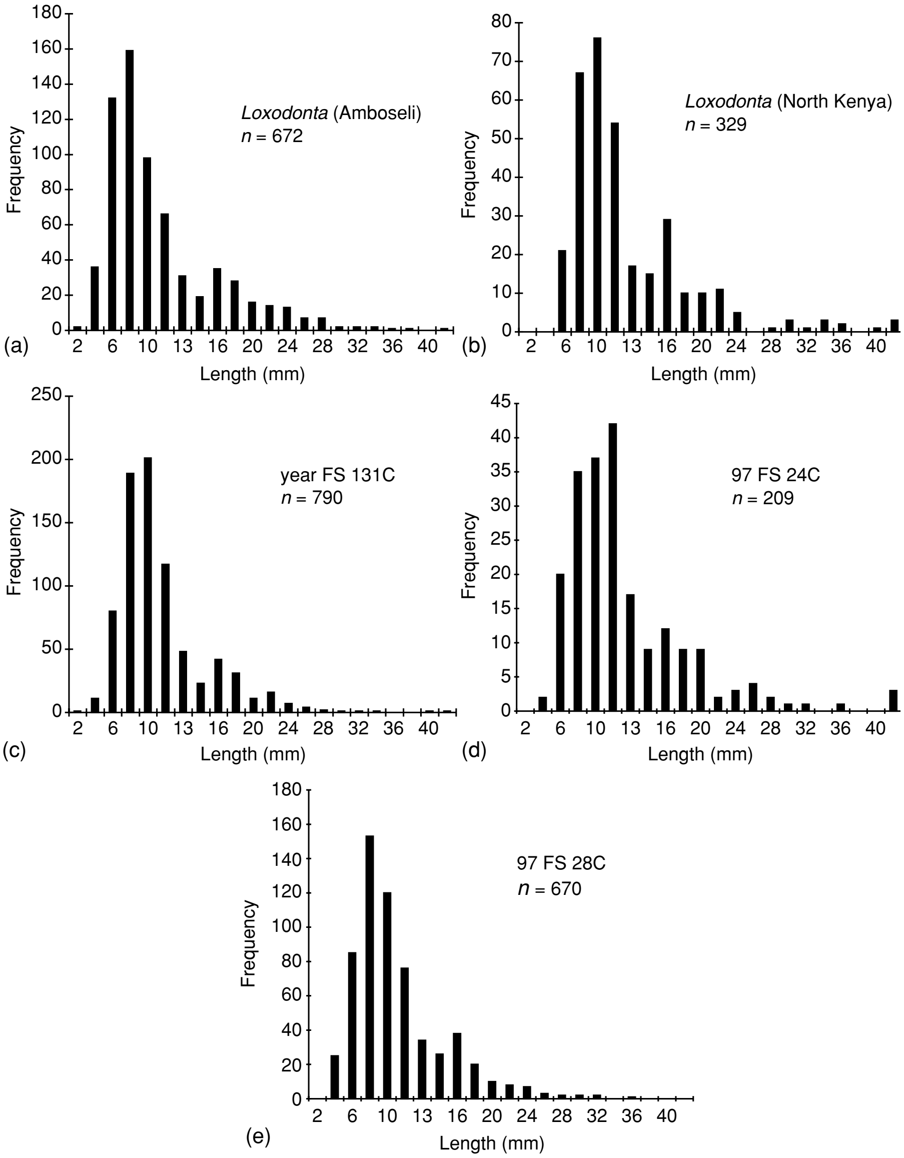


Figure 10.3 Comparative data for wood specimen lengths.

Comparisons of the diameters of the wood fragments of the Page-Ladson samples and African elephant dung (Table 10.3; Figure 10.4) reveal details about how extensively the individual plants were consumed and how selective were the mastodons producing the dung when feeding on the range of available woody browse. In all cases, the diameters of the wood fragments of the Page-Ladson samples tend to be wider than those of the African elephant samples with mean specimen diameters ranging from 2 to 2.6 mm. The modern elephant samples have smaller mean twig diameters of 1.5–1.6 mm (Table 10.3). Because the data deviate from a normal distribution, the mean is misleading. Modal diameters of woody fragments in the proboscidean dung were 1 mm (Fig. 10.4a,b). However, modal values of the woody fragments in Page-Ladson samples were more variable, ranging from 1 to 3 mm (Fig. 10.4c–e). The maximum diameters were similar, with a maximum of 7 mm for African elephants and a

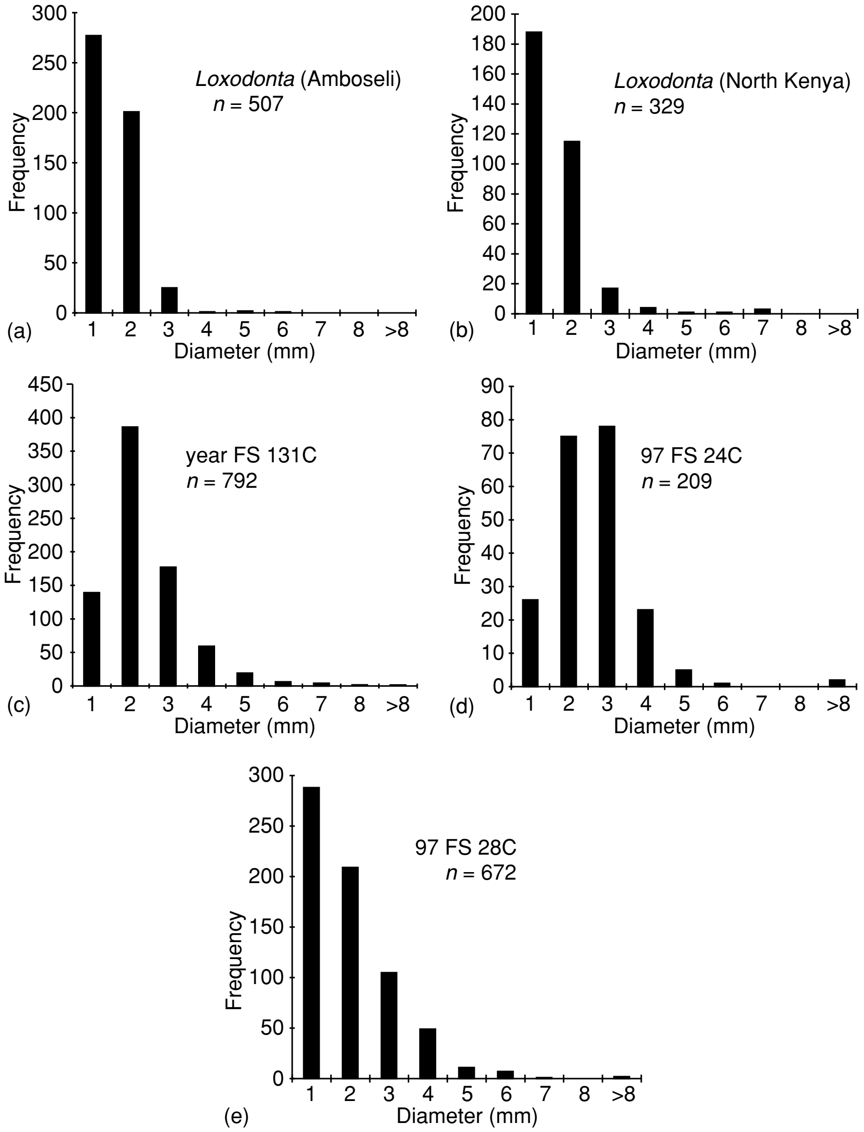


Figure 10.4 Comparative data for wood specimen diameters.

maximum of 9 mm for the Page-Ladson dung samples. If indeed the dung-like materials from Page-Ladson derive from mastodons, as seems to be the case, it suggests that their foraging on woody vegetation was perhaps less selective that the elephants producing the modern samples, the mastodons consuming a greater proportion of woody growth, occasionally ingesting material that exceeded a thickness of 8 mm. Alternatively, this may simply be a reflection of the fact that mastodons were somewhat larger animals with a greater capacity to consume more of the tree, i.e. larger, more mature growth.

A precautionary note should be included here – we do not suggest that the distribution of the lengths of the twigs supports (or negates) our contention that the Page-Ladson dung-like material is dung from an elephant sized herbivore. The volumetric measurements of the sieved subfractions (presented above) are a better indicator of the size of the animal that produced the dung. FS 24C, for instance, which was not from a primarily "dung" "stratum" contains similar "chopped" twigs with the same modal distribution. It is possible that there was dung in 24C in a lesser concentration, but if that is the case (which we suggest it is), then these data do not sufficiently falsify the possibility that twigs in non-dung deposits will have similar modal frequency. Other levels lack an abundance of "chopped twig" material, so a true comparison of proboscidean "chopped twigs" versus non-masticated broken twigs that might occur in other non-dung deposits is not readily available. The fact that there are fewer or no such twig-like, bark-free woody fragments in other levels is better evidence that the "straw mat" which contains supernumerary quantities of such "clipped twigs" is primarily large mammal dung, while other levels are primarily composed of non-dung organic detritus. Nonetheless, the similarity of the modal length of the twigs with proboscidean dung is striking. We cannot say with certainty, however, whether or not the twigs break into this modal length for reasons having to do with mechanical properties of elephant and mastodon mastication and digestion, or if it relates to the mechanical properties of the twigs themselves having a tendency to break into fragments of this size (however Newsom is doubtful of such an inherent breakage pattern, considering the structure of woody tissues and based on experience with other peat and wetland deposits). We note that while mastodons retained a more primitive proboscidean masticatory apparatus consisting of a low crowned cusp pattern with a bucco-lingual chewing stroke (Laub, 1996), unlike the unique vertical enamel shearing plates and antero-posterior chewing pattern of true elephants and mammoths (Maglio, 1972), the size analysis of the dung from Page-Ladson seems to indicate that mastodons masticated food to a similar particle-size distribution as living elephants.

10.3.2 Paleobotanical Indications of Mastodon Diets and Foraging Behavior

10.3.2.1 Taxonomic Diversity

The Page-Ladson dung deposits reveal a diverse but rather specific paleobotanical assemblage. The complete list of plant identifications is provided in Table 10.5. All together, at least 57 taxa were identified representative of a variety of lifeforms,

Table 10.5 Paleobotanical constituents of megafauna dung samples

Taxon (family)	*Taxon (genus, species)*	*Vernacular*	*Habit*	*Habitat*	*Specimen, condition*
Amaranthaceae	*Amaranthus/Alternanthera* type	Amaranth/alligator weed	Herb	Moist/wet areas	Seeds, whole
Aquifoliaceae	cf. *Ilex* sp.	Holly, yaupon	Tree/shrub	Mesic forest	Seed(s) (91.31.2)
Asteraceae	*Xanthium* sp.	Cocklebur	Robust herb	Open, alluvial banks	Fruits, whole and whole-compressed, proximal half, fragments
cf. Asteraceae	Unidentified	Sunflower family	(Herb)	(Open, disturbed)	Seed(s) (91.31.2)
cf. Betulaceae	cf. *Alnus* sp. and/or *Betula nigra*	Alder and/or river birch	Trees	Bottomland forests, floodplains	Catkin fragment; nut or samara
Betulaceae	*Carpinus caroliniana*	Bluebeech/hornbeam	Tree	Moist forest, swamp	Seeds, whole
Betulaceae	*Corylus* sp.[1]	Hazelnut	Tree/shrub	Mesic forest	Nuts, whole, whole-compressed (green), whole-crushed into four fragments, individual fragments
Cabombaceae	*Brasiena schreberi*	Water-shield	Aquatic herb	Ponds, slow streams	Seeds, whole
Caprifoliaceae	*Viburnum* (cf. *V. prunifolium*)[1]	Black haw	Tree/shrub	Moist-wet forest	Seeds, whole
Ceratophyllaceae	*Ceratophyllum demersum*	Coon-tail	Aquatic herb	Ponds, slow streams	Seeds, whole
Chenopodiaceae	cf. *Cycloloma* sp.	Ringweed	Herb	Open, river bars/shores	Seeds, whole (FS 73)
Cornaceae	*Cornus amomum/foemina* type	Swamp dogwood	Tree/shrub	Moist forest, swamp	Seeds, whole
Cucurbitaceae	*Cucurbita* (cf. *C. pepo*)[1,2]	Wild gourd/squash	Vine	Riparian forest and/or disturbed habitats (based on extant wild gourd populations)	Seeds, whole and fragments (a few possibly immature); fruit distal end fragment with blossom scar; rind fragments; possible vine tendril fragments
Cucurbitaceae	*Melothria* sp.	Creeping cucumber	Vine	Various forest	Seeds
Cupressaceae	*Taxodium* sp.	Cypress, bald cypress	Tree	Wet forest, swamp	Abundant cone scales and twigs; possible leaves, possible seeds (e.g. FS 77)
Cyperaceae	*Carex gigantea/lupulina* type	Sedge	Herb	Wetland, pond edge	Seeds, whole
Cyperaceae	*C. joorii*	Sedge	Herb	Wetland, floodplain	Seeds, whole

Cyperaceae	*Cyperus* sp.	Flat sedge	Herb	Damp ground	Seeds, whole
Cyperaceae	*Rhynchospora* sp.	Beak-rush	Herb	Wetland, pond edge	Seeds, whole
Cyperaceae	*Scirpus* sp.	Bulrush	Herb	Wetland, pond edge	Seeds, whole
cf. Cyperaceae	Unidentified	(Sedge, unk. taxon 2)	(Herb)	Uncertain	Seeds, whole
Cyperaceae	Unidentified	(Sedge, unk. Taxon 4)	(Herb)	Uncertain	Seeds, whole
Ebenaceae	cf. *Diospyros virginiana*	Wild persimmon	Tree	Dry deciduous forests, pinelands, early successional habitats	Seed, whole
cf. Euphorbiaceae	cf. *Euphorbia* sp.	Spurge	Herb	Open, disturbed	Seed(s) 91-20-3
Fabaceae	cf. *Gleditsia aquatica*, and/or *G. triacanthos*	Water locust and/or honey locust	Tree(s)	Wet to mesic forests	Robust, branched thorns
Fabaceae	cf. *Medicago*, *Trifolium* sp.	Clovers	Herb	Open, disturbed (?)	Seeds, whole (especially FS 77)
Fagaceae	*Fagus grandifolia*	American beech	Tree	Mesic forest	Nut, involucre valves
Fagaceae	*Quercus alba/michauxii* type	White type oak	Tree	Mesic–wet forest	Acorn fragments
Fagaceae	*Q. lyrata*	Over-cup oak	Tree	Moist forest	Acorn with involucre
Fagaceae	*Q. nigra/laurifolia* type	Water/laurel type oak	Tree	Wet/mesic forest	Acorn, whole compressed, halves
Fagaceae	*Q*. sp.	Oak, indeterminate	Tree	Various forest	Acorns compressed, one with partial involucre; involucre fragments; leaf fragments
Hamamelidaceae	*Liquidambar styraciflua*	Sweetgum	Tree	Mesic–wet forest	Seeds, whole
Hydrophyllaceae	cf. Hydrolea (e.g H.*corymbosa*)	Skyflower	Herb	Marshes, ponds, swamps	Seeds, whole
Juglandaceae	*Carya* sp.	Hickory	Tree	Various forest	Mature nuts (halves, quarters, smaller fragments, outer husk fragments); immature nuts (whole, halves, thirds)
Lythraceae	*Decon verticillilatus*	swamp loosestrife	Tree/Shrub	Swamps	Seed, whole
cf. Magnoliaceae	cf. *Magnolia* sp.	Magnolia	Tree	Various forest	Seed, whole
cf. Moraceae	cf. *Maclura pomifera*[1,2]	Hedge apple	Tree	Open, alluvial terraces	Seeds, whole
Myrtaceae	cf. *Myrica cerifera*	Wax myrtle	Shrub	Moist habitats	Nutlets, whole
Nymphaceae	*Nuphar luteum*	Spatter-dock	Aquatic herb	Ponds, rivers, streams	Seeds, whole
cf. Nymphaceae	cf. *Nymphaea* sp., especially *N. odorata*	Water lily	Aquatic herb	Ponds, slow streams	Seed(s) (FS 91.31.2)

(*Continued*)

Table 10.5 Paleobotanical constituents of megafauna dung samples—(*Continued*)

Taxon (family)	*Taxon (genus, species)*	*Vernacular*	*Habit*	*Habitat*	*Specimen, condition*
Oleaceae	*Fraxinus* sp.	Ash	Tree	Various forest	Wood
Palmae	*Sabal*, *Serenoa* sp.	Palm, palmetto	Tree or shrub	Various forest	Leaf fragments
cf. Papaveraceae	cf. *Argemone* sp.	Prickly poppy	Herb	Disturbed ground	Seed, whole
Phytolaccaceae	*Phytolacca americana*	Pokeweed	Perennial herb	Disturbed, floodplain	Seeds, whole
Polygonaceae	*Polygonum* spp.	Smartweed/knotweed	Herb	Damp ground	Seeds, whole
cf. Portulacaceae	cf. *Portulaca* sp.	Portulaca	Herb	Disturbed ground	Seed(s) (FS 91.20.3)
Potamogetonaceae	*Potamogeton* sp.	Pondweed	Aquatic herb	Ponds, streams	Seeds, whole
Rhamnaceae	*Berchemia scandens*	Rattan-vine	Liana	Wet forest, swamps	Seeds, whole
Rosaceae	*Crataegus* sp.[2]	Hawthorn	Tree/shrub	Mesic–wet forest	Seeds, whole; spines
Rosaceae	cf. *Malus angustifolia*	Southern crab apple	Small tree	Mesic, open woods	Seed, whole
Rosaceae	*Prunus* sp., *P. americana* and/or *P. angustifolia*	Wild plum(s)	Small trees, shrubs	Various forest	Seeds, whole
Rosaceae	cf. *Rosa* sp.	Wild rose	Shrub, rambler	Mesic–wet, open woods	Thorns, possibly also seeds
Rosaceae	*Rubus* sp.	Blackberry	Herb, rambler	Open, disturbed	Seed, whole
Rubiaceae	*Cephalanthus occidentalis*	Buttonbush	Shrub	Wet forest, swamp	Seeds, whole; twigs
cf. Rubiaceae	cf. *Galium* sp.	Bedstraw	Herb	Open, disturbed	Seed(s) (FS 91.20.3)
cf. Salicaceae	cf. *Salix* sp.	Willow	Tree/shrub	Wet forest, swamp	Juvenile wood (twig)
Sparganiaceae	*Sparganium* sp.	Bur-reed	Herb	Ponds, shallow water	Seeds, whole
cf. Theaceae	cf. *Franklinia* sp. (*F. altamaha*)[1]	Franklinia	Small tree or shub	Mesic forest, riparian habitats	Fruits, whole
cf. Tiliaceae	cf. *Tilia* sp.	Basswood	Tree	Moist forest	Seed, whole
Vitaceae	*Vitis* sp.	Wild grape	Liana	Various wooded habitats	Seeds, whole and fragments
Vitaceae	*Vitis*/*Ampelopsis* type	Wild grape/peppervine	Lianas	Various wooded habitats	Seeds, whole; vine and tendril fragments

Sources for habit and habitat data: Elias (1980); Godfrey and Whooten (1979, 1981); Radford *et al*. (1968); Wunderlin (1998).

[1] Taxon's current geographic range does not include Florida.

[2] Taxon inferred as anachronistically associated with megafauna (e.g. Janzen and Martin, 1982).

including trees, shrubs, lianas, vines, and aquatic and terrestrial herbs. These taxa are represented by wood and bark, as well as seeds and fruits of several types, including conifer cones (e.g. cypress, *Taxodium* sp.), soft pulpy berries and drupes (e.g. wild plum, *Prunus* sp.; generally the seeds but in a few instances also remnants of the soft outer tissues), and others commonly termed nuts, complete in some cases with their husks (e.g. hickory, *Carya* sp.) or involucres (e.g. beech, *Fagus* sp., and oak/acorns, *Quercus* sp.). Also present are vine sections and isolated bits of tendril, as well as fruit peduncles (stems), leaves, thorns, and abundant fine woody debris consisting predominantly of the terminal or distal growth, i.e. twigs, of trees or shrubs, including insect galls. A mass of fungi spores, probably from one of the shelf fungi (Polyporaceae) that grow on tree trunks, was identified from one sample.

10.3.2.2 Habitats and Biogeographic Patterns

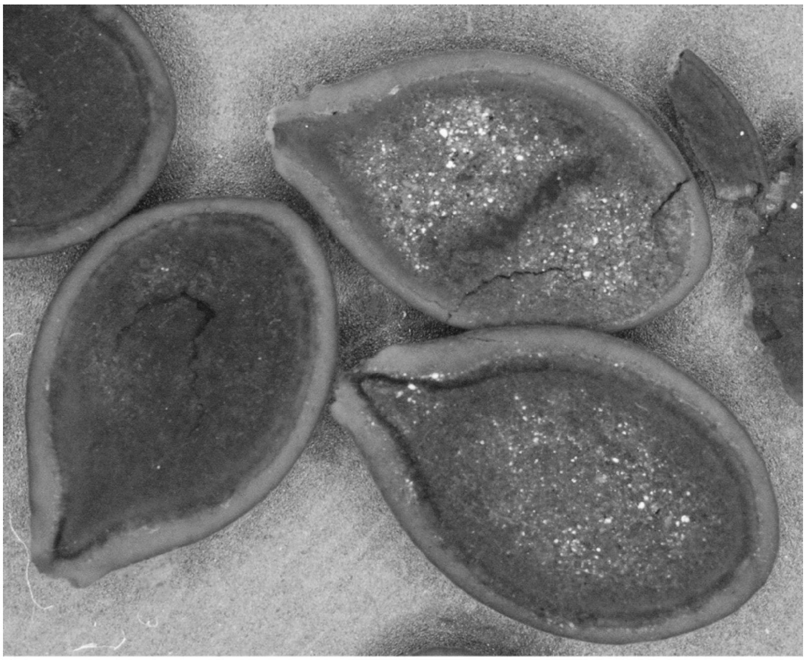
The habitats represented by the plant taxa are predominantly associated with various freshwater wetland and bottomland environments (e.g. pond/stream, riparian, and swamp forests [Ewel, 1990; Kushlan, 1990; Nordlie, 1990]) (Table 10.5). Others are common to mesic forest associations such as would have grown on the bluff slopes around the sinkhole pond, in near by pine woodlands, such as are likely to have occurred in the adjacent uplands (see Hansen, this volume), and still others are most indicative of disturbed settings (Table 10.5). Considered together the majority of plant remains suggest a forest mosaic with predominantly cypress and mixed hardwoods that presumably would have grown in the general and immediate vicinity of the ancient sinkhole, much as survives as bottomland and bluff forest in the area today (Platt and Schwartz, 1990).

Three of the plant taxa from the dung samples are not currently associated with the native flora of Florida (Wunderlin, 1998). These include hazelnut (*Coryleus* sp., cf. *C. americana* [American hazelnut], whole and fragmentary nuts; Fig. 10.5a–d), wild gourd (*Cucurbita* sp., cf. *C. pepo*, seeds and occasional rind fragments) (Fig. 10.6a,b), and provisionally identified Osage orange (cf. *Maclura pomifera*, seeds; this is a tentative assignment due to uncertainty about the morphology based on the incomplete preservation of the individual specimens) (Table 10.5). The southern extents of the modern ranges of hazelnut and Osage orange are Georgia–Alabama–Mississippi and Georgia–Mississippi, respectively. Osage orange is actually reported to occur in three Florida counties (Leon, Marion, and Volusia), but is considered to represent escapes from cultivation (Nelson, 1994:51–52; Wunderlin, 1998:264).

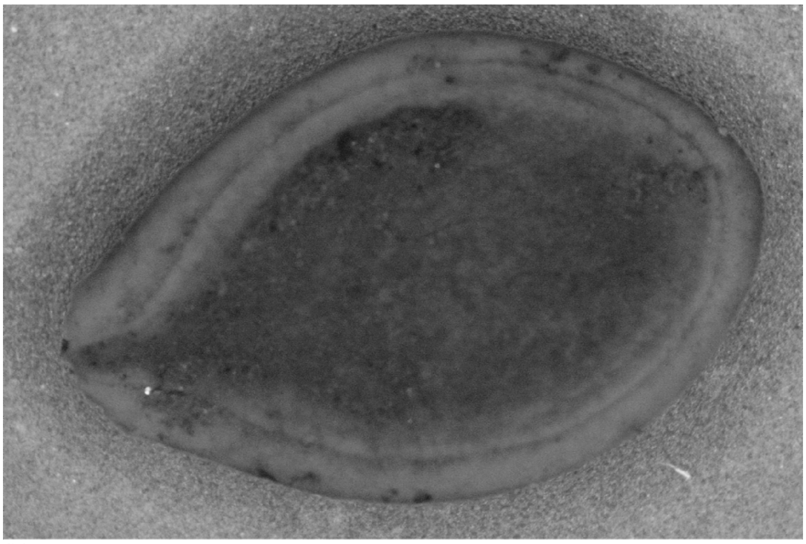
The wild gourd seeds conform closely to those of *C. pepo*, particularly the subspecies *ovifera* (Newsom *et al.*, 1993), and are distinct from seeds of native *C. okeechobeensis*. However, it is entirely possible that the seeds represent another species, even one that is extinct. Unfortunately, DNA analyses (P. Soltis, D. Soltis, Edwards, Decker, and Newsom, laboratory data 2004) that might clarify the taxonomic relationships of the Page-Ladson *Cucurbita* specimens have thus far been unsuccessful. The history and biogeography of North American *Cucurbita pepo*, including several subspecies and varieties, is complex. Presently *Cucurbita pepo*, aside from cultivated populations, is limited to isolated wild, waif, or feral populations of subspecies *ovifera*

Figure 10.5 Hazelnut (*Coryleus americana*): (a) FS 82C, 15.14 long, 11.82 mm wide, 9.62 mm thick; (b) FS 82C, 14.24 mm long, 10.64 mm wide, 9.20 mm thick; Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Figure 10.5 (*Continued*) (c) FS 29C (7x); (d) FS 82C, cross section showing vascular bundles in sectional view. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.



(a)



(b)

Figure 10.6 *Cucurbita* sp.: (a) group of seeds from FS29C (7×); (b) closer view of seed from FS 183C (11×). Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

var. *ovifera*, var. *ozarkana*, and var. *texana* found along roadsides, river banks, and among disturbed vegetation generally north and west of Florida (Radford *et al.*, 1968:998–999; Decker-Walters *et al.*, 1993; Smith *et al.*, 1992). Wild populations of the endemic Okeechobee gourd (*C. okeechobeensis*) are known from peninsular Florida (Ward, 1979; Ward and Minno, 2002) but again, the seeds of this species exhibit subtle morphological differences compared with the seeds from Page-Ladson and other paleobotanical and archaeological *Cucurbita* seed assemblages from Florida (Newsom *et al.*, 1993; unpublished laboratory data on Latvis–Simpson seeds).

10.3.2.3 Mastodon Foraging Patterns

Given the paleoclimatic and paleofloristic circumstances of the late Pleistocene (Delcourt and Delcourt, 1993), it is possible that all three taxa – hazelnut, Osage orange, and *Cucurbita* (*pepo*) gourds – had former ranges that encompassed present-day Florida. None of these taxa were found to occur in later deposits at Page-Ladson which might indicate that either those former ranges had by the early Holocene adjusted to a more northernly position at or approaching the modern ranges as the climate ameliorated, or mastodons had a direct role in their presence at Page-Ladson culminating in their presence during the period of mastodon activity at the site. Interestingly, both wild gourd and Osage orange are among the several taxa hypothesized to have anachronistic ties with megafauna dispersers (a point to which we return later in this chapter) (Barlow, 2000). Moreover, the virtual absence of gourd rind – which is very bitter and generally avoided by mammals – as opposed to seeds in the Page-Ladson samples may be further evidence of such a direct association. Thus, an alternative explanation for the presence of these plants at Page-Ladson is that mastodons effectively transported them to the area in general and the site in particular, which is further discussed below. A fourth taxon, *Viburnum* cf. *V. prunifolium* (Caprifoliaceae, black haw) (Table 10.5), a shrub with fleshy drupes 9–14 mm long, may also represent a disparity between the modern (Georgia–Alabama [Radford *et al.*, 1968:994–995]) and former geographic range. Like the other three taxa, black haw has not been identified among later, Holocene deposits at the site.

What additional, perhaps more specific evidence exists concerning the Page-Ladson samples that might relate directly to mastodon foraging, mastication, and consumption behaviors? First, as we have indicated the samples are predominantly composed of very regularly sized fragments of radial wood, which consists almost entirely of distal growth in the form of abundant twigs less than two–three years of age (growth increments fewer than three, typically one–two growth rings are present). This is probably the most distinctive characteristic of the dung samples and is what really distinguishes them from other naturally deposited paleobotanical assemblages from Florida wetlands, including older and later deposits at Page-Ladson. For example, peat and other organic sediments from other sites or strata generally tend to demonstrate a broader range in wood species, age classes, diameters, and lengths, with specimens often retaining the bark and sometimes exhibiting partial charring presumably from natural fires; they also contain seeds of various native taxa reflective of their general environmental setting (e.g. freshwater marsh, swamp, mangrove forest; compare Newsom 1987, 2002, and this volume). The abundant twig component of the dung deposits typically comprises upwards of 98% of the mass of individual dung samples (plant constituents), which is very unusual, and is generally accompanied by bits of loose bark, galls, leaves, thorns, cone scales, nuts, gourd seeds, other seeds, vines, and tendril fragments (Table 10.5). The uniform lengths of the twigs are also unique and we attribute this to mastodon mastication based on the analysis described above, particularly since the majority of the specimens show evidence of this action by their "clipped" ends (Fig. 10.7a,b).

This conspicuous woody debris is predominantly from cypress (*Taxodium* sp., *T. distichum*, bald cypress, and/or *T. ascendens*, pond cypress [Wunderlin, 1998:63]). Additional specimens associated with some of the dung samples not listed above include an unidentified "seed type" found as whole specimens in three samples (8c, 29c and 203) as well as occasional fungi spores and spore masses, insect galls, insect remains, and bones of acquatic fauna trees, which would have grown around the edge of the pond and any low moist or flooded ground in the area. This includes both the superabundance of twigs and numerous separated cone scales. The cypress twigs are definitively the most abundant plant constituents in individual samples. Direct microscopic analysis of the cell structure for wood identification was performed on up to 30 specimens per sample; however, macroscopic inspection of additional twigs in individual samples demonstrates consistency with cypress, indicating that this taxon comprises all or most of the twig component of individual samples, and generally occurs in counts of ca. 400–500 per liter of sample. Occasional larger specimens of cypress branch or trunk wood were also recorded. For example, field sample 77 from the 1987 unit E also included two larger segments of cypress stem or branch, ca. 2 cm diameter, one of which was flattened or compressed. The additional woods, typically one or a few specimens, identified as part of the twig component in individual samples include willow (*Salix* sp.), buttonbush (*Cephalanthus occidentalis*), and ring-porous hardwoods, i.e. oak (*Quercus* sp.), ash (*Fraxinus* sp.), and beech (*Fagus* sp.), all also generally indicative of the wetland/bottomland setting. That the bulk of the samples consists of large quantities of crude fiber – basically the twigs, i.e. clipped and pulverized woody browse – is consistent with large mammal foraging behaviors. Specifically, the consumption by modern megamammals, including elephants, of great quantities of low quality leaf and stem matter (ca. 50–90% fiber mass), as is described below and was reflected in the particle-size analysis described earlier, compares favorably with our observations from the Page-Ladson samples.

Stout spines and robust thorns ranging from 3 to about 6 cm long, including some that are simple (unbranching) (Fig. 10.8a,b) and others with 1–4 short branches (Fig. 10.8c) also frequently occur within the dung samples, contributing to the overall fiber "roughage" (this may seem odd for foraging mammals, but see the discussion below on composition of modern elephant dung; and see Barlow, 2000). The simple spines probably represent hawthorn (*Crataegus* sp., e.g. species like *C. crus-gali* with stiff spines 3–7 cm long [Radford *et al.*, 1968:561–562]), but may include Osage orange (armed twigs [Nelson, 1994:233; Radford *et al.*, 1968:390–391]). They may alternatively derive from either of two species of tree legume in the genus *Gleditsia* sp. (water locust, *G. aquatica*, or honey locust, *G. triacanthos*); the

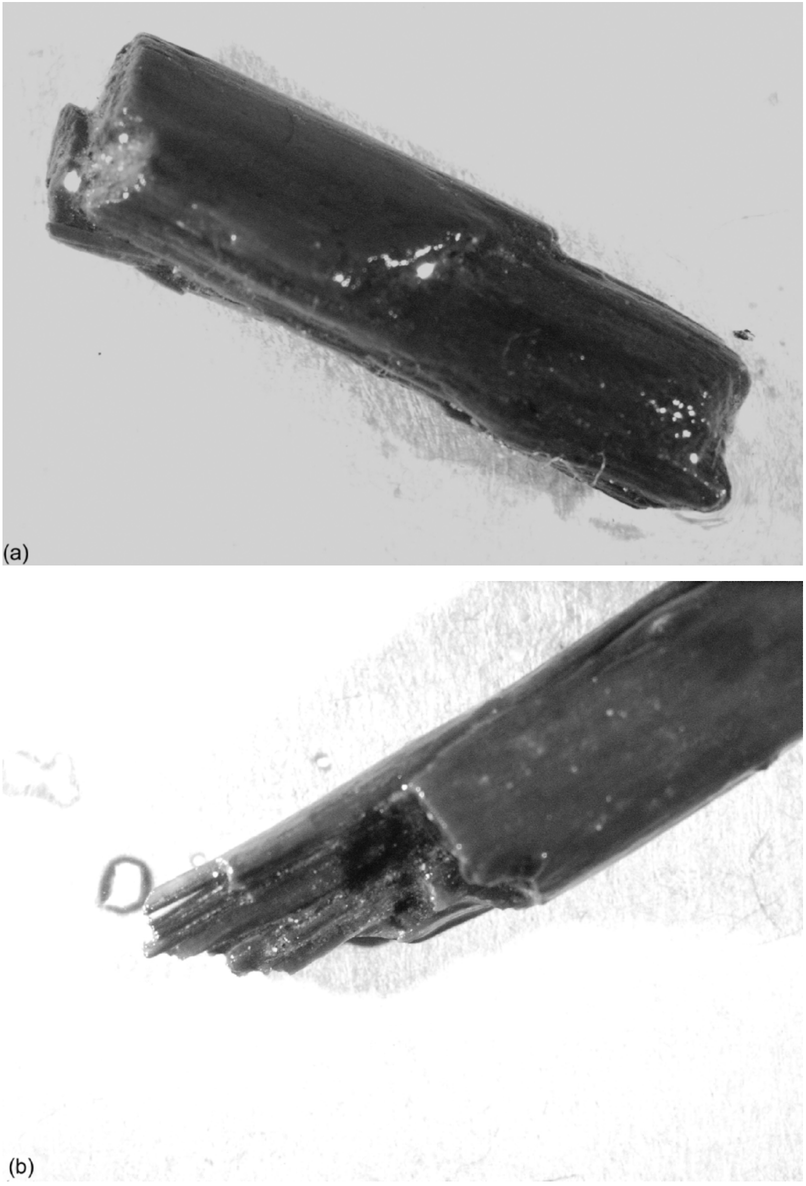


Figure 10.7 *Taxodium* sp. (cypress) “twig” specimens showing “clipped” ends: (a) FS 91.24.2, 17.08 mm long × 4.62 mm diameter; (b) FS 91.22.2, 46.48 mm long × 5.0 mm diameter. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

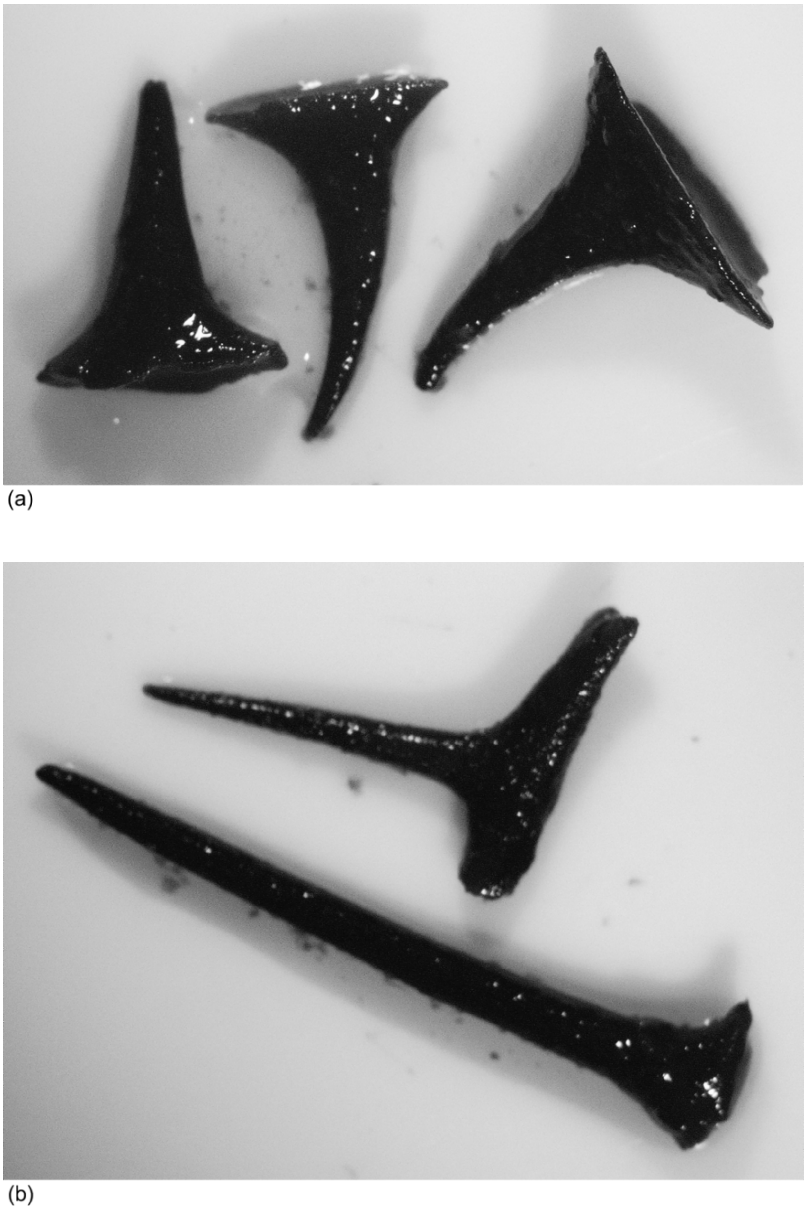


Figure 10.8 Thorns: (a) small rose-family (Rosaceae) type from FS 91.26.4; (b) stout simple (unbranched) spines, FS 91.26.4;

Figure 10.8 (*Continued*) (c) branched spine, FS 91.26.3 (all 7×). Photo by Aucilla River Prehistory Project.

branched thorns almost certainly represent this genus (Radford *et al.*, 1968:578–579; Nelson, 1994:214–215). Janzen and Martin (1982) suggested that among the likely anachronistically dispersed plants were in fact hawthorns and honey locust, the former with sweet fleshy fruits, the latter with sweet pods (see also Barlow, 2000). Of the two native locusts, only honey locust has pods with seeds embedded in a sugary pulp. Water locust pods are smaller and they lack pulp (Radford *et al.*, 1968:578–579), thus a similar co-evolutionary relationship for that particular species with large mammal seed dispersers has been considered but thought less plausible (Barlow, 2000:41).

The presence and condition of some of the other plant remains provide additional insights into mastodon foraging behaviors. The quantities (raw frequencies; some fragmentary materials are indicated by simple presence "X") and relative distributions of all plant materials along with other items (faunal remains) comprising the dung samples are shown in Table 10.6. The taxa are grouped by lifeform, beginning with arboreal taxa – the trees and shrubs – followed by the non-arboreal taxa, including climbers, then dry-ground herbs, damp-ground and aquatic herbs, and finally, miscellaneous and unidentified specimens. Among the arboreal species, overwhelmingly the most common remains are cypress twigs and cone scales, as indicated above. When whole, the spherical female cones are ca. 2–3.5 cm in diameter and dull greenish-brown colored; they are composed of several thick, resinous interlocking scales that disarticulate like a puzzle, each scale being approximately 3 × 8 mm in size (Elias,

Table 10.6 Distribution of plant remains among representative Page-Ladson megafauna dung samples[1]

	Unit C	*Unit D′*	*Unit E*	*Unit F-91/14*	*Unit F-91/17*	*Unit F-91/19*	*Unit F-91/20*	*Unit F-97-1*	*Unit F-97-2*
Taxon	*FS 131*	*FS 73*	*FS 77*	*FS 91.17.4*	*FS 91.20.3*	*FS 91.22.2*	*FS 91.24.2*	*All samples*	*All samples*
Arboreal taxa									
cf. *Alnus* sp., *Betula nigra*, catkin/samara	1				X				
Carpinus caroliniana	5	4	10		X			1	
Carya sp., mature nut		2						7	
Carya sp., immature nut or *C. aquatica*								4	5
Cephalanthus occidentalis, seed			4						
Cephalanthus occidentalis, twig	3								
Cornus amomum/asperifolia	2	3	4						
Coryleus cf. *C. americana*	13	4	2		2		2	16	3
Crataegus sp.	11	7	12		X			6	
Diospyros virginiana							1		
Fagus sp., nut								1	
Fagus sp., involucre valve	2		2					1	
cf. *Franklinia* sp.								5	
Fraxinus sp., wood		1							
Liquidambar styraciflua	1								
cf. *Maclura pomifera*					1 or 2	1	1		2
cf. *Malus* sp., e.g. *M. angustifolia*									1
cf. *Myrica* sp.			2		X				
Prunus sp., plum type			1					5	3
Quercus alba/michauxii type									1
Quercus lyrata								1	

Quercus nigra/laurifolia type								4	1
Quercus sp., mature compressed acorn								2	
Quercus sp., immature or aborted acorn		6	4						
Quercus sp., indeterminate nut shell	2	5			3				
Quercus sp., involucre fragment		2							1
cf. *Rosa* sp., thorn							1		
cf. *Salix caroliniana*, wood (twig)	1								
Taxodium sp., scale (cone segment)	109	76	91	24	19	2	7	6	2
Taxodium sp., wood (twig)	20[2]	20[2]	20[2]	20[2]	20[2]	20[2]	20[2]	20[2]	20[2]
Taxodium sp., wood (stem/branch)	3	2	2						
cf. *Tilia* sp., seed								1	
Viburnum sp., cf. *V. prunifolium*	10	1							
Robust spine, thorn (*Crataegus*, *Gleditsia*)	3	6	19	1	3			1	2
Dicotyledonous leaf fragment				X	X				
Monocot (Palmae) leaf fragment						X			
Insect galls (cf. *Quercus*, oak galls)	1	50[2]+	50[2]					6	5
Non-arboreal taxa									
I. Lianas/vines									
Berchemia scandens, seed	5				X				
Cucurbita (*C. pepo*), mature seed	2				X	2		62	38

(*Continued*)

Table 10.6 Distribution of plant remains among representative Page-Ladson megafauna dung samples[1]*—(Continued)*

	Unit C	*Unit D'*	*Unit E*	*Unit F-91/14*	*Unit F-91/17*	*Unit F-91/19*	*Unit F-91/20*	*Unit F-97-1*	*Unit F-97-2*
Taxon	*FS 131*	*FS 73*	*FS 77*	*FS 91.17.4*	*FS 91.20.3*	*FS 91.22.2*	*FS 91.24.2*	*All samples*	*All samples*
C. (*pepo*), immature seed	9				X				
Cucurbita sp., rind (fruit)							1[2]		1
Melothria sp., seed					1				
Vitis sp., seed	19	19	1		X			6	
Vitaceae, seed								9	10
Herbaceous vine/tendril (Cucurbitaceae)					X				
Woody vine/tendril (Vitaceae)	28	4		10	2	1	10	6	2
Fine woody tendril (cf. *Parthenocissus*)							1		
II. Dry ground									
cf. *Argemone* sp.	1								
Chenopodiaceae		3							
cf. *Euphorbia* sp.					X				
Fabaceae, cf. *Medicago* sp.	2	68	112		X				
cf. *Galium* sp.					X				
Poaceae		1							
Phytolacca americana	4				X			1	
cf. *Portulaca* sp.					X				
Rubus sp., seed		1	[2]		X				
Rosaceae, *Rosa/Rubus* sp., thorn					X				
Xanthium sp.								5	
III. Damp ground/aquatic									
cf. *Amaranthus* sp./other			5		X				
Brasenia schreberi	15	11	2		X				
Carex sp., cf. *C. gigantea/lupulina*	3	6	9		X				

Carex sp., cf. *C. joorii*		3	5						
Ceratophyllum sp., cf. *C. demersum*	24	35	1		X	1			
Cyperus sp.	1								
Cyperaceae			9						
Decodon verticillatus			1						
cf. *Hydrolea* (*H. corymbosa*)			5		X				
Nuphar lutea		3	1					1	1
Potamogeton sp.			[1]						
Polygonum spp.	4	13	7		X				
Scirpus sp.	1	4			X				
Sparganium sp.		1	4		X				
Rhynchospora sp.									1
Other									
Uniden. small fruit		2	2					1	
Uniden. Seed	47	8	31		X				
Uniden. bud (angiosperm tree)	3				X				
Uniden. fungi spore mass								1	
Unidentified bark fragment		X	X	X		X	X		
Unidentified wood fragment				X		X	X		
Fish scales	X			X	X				
Vertebrate bone (fish, turtle)					X		X		
Insect wing (beetle)	1				X				
Insect egg case (?)	1								

---

[1] "X" signifies simple presence.

[2] *Cucurbita* rind was identified from one additional sample: Unit F-91/21 (FS 91.25.4), two fragments.

1980:121). The ubiquitous presence of cypress cone scales along with the twigs in the Page-Ladson samples may correspond to Janzen's (1984) "foliage-as-fruit hypothesis", i.e. consumption of the cones may have been incidental to general browsing on the distal growth of cypress trees and were not necessarily themselves a direct focus of the foraging activity.

Other prominent woody taxa in terms of abundance and ubiquity include whole and fragmentary nut specimens: hazelnut, oak (*Quercus* spp.), hickory (*Carya* sp.), and beechnut (*Fagus* sp.) (Table 10.6). Some hazelnut specimens are complete (e.g. Fig. 10.5a-c), but most are shell fragments exhibiting the distinctive vascular traces in sectional view (Fig. 10.5d). They demonstrate three distinct morphologies indicative of at least three separate species of oak, including a white-oak type (here designated *Q. alba/michauxii*), another type with an involucre fully covering or nearly covering the acorn, as characterizes overcup oak (*Q. lyrata)*, and another classified as water-laurel type (designated *Q. nigra/laurifolia*) (Tables 10.5 and 10.6). Live oak (e.g. *Q. geminata, Q. virginiana*) acorn morphologies have not been identified among the samples. Acorn sizes vary according to species. Those of the white oak group, including overcup oak, are the largest of the native acorns being around 1.5–3.0 cm long and are all non-bitter types; Florida black or water oak and laurel oak acorns are relatively bitter and about 0.8–2.6 cm long by 1.0 cm broad (Radford *et al.*, 1968:372–385; Elias, 1980:320–375; Nelson, 1994:182–195). Hickory fruits range between 2.5 and 5 cm long by about 2–3.5 cm in diameter, depending on the species (Radford *et al.*, 1968:363–366), and the edible kernel is contained in a hard woody shell that is encased within a tough pale green exocarp or husk. The hickory specimens from the Page-Ladson dung samples include some whole specimens, most or all of which appear immature and underdeveloped, and some shell halves and fragments mostly from mature nuts; occasional exocarp fragments were also recovered. Two hickory nut half-shells from FS 82C (unit F-97-2 [Table 10.4]) measure 20.19 × 13.70 and 17.69 × 14.99 mm, respectively. Bracts that form a four-valved involucre with short recurved spines enclose beechnuts. These open in the late summer to expose the nuts; the entire fruit is about 1.8–2.2 cm long (Radford, 1968:370; Elias, 1980:302). Individual mature beech involucre valves and one whole nut lacking the involucre were recovered from the dung samples (Table 10.6).

Particular morphological details from individual nut specimens are revealing, we believe, as to mastodon foraging and consumption, in addition to noting size, color, or relative bitterness of live/fresh fruits (i.e. details that may have attracted megafaunal consumers, which is treated in depth below). The general condition and other observations from nut remains are described in Table 10.7. Hickory nut remains include whole specimens that did not reach full maturity, as well as mature nutshell halves (Fig. 10.9) and shell fragments of various sizes (1/4 shells and smaller), as well as stray bits of the separated exocarps. It is difficult or impossible to know whether the immature specimens represent nuts that were naturally aborted prematurely or alternatively were foraged from the trees before reaching full maturity. The hazelnut specimens include whole nuts, some of which appear to have been compressed while still in the green state and others that have cracks in the shells and some with roughly

Table 10.7 Morphological details from Page-Ladson nut specimens

Provenience	*FS #*	*Taxon*	*Count*	*Details/condition*
87′ Unit D′, Zone A	73	*Carya* sp., hickory nut	5	Nut shell fragments
87′ Unit E, Zone E	84	*Carya* sp., hickory nut	4	Nut shell fragments, *C. aquatica* or immature form of another species
F-97-1	22C	*Carya* sp., hickory nut	4	Complete 1/2 nut, and 3 fragments
F-97-1	86C	*Carya* sp., hickory nut	6	One complete 1/2 nut, and 5 shell fragments
F-97-1	196C	*Carya* sp., hickory nut	1	1/4th section of nutshell, small, possibly immature
F-97-1/NC	90C	*Carya* sp., hickory nut	1	Complete 1/2 nut, very small, possibly immature
F-97-1/NC	94C	*Carya* sp., hickory nut	1	Husk fragment
F-97-1/NE	92C	*Carya* sp., hickory nut	2	2 complete halves, small, possibly immature
F-97-1/NW	135C	*Carya* sp., hickory nut	1	Whole nut, very small, possibly immature
F-97-1/SE	8C	*Carya* sp., hickory nut	1	Complete 1/2 nut
F-97-2/NE	78C	*Carya* sp., hickory nut	1	1 whole nut, small, possibly immature
F-97-2/NE	82C	*Carya* sp., hickory nut	4	All whole nuts, small, possibly immature
87′ Unit D′, Zone A	73	*Coryleus* sp., hazel nut	4	Nut shell fragments
87′ Unit E, Zone E	77	*Coryleus* sp., hazel nut	2	Nut shell fragments
91′ Unit F, Level 17	20.3	*Coryleus* sp., hazel nut	2	Nut shell fragments
91′ Unit F, Level 20	24.2	*Coryleus* sp., hazel nut	2	Nut shell fragments
F-97-1	22C	*Coryleus* sp., hazel nut	6	2 whole nuts, 1 compressed; 4 fragments (probably = one original)
F-97-1	29C	*Coryleus* sp., hazel nut	2	2 whole nuts
F-97-1	86C	*Coryleus* sp., hazel nut	4	4 whole nuts, 1 compressed, 1 cracked, 1 with distal end sheered off
F-97-1	196C	*Coryleus* sp., hazel nut	2	2 whole but compressed nuts and each with circular divit in shell
F-97-1/NE	92C	*Coryleus* sp., hazel nut	1	1 nut shell fragment
F-97-1/SE	8C	*Coryleus* sp., hazel nut	4	3 whole nuts, 2 have one large divit in shell; one fragment
F-97-2/NE	82C	*Coryleus* sp., hazel nut	3	All whole nuts, one compressed
87′ Unit E, Zone E	77	*Fagus* sp., beech	2	Separated l/4rd segments (bract/valve) of involucre
F-97-1/NE	203	*Fagus* sp., beech	1	1/4 bract/valve
F-97-1/SC	132C	*Fagus* sp., beech	1	1 whole nut

(*Continued*)

Table 10.7 Morphological details from Page-Ladson nut specimens—(*Continued*)

Provenience	*FS #*	*Taxon*	*Count*	*Details/condition*
87′ Unit D′, Zone A	73	*Quercus* sp., oak	13	6 immature or aborted acorns; 5 mature shell and 2 involucre fragments
87′ Unit E, Zone E	77	*Quercus* sp., oak	4	Whole immature and/or aborted acorns
91′ Unit F, Level 17	20.3	*Quercus sp., oak*	3	Acorn shell fragments
F-97-1	22C	*Quercus* sp., *nigra*-type	4	4 acorn halves
F-97-1/NC	94C	*Quercus lyrata*, overcup oak	1	Whole acorn with involucre
F-97-1/SE	102	*Quercus* sp., indeterminate	1	1 whole nut, compressed, retaining part of involucre
F-97-2/SE	114C	*Quercus* sp., white oak type	1	Acorn, complete 1/2
F-97-2/SE	114C	*Quercus* sp., *nigra*-type	1	Whole acorn, compressed
F-97-2/SE	114C	*Quercus* sp., indeterminate	1	Involucre fragment

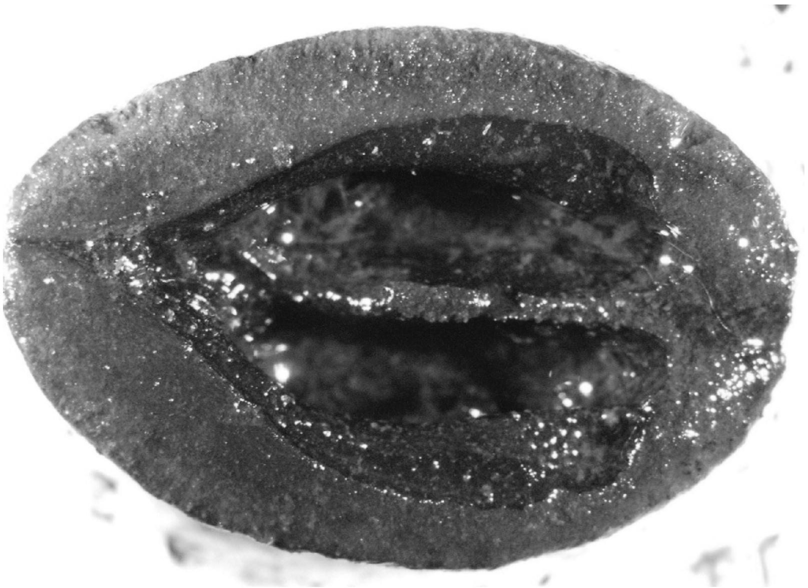


Figure 10.9 *Carya* sp. (hickory) one-half nutshell, FS 82C, 20.16 mm long. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

circular “divits” (Fig. 10.10a–c) that appear to have been sheared off the nut. Various hazelnut shell fragments are also present. Beechnut specimens are primarily single bracts or valves separated from the four-valved involucres, as well as a single whole nut. Finally, the acorn remains include various shell and involucre fragments, including some acorn halves, whole immature nuts, one whole mature nut complete with its involucre, and two whole but compressed nuts, much like the hazelnut specimens described above (Table 10.7). The combinations of immature and mature nut specimens may suggest browsing directly from growth while still on the trees, some nuts having reached full maturation, others in various stages of development. Specimens that appear compressed (somewhat flatted and with a wrinkled shell) must surely have become so while still green and the shells still supple; others that were perhaps more mature did crack and split or suffered sheared portions (the divits), all of which may also be a strong indication of mastodon browsing and consumption (and these morphologies have not been recorded for other peat/wetland deposits). There is no indication of weevil holes, particularly in the acorns, such as appears in fallen acorns found on the ground.

Other arboreal taxa identified among the samples highlight more of the potential diversity of browsed materials, thus mastodon foraging behavior. Particularly, noteworthy are hawthorn seeds and probably also the spines, as described above, ironwood seeds (*Carpinus caroliniana*), the possible Osage orange seeds (*Maclura pomifera*), a possible wild apple seed (or seeds) (cf. *Malus* sp., especially *M. angustifolia*, southern crab apple), wild plum pits (*Prunus* sp.), and a persimmon seed

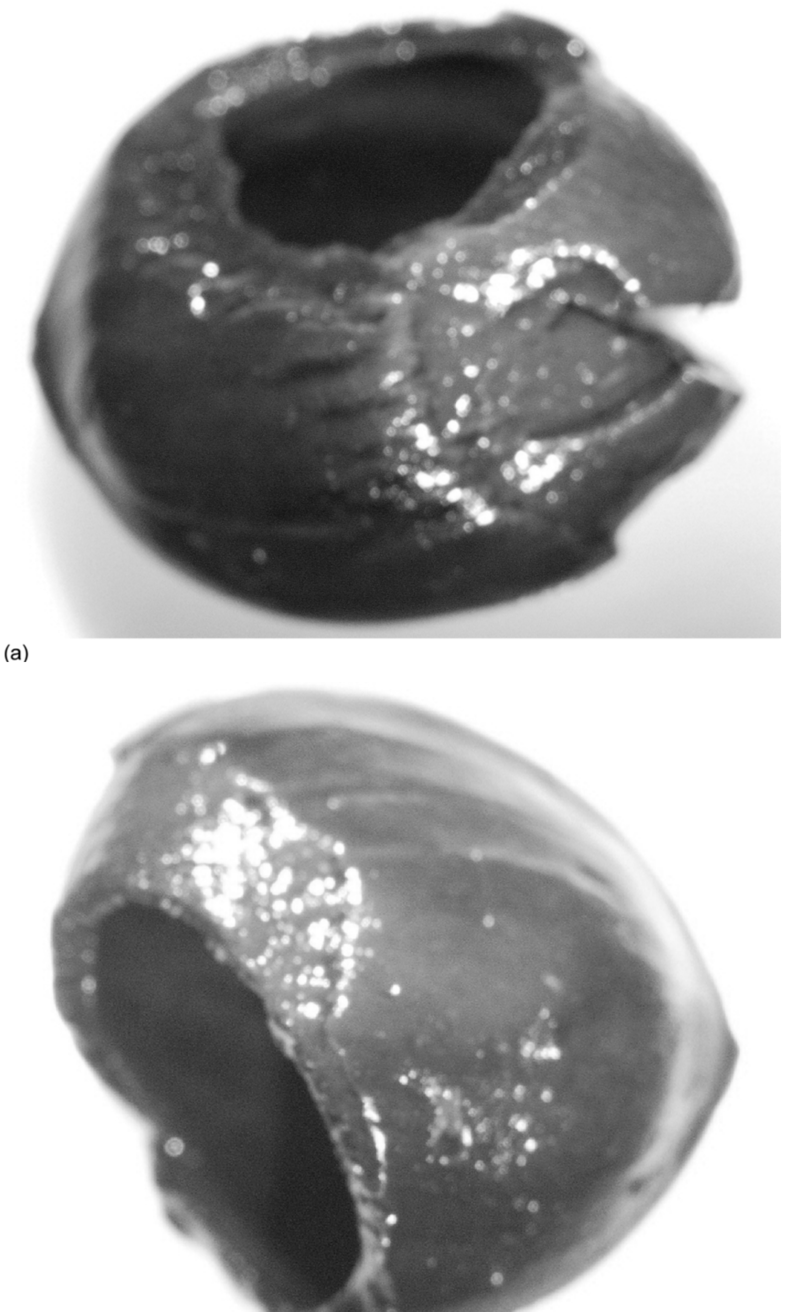


Figure 10.10 Hazelnut (*Coryleus americana*) specimens with sheared surfaces leaving “divit”: (a) FS 196C; (b) FS 196C

Figure 10.10 (*Continued*) (c) FS 36C (all 7×). Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

(*Diospyros virginiana*) (Table 10.6). Hawthorn fruits are slightly sweet, spherical, ca. 1 cm or less in diameter, and range in color from greenish to reddish to brown, depending on the species (Radford *et al.*, 1968:560–563). Ironwood fruits are small dry nutlets (4–6 mm long by 3.5–4.5 mm broad [Radford *et al.*, 1968:370]). The spherical fruits of Osage orange are quite large, 10–14 cm in diameter, and green; the individual seeds, technically nutlets, are nearly 1 cm long (Radford *et al.*, 1968:391). Wild crab apple and wild plum, the former a provisional identification, are both members of the rose family (Rosaceae), as is hawthorn. These have fleshy, sweet fruits (pomes) of about 2.5–3.5 cm in diameter with a single hard seed, technically a "stone" (Radford *et al.*, 1968:556, 566); crab apples are green whereas wild plums may be red, yellow, or dark purple depending on the species. The plum seed size – e.g. 13.66 mm diameter by 8.45 mm wide for a representative plum specimen from FS 82C, unit F-97-2 – could represent any one or more of the three common native wild plums: *P. americana*, American plum, *P. angustifolia*, Chickasaw plum, or *P. umbellate*, hog plum (Radford *et al.*, 1968:566; Nelson, 1994:267–271). An additional member of the rose family, wild rose (cf. *Rosa* sp.) is suggested by the presence of the distinctive recurved thorns (Tables 10.5 and 10.6). Persimmon fruits (a dull yellow-orange "berry") are about 4 cm in diameter, hard and astringent when immature, pulpy and sweet when ripe (Radford *et al.*, 1968:826). The single persimmon seed recovered with the Page-Ladson dung samples (FS 91.24.2 [Table 10.6]) is 15.57 mm long by 8.85 mm wide. This particular tree grows in dry deciduous forests and pinelands, also old clearings (Table 10.5), thus it may represent a fruit type transported by mastodon dispersers to the sinkhole, where it was finally deposited among the dung strata. This may be true also of crab apple (dry, often calcareous hammocks, eastern and central panhandle [Wunderlin, 1998:329]) and wild plum, depending on the species.

The next category of plant taxa (Table 10.6) is the climbers, i.e. herbaceous vines and woody lianas. Rattan-vine (*Berchemia scandens*) seeds are infrequent among the samples, though may have been fairly common in the bottomland forests; the drupes are blue-black, ellipsoid, 5–7 mm long (Radford *et al.*, 1968:693; Nelson, 1994:264–265). Wild grape (*Vitis* sp.) seeds and others that may represent closely related genera ("Vitaceae seed", i.e. *Ampelopsis* sp., pepper-vine, and/or *Parthenocissus quinquefolia*, Virginia creeper) frequently appear in the samples, as do fragments of woody fine and tendril that are almost certainly from this family. The lianas common today in the forests around the site; they prolifically bear fruit, the berries being relatively sweet, blue or black in color, globose and about 5–20 mm diameter, depending on the species (Radford *et al.*, 1968:694–698; Nelson, 1994:363–370).

Wild gourd (*Cucurbita* sp. cf. *C. pepo*) seeds are fairly ubiquitous in the dung deposits, and are accompanied by a few tiny rind specimens (ca. 2–5 mm across). Altogether 156 *Cucurbita* sp. seeds have been recovered, and individual samples produced from 1 to as many as 11 seeds, with 100 seeds coming from the 1997 excavations (Table 10.8; this list includes more samples than shown in Tables 10.4 and 10.6 because it includes samples that were processed in the lab [wet sieving and separation into the four sample subfractions] but were not analyzed, aside from extracting the gourd remains). The *Cucurbita* seed dimensions are provided in Table 10.9. Average length is 9.68 mm (sd 0.57), with a range of 8.45–11.15 mm. Seed width at midsection averages 6.55 mm (sd 0.41), the minimum and maximum widths being 5.07 and 7.60 mm, respectively. The seed width:length ratios average about 0.67, indicating relatively narrow forms. A few of the seeds exhibit marginal hair, particularly the three indicated in Table 10.8, though this feature of the seed coats is not well preserved and may simply result from exfoliating epidermal tissues. A few of the gourd seeds appear to be immature or otherwise underdeveloped. It is intriguing that so little rind material (four fragments total) is preserved relative to the number of seeds recovered. This may be explained by the fact that wild gourds have extremely bitter rind, a feature that is generally explained as a chemical defense against insect herbivory and may also have discouraged complete consumption of the fruits by megafauna. Extant wild gourds have small round greenish-beige fruits generally about 8 cm in diameter. Herbaceous vine tendrils in at least one sample (Table 10.6) may come from gourd vines. One additional member of the gourd/squash family (Cucurbitaceae) is represented among the plant remains from Page-Ladson: *Melothria* sp., creeping cucumber, based on a single seed from Level 17 of the 1991 excavations (Tables 10.5 and 10.7). *Melothria* berries are small, pulpy, pale green, globose to ellipsoid, and about 1–1.5 cm long.

Table 10.8 Page-Ladson Cucurbita *specimens*

Unit	*FS #*	*Count*	*Notes*
88′ Test C, Zone D	131	2	
F-91 Level 14	17.1	1	
F-91 Level 17	20.3	1	
F-91 Level 19	22.2	2	
F-91 Level 20	24.2	0	*Cucurbita* sp. rind only, 1 fragment
F-91 Level 21	25.1	3	
F-91 Level 21	25.3	3	
F-91 Level 21	25.4	3	Also *Cucurbita* sp. rind, 2 fragments
F-91 Level 22	26.1	8	
F-91 Level 22	26.2	3	
F-91 Level 22	26.3	6	
F-91 Level 22	26.4	1	
F-91 Level 23	28.4	3	
F-91 Level 24	29.1	5	
F-91 Level 24	29.2	1	
F-91 Level 24	29.4	6	
F-91 Level 25	30.4	1	
F-91 Level 26B	31.3	1	
F-91, exc. screen	–	6	
F-97-1	29C	11	
F-97-1	45C	10	
F-97-1	50C	10	
F-97-1	58C	1	
F-97-1	86C	4	
F-97-1	196C	2	
F-97-1	198C	1	
F-97-1	200C	1	
F-97-1/NE	194C	10	
F-97-1/NE	203	2	
F-97-1/nc	90C	3	
F-97-1/nc	128C	1	
F-97-1/SE	102	2	
F-97-1/SE	179C	1	
F-97-1/sc	79C	1	
F-97-1/sc	136C	2	
F-97-2	125C	10	Also fruit/rind blossom scar, 8.04 mm diameter
F-97-2/NE	82C	3	
F-97-2/NE	110C	7	
F-97-2/NE	115C	7	
F-97-2/SE	100C	2	
F-97-2/SE	183C	4	
F-97-2/SE	184C	1	
F-97-2/SW	114C	1	
F-97-2/sc	187	3	
Total		156	

Table 10.9 Page-Ladson Cucurbita *(C. pepo) seed measurements (mm)*

Seed/provenience	*Length*	*Width*			*Thick*	*W/L*[1]
		Proximal	*Mid-sect.*	*Distal*		
1 lv. 14, 91.17.1	–	–	6.96	4.41	–	–
2 lv. 21, 91.25.1	9.48	2.49	6.28	4.42	1.04	0.66
3 lv. 22, 91.26.1	9.90	2.70	6.15	5.23	0.50	0.62
4 lv. 22, 91.26.1	10.05	3.15	7.20	4.80	0.90	0.72
5 lv. 22, 91.26.1	9.90	2.90	6.15	4.50	0.70	0.62
6 lv. 22, 91.26.1	10.40	2.45	7.10	5.15	1.20	0.68
7 lv. 22, 91.26.1	10.15	2.83	7.10	4.80	0.90	0.70
8 lv. 22, 91.26.1	10.40	2.70	6.30	4.83	1.05	0.61
9 lv. 22, 91.26.1	10.15	2.15	6.80	4.95	1.05	0.67
10 lv. 22, 91.26.1	–	–	7.10	5.00	0.90	–
11 lv. 22, 91.26.2	10.46	2.88	6.80	4.51	–	0.65
12 lv. 22, 91.26.2	9.14	2.36	6.38	4.78	–	0.70
13 lv. 22, 91.26.2	10.03	2.66	6.45	4.47	–	0.64
14 lv. 22, 91.26.3	10.15	2.65	6.72	5.07	0.55	0.66
15 lv. 22, 91.26.3	9.11	2.61	6.53	3.68	0.95	0.72
16 lv. 22, 91.26.3	10.13	2.26	6.17	4.77	1.00	0.61
17 lv. 22, 91.26.3	8.73	2.00	5.07	3.46	–	0.58
18 lv. 22, 91.26.3	9.32	2.45	6.47	4.44	–	0.69
19 lv. 22, 91.26.3	–	2.36	5.95	–	–	–
20 lv. 22, 91.26.4	10.13	2.28	6.43	4.54	0.85	0.63
21 lv. 23, 91.28.4	9.71	1.91	5.94	3.91	–	0.61
22 lv. 23, 91.28.4	10.03	2.65	6.71	4.48	–	0.67
23 lv. 23, 91.28.4	8.89	2.84	6.47	4.72	–	0.73
24 lv. 24, 91.29.1	9.71	2.49	6.49	4.40	0.63	0.67
25 lv. 24, 91.29.1	9.97	1.85	6.82	4.72	0.95	0.68
26 lv. 24, 91.29.1	9.61	2.15	6.86	4.87	0.79	0.71
27 lv. 24, 91.29.1	10.55	2.37	6.94	5.02	0.42	0.66
28 lv. 24, 91.29.1	–	2.27	5.64	–	–	–
29 lv. 24, 91.29.2	9.35	2.70	7.00	5.25	1.00	0.75
30 lv. 25, 91.30.4	10.40	1.93	7.30	4.50	1.00	0.70
31 lv. 26b, 91.32.3	9.60	2.95	6.55	5.20	1.05	0.68
32 level uncertain	9.20	3.00	7.40	5.15	0.90	0.80
33 level uncertain	11.15	3.15	7.10	5.50	0.95	0.64
34 level uncertain	10.50	2.95	7.60	6.40	1.05	0.72
35 level uncertain	9.65	2.35	6.90	5.25	0.70	0.72
36 1997 FS 29C	9.61		6.87			0.71
37 1997 FS 29C	10.50		6.63			0.63
38 1997 FS 29C	10.24		6.18			0.60
39 1997 FS 29C	9.47		6.79			0.72
40 1997 FS 29C	10.26		6.18			0.60
41 1997 FS 29C	9.84		6.49			0.66
42 1997 FS 29C	9.87		6.25			0.63
43 1997 FS 29C	9.55		0.00			
44 1997 FS 29C	0.00		6.47			
45 1997 FS 29C	0.00		7.30			
46 1997 FS 50C	10.96		7.16			0.65
47 1997 FS 50C	10.80		6.74			0.62
48 1997 FS 50C	10.00		6.55			0.66
49 1997 FS 50C	9.78		5.97			0.61
50 1997 FS 50C	9.30		6.53			0.70

51 1997 FS 50C	9.45	6.71	0.71
52 1997 FS 50C	10.04	6.61	0.66
53 1997 FS 50C	9.35	7.02	0.75
54 1997 FS 50C	9.57	0.00	
55 1997 FS 58C	9.13	0.00	
56 1997 FS 79C	10.94	6.88	0.63
57 1997 FS 82C	10.00	6.51	0.65
58 1997 FS 82C	9.20	6.49	0.71
59 1997 FS 82C	9.46	0.00	
60 1997 FS 86C	10.01	6.91	0.69
61 1997 FS 86C	9.49	6.48	0.68
62 1997 FS 86C	10.00	6.89	0.69
63 1997 FS 86C	10.19	6.85	0.67
64 1997 FS 102	10.78	6.45	0.60
65 1997 FS 102	10.29	6.81	0.66
66 1997 FS 110C	9.18	6.51	0.71
67 1997 FS 110C	10.46	7.27	0.70
68 1997 FS 110C	9.72	6.80	0.70
69 1997 FS 110C	9.69	6.59	0.68
70 1997 FS 110C	8.92	6.17	0.69
71 1997 FS 110C	9.83	6.43	0.65
72 1997 FS 110C	9.04	6.90	0.76
73 1997 FS 114C	9.48	6.66	0.70
74 1997 FS 115C	9.06	5.96	0.66
75 1997 FS 115C	9.62	6.88	0.72
76 1997 FS 115C	8.45	5.91	0.70
77 1997 FS 115C	9.17	6.04	0.66
78 1997 FS 115C	8.80	6.46	0.73
79 1997 FS 115C	9.06	6.25	0.69
80 1997 FS 115C	8.93	6.48	0.73
81 1997 FS 136C	9.50	6.46	0.68
82 1997 FS 136C	9.35	6.34	0.68
83 1997 FS 183C	10.01	7.17	0.72
84 1997 FS 183C	9.97	6.49	0.65
85 1997 FS 183C	9.46	6.29	0.66
86 1997 FS 184C	8.67	6.19	0.71
87 1997 FS 187	9.63	6.24	0.65
88 1997 FS 187	9.02	5.68	0.63
89 1997 FS 187	9.52	6.24	0.66
90 1997 FS 194C	8.93	6.63	0.74
91 1997 FS 194C	9.30	6.78	0.73
92 1997 FS 194C	9.40	6.50	0.69
93 1997 FS 194C	10.27	6.74	0.66
94 1997 FS 194C	10.14	6.80	0.67
95 1997 FS 194C	8.80	6.07	0.69
96 1997 FS 194C	9.31	5.91	0.63
97 1997 FS 194C	8.89	6.30	0.71
98 1997 FS 194C	9.20	6.19	0.67
99 1997 FS 196C	8.56	6.10	0.71
100 1997 FS 196C	9.78	6.53	0.67
101 1997 FS 198C	9.47	6.68	0.71
102 1997 FS 203	8.92	6.30	0.71
103 1997 FS 203	9.94	6.29	0.63

---

[1] Width to length ratio is based on midsection (widest) width. Additional but fragmentary seeds from these units and others were not measured (see Table 10.8).

Several herbaceous perennials and annuals occur among the samples that may represent dry-ground habitats (Table 10.6; second group under non-arboreal taxa), though in most cases this is uncertain. Among these, three are especially noteworthy: *Phytolacca americana* (pokeweed), *Rubus* sp. (blackberry, bramble), and *Xanthium* sp. (cocklebur). Pokeweed or pigeonberry is a robust perennial herb, 1–3 m tall, generally found in disturbed habitats; it produces abundant purple-black berries, 7–10 mm in diameter (Radford *et al.*, 1968:429). Blackberries are robust woody plants with thorny, arching or trailing stems. There are a number of species in three subgenera; all produce sweet berries; they grow in dry to moist woodlands, thickets, and old clearings (Radford *et al.*, 1968:537–541). Two species of *Xanthium* are described for the southeastern flora (Radford *et al.*, 1968:1018–1019; but one species with two varieties is documented for Florida, according to Wunderlin [1998:653–654]); the size and morphological details of the specimens from Page-Ladson (Fig. 10.11) conform to either. Cockleburs are tall annual herbs with dry spiny fruits (between about 1–3 cm long, with lateral spines 1.5–5.0 mm long) (Radford *et al.*, 1968:1018–1019), suggestive of adaptation for dispersal by attachment to mammalian hair (Judd *et al.*, 2002:80–81). The habitat of cocklebur is generally open ground, grassland, and disturbed habitats (Radford *et al.*, 1968:1018; Wunderlin, 1998:654). I note also that provisionally identified *Medicago* sp. (clover-like weedy leguminous herbs), which is quite abundant in the sample from unit D′ and one from E (Table 10.6) may also represent upland plant communities. *M. lupulina*, black medic, is an annual with seeds 2–3 mm diameter and available in April–August (current habitats include "roadsides" and "waste places" [Radford, pp. 595–596]); the spotted medic, *M. arabica*, is similar; also possible is bur

Figure 10.11 Cocklebur (*Xanthium* sp.), FS 22C, 13.04 mm long. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

clover, *M. polymorpha*. The possible presence of this leguminous forb in potential mastodon dung recalls the (also provisional) identification of a close relative, clover, *Trifolium* sp. (Lepper *et al*., 1991:123), from the evidently ingested materials found with Burning Tree mastodon in Ohio that was mentioned earlier .

A number of damp-ground, wetland, and aquatic herbs are represented among the plant remains in the dung samples (Table 10.6; third group under non-arboreal taxa). All of these have the greatest potential to represent purely environmental deposition of seeds in the dung layers from the shallow water and fringing shore without necessarily having been eaten by mastodons, and in fact, most have been identified from other deposits bracketing the primary dung layer (Newsom, this volume). This does not preclude the possibility of consumption by mastodons, however, at least of water shield (*Brasenia schreberi*), coontail (*Ceratophyllum* sp.), waterlilies (*Nuphar lutea* and *Nymphaea* sp.), pondweed (*Potamogeton* sp.), and smartweed (*Polygonum* spp.), with their large green edible tissues and fruits (*Polygonum* species are commonly associated with wet-moist habitats, but to some extent also disturbed sites [Wunderlin, 1998:274–275]). Some of the same taxa, e.g. pondweed, water lily, sedges, have been identified among the intestinal contents from the other mastodon finds described below.

10.3.2.4 Seasonal Indications

The phenologies, specifically the periods when fruits are ripe and available for animal consumers and dispersers, of key taxa in the dung deposits are shown in Table 10.10. The periods indicated in the table are based primarily on southeastern floristics data, particularly for the coastal plain region (Radford *et al*., 1968; Godfrey and Wooten, 1979, 1981), as opposed to emphasizing exclusively the current vegetation in Florida (e.g. Wunderlin, 1998). This incorporates a broader perspective given the climatic contrasts between late Pleistocene and modern conditions. Though some taxa in the Page-Ladson assemblage were potentially available as early as May, the majority produce ripe, mature fruit in the late summer and fall. This is clearly demonstrated with regard to the various types of nut, which are relatively prominent in the Page-Ladson samples: August–September for hazelnut; September–October for beech; September–November for the oaks; generally October for hickory (Table 10.10). Osage orange likewise bears ripe fruit basically during October. The ovulate cones of cypress trees are evident in the summer and develop fully through the late summer-fall months and release seeds in or around October (Kurz and Godfrey, 1962:16–17; Radford *et al*., 1968:40–41). The rose family members – hawthorn, crab apple, wild plum – bear ripe fruit during July to about October. Similarly, the wild gourds and the grape family fruiting periods are primarily August–October. Among the terrestrial herbs, cocklebur, pokeweed, the smartweeds (disturbed areas, some damp ground), and blackberry, generally bear fruit from early summer to frost. The aquatic taxa demonstrate greater variability, from spring through fall.

The cypress remains are perhaps most telling as to the timing of mastodon visits to the site. The superabundance among the samples of cypress twigs and the abundance of mature cone scales, but very minimal presence of cypress leaves and seeds seems perplexing, envisioning mastodons broadly foraging on the apical growth of the trees. The only clear explanation for this apparent paradox is that mastodon foraging occurred or

Table 10.10 Fruit availability periods for key plant taxa from megafauna dung samples

Taxon	*Vernacular*	*Form*	*Phenology*
Arboreal			
Betulaceae			
Carpinus caroliniana	Bluebeech/hornbeam	Nutlet	September–October
Corylus americana	Hazelnut	Nut	August–September
Caprifoliaceae			
Viburnum (*prunifolium*)	Black haw	Drupe	September–October
Cornaceae			
Cornus amomum/foemina	Swamp dogwood	Drupe	August–September
Cupressaceae			
Taxodium sp.	Cypress, bald cypress	Cone	Fall–winter; seeds shed around October
Ebenaceae			
cf. *Diospyros virginiana*	Wild persimmon	Berry	September–October
Fagaceae			
Fagus grandifolia	American beech	Nut	September–October
Quercus alba/michauxii	White type oak	Acorn	September–November
Q. lyrata	Over-cup oak	Acorn	September–October
Q. nigra/laurifolia	Water/laurel type oak	Acorn	September–November
Juglandaceae			
Carya sp.	Hickory	Nut	October
Moraceae			
cf. *Maclura pomifera*	Hedge apple	Berry	October
Rosaceae			
Crataegus sp.	Hawthorn	Berry-like pome	August–October
cf. *Malus angustifolia*	Southern crab apple	Pome	August–September
Prunus sp.	Wild plum	Drupe	May–August
cf. *Rosa* sp.	Wild rose	Hip	(September–October)
Vines and Lianas			
Cucurbitaceae			
Cucurbita (*pepo*)	Wild gourd/squash	Berry	August–October
Vitaceae			
Vitis/*Ampelopsis* sp.	Wild grape/peppervine	Berry	August–October
Terrestrial Herbs			
Asteraceae			
Xanthium sp.	Cocklebur	Spiny achene	July–frost
Cyperaceae			
Carex gigantea/lupulina	Sedge	Achene	June–September
C. joorii		Sedge	AcheneJune–October
Rhynchospora sp.	Beak-rush	Achene	July–October
Scirpus sp.	Bulrush	Achene	July–September
Phytolaccaceae			
Phytolacca americana	Pokeweed	Berry	May–frost
Polygonaceae			
Polygonum spp.	Smartweed/	Achene knotweed	June–November
Rosaceae			
Rubus sp.	Blackberry	Drupelets	May–July
Aquatic Herbs			
Ceratophyllaceae			
Ceratophyllum demersum	Coon-tail	Achene	May–September
Nymphaceae			
Nuphar luteum	Spatter-dock	Berry	April–October
Potamogetonaceae			
Potamogeton sp.	Pondweed	Achene	June–September

Sources for fruit periods: Godfrey and Wooten (1979, 1981); Radford *et al*. (1968); Wunderlin (1998).

was concentrated during the cool months of the year, specifically the period when cypress trees drop their leaves and shed their seeds, but retain their ripe cones. *Taxodium distichum*, bald cypress, and the closely related *T. ascendans*, pond cypress (if they are indeed separate species), are among the few native conifers in North America that are seasonally deciduous, with leaf abscission occurring in the fall (Radford *et al*., 1968:40; Wunderlin and Hansen, 2000:320–322). The actual timing of leaf drop, as well as cone development and maturation, therefore seed release, is influenced by a number of factors, including moisture and other growth conditions during the year. Generally, in the spring the new leaves appear and the male cones release pollen (March–April [Radford *et al*., 1968:40]). The female cones develop through the summer, ripening in the fall months, and release their seeds generally in October. Most but not all cones and leaves then drop gradually from the trees during the mid–late fall and winter after or in conjunction with seed release (Newsom, personal observation). Considering this cycle of growth, the cypress cone scales in the dung deposits potentially represent whole mature cones browsed and then broken apart by mastodons along with the twigs and branchlets in the late summer-fall (no immature or otherwise underdeveloped cones have been identified in the samples). Alternatively or at least in some cases the cone scales may represent naturally abscised cones that dropped into the deposits, apart from any mastodon foraging activity. Either way, there conceivably would have been periods, beginning in the middle fall around October, when only the bare distal woody growth with or without cones would have remained on the trees for mastodons to browse upon. The triangular seeds of cypress are very few among the numerous seed remains identified from the samples, which may be a further indication of mid-to-late fall browsing, i.e. mastodons ingesting terminal woody growth with cones but following seed release. Likewise, whole or fragmentary cypress leaves are virtually absent among the samples. Moreover, whereas Hansen (this volume) has identified cypress leaf cuticles among most of the deposits at the site, they were not encountered in samples from the dung levels. We might expect that the released seeds and fallen leaves should still have become incorporated in the bottom sediments, including dung, of the sinkhole as they naturally fell from the trees over a period of time in the early fall and given the high degree of organic preservation at the site. Since these remains are in fact present in non-dung strata (though still infrequently, Hansen, this volume; Newsom, this volume), it would seem that their basic absence among the dung deposits may be a further indication that the mid–late fall period was in fact the time of mastodon foraging around the sinkhole, resulting in relatively rapid deposition of large volumes (inflation effect) of dung that included cypress twigs and likely also cones, with little or no seeds or leaf structures.

10.4 Discussion

The distinctive composition of the Page-Ladson dung samples displayed by the superabundance of uniformly clipped wood fragments and the particular combination of seeds, nuts, rind, and thorns, is strongly suggestive that this material is correctly identified as proboscidean dung, especially as these characteristics compared favorably with elephant dung in basic texture. In the following sections we summarize research based on elephant dung that demonstrates also some rather striking similarities in composition with the Page-Ladson dung deposits. We assume the deposits to be mastodon rather than mammoth or sloth dung, based on prior data on the diets of these fossil proboscideans and giant sloths from recovered stomach contents and/or dung, as well as the dental microwear and stable isotope studies of the proboscideans described in preceding sections.

A number of plant taxa were identified from the Page-Ladson dung deposits, several of which were quite conspicuous. First and foremost of these is the woody debris from cypress trees, based on the common presence and relatively high frequencies of cypress twigs and cone scales. Cypress browse, at least during the period of their stay in the immediate area, seems to have constituted the abundant low-quality bulk forage. Six types of nut (beechnut, hazelnut, hickory, white-type oak, overcup oak, water-laurel type oak) are likewise represented among the dung samples, one of which no longer occurs in Florida. Eight types of sweet fleshy fruits were identified, some fairly ubiquitous and others conspicuous by their simple presence, not being generally associated with the riparian, bottomland setting of the site or currently existing in ranges that exclude the study area. These include wild persimmon, Osage orange (assuming the assignment is correct), hawthorn, southern crab apple, wild plum, wild grape, pokeweed, and blackberry. Some of these taxa, as well as some of the herbs such as cocklebur, may have been consumed or encountered in upland or drier open settings and eventually deposited in the wet sinkhole sediments. Wild gourds, with their bitter rind, but edible seeds and flesh are well represented among the samples by the numerous seeds, though peduncles and rind fragments are entirely absent or virtually so. Although they apparently are not included in the extant vegetation of the region, these gourds may have grown in the vicinity of the sinkhole environment as part of the native flora in the late Pleistocene; however, their presence in Florida at the time may have resulted directly from mastodon foraging and migration patterns (Newsom *et al*., 1993). A number of other herbaceous plants were identified in the samples, including several damp-ground, e.g. smartweed, and emergents or aquatics such as water lily. The fruits, leaves, and other tissues of at least some of these wetland plants may have been consumed by mastodons (and perhaps other herbivores such as those mentioned previously), but others of the plant taxa may simply represent natural seed rain from the vegetation growing in and around the sinkhole pond. Exclusive of the aquatic and damp-ground-herb component, 27 plant genera from 21 families have been identified from the dung samples.

10.4.1 Insights from Previous Research on Living and Extinct Mammals

Analyses of gut and fecal materials from live and extinct animals – even those long extinct such as dinosaurs (Chin, 1995) – have proven a rich avenue of research on specific diets and foraging behaviors, and they are instructive when considering some of the details gleaned from the Page-Ladson dung samples. Toward that end, we provide the following summary of relevant results from previous research based on studies of several extant large mammals, including African elephants, and we mention some additional insights deriving from prior work with mastodon dung and gut contents. These studies provide greater perspective and context for our research with the Page-Ladson materials.

10.4.1.1 Extant Fauna

Detailed analyses of the dung of live carnivores (e.g. giant otter [Rosas *et al.*, 1999]), omnivores (e.g. sloth bear [Sreekumar and Balakrishnan, 2002]), and herbivores (e.g. various ungulates [Dinerstein, 1989]) have provided critical insights into food selection and foraging patterns specific to the individual animals investigated, and is sometimes the only means to discover important details of the diets of endangered or remote animals. Several of these studies have examined the foraging behaviors and diets of large mammalian browser-frugivores based primarily on their dung.

Middleton and Mason (1992) analyzed dung from three large grazer/browsers – nilgai cattle, feral cattle, and wild boar – in northern India to consider the extent of whole seed ingestion (therefore, the animals' respective roles as seed dispersers and their potential affects on the local forest ecology). Their results indicated that the dung of these species characteristically contained between 34 and 38 types of whole, viable seeds. Moreover, the seed constituents of individual dung samples varied according to the seasonal availability of particular types of fruit, for example, tree legume seeds were abundant in dung deposited during the hot–dry season, and those of a native grass during the wet monsoon period (Middleton and Mason, 1992). Similarly, rhinoceros dung from nearby Nepal included seeds belonging to 13 plant taxa, reflecting both the availability of food items in the local environment and the animal's food preferences (Dinerstein, 1989).

The tapir (*Tapirus terrestris*) is the largest extant native herbivore in the lowland tropical forests of South America (Eisenberg, 1989). Tapirs are known to feed on upwards of 100 plant species, including a wide variety of fruits (Henry *et al.*, 2000). Individual dung samples have been found to contain seeds of more than 40 species of fruit, the largest recorded specimens being 6.0–8.5 cm in diameter (Henry *et al.*, 2000). Tapir dung may include as much as 30% fruit, along with large quantities of more abundant low quality browse consisting generally of leaf and stem matter (ca. 50–90% fiber) (Bodmer, 1990, 1991; Salas and Fuller, 1996; Henry *et al.*, 2000; Tobler, 2002). Olmos *et al.* (1999) indicate that despite the fact that tapirs chew or ingest seeds of many species, as hindgut fermenters they have a limited capacity to digest them. Indeed, dung samples revealed that fruit was poorly digested, though the seed coats and their associated pericarps (soft ovulate tissues, fruit wall) exhibited signs of having been chewed (Olmos *et al.*, 1999). Moreover, because of a relatively long residence time in the digestive track, tapirs may disperse many seeds long distances from parent trees (Fragoso, 1997; Olmos *et al.*, 1999; Henry *et al.*, 2000). It has been suggested also that between their selective browsing, rummaging behavior, and seed dispersal, tapirs may influence forest composition in terms of maintaining a relatively species rich plant community in an intermediate succession (Salas and Fuller, 1996; Henry *et al.*, 2000). Though we have essentially ruled tapir out as the primary source of the ancient dung at Page-Ladson based on our particle-size analyses, their presence in the area is documented from the *Tapirus* skeletal materials recovered at the site, thus we might infer that extinct tapirs were similarly part of the local forest ecology and they may have accounted for at least some, albeit an as yet unknown quantity of the dung from the submerged deposits.

Likewise, modern elephants, through their feeding and foraging behaviors, are known to exert considerable influence on forest structure and ecological dynamics, which under ideal circumstances can promote growth beneficial to elephant populations by ensuring the spread of edible species and generally influencing forest succession and replacement efficiency. Basically, browsing African elephants and other large herbivores are keystone species in maintaining dry savanna environments, converting densely wooded areas into grasslands and more open shrub-dominated woodlands by heavily feeding on woody vegetation and bark (Laws, 1970; Owen-Smith, 1987, 1988) (not to mention seed dispersal and deposition such as was described about tapirs). Elephants have been shown to crop woody vegetation well beyond the leaves, buds, and shoots, and typically consume a large proportion of woody twigs and branches (Owen-Smith, 1988; Buss, 1990). Buss (1990) indicated that up to 97% of woody plant utilization by African elephants consists of breaking and tearing off branches of trees and eating terminal growth. The predominantly woody remains of the mastodon digesta appear to reflect a similar degree of this activity and may indicate that the feeding habits of mastodon populations were roughly similar to the behavior of modern browsing elephants, including having had similar large-scale environmental effects. Their feeding behavior and subsequent impact on the local flora seem to have involved at the least stripping trees of terminal/apical growth, possibly also uprooting trees.

Detailed dung compositional analyses focused on living elephants have provided a wealth of additional insights into their food preferences and foraging patterns. Haynes (1991:324) observed that elephants grind their food into smaller, more easily digestible bits, however the grinding rarely reduces the food to an undifferentiated mass, resulting in dung with clearly recognizable plant constituents, e.g. mashed wood, bark, compressed leaves, and other plant parts, much as we have observed with the modern elephant dung and Page-Ladson samples that are analyzed herein. Like tapir, elephants are cecalid (non-ruminant, hindgut fermenting) seed dispersers, thus seeds in particular have a tendency to survive consumption and digestion intact and they readily germinate after deposition (Dudley, 2000).

Several studies have concentrated on the seed constituents of elephant dung deposits specifically to address the question of the animals as agents of seed dispersal and influencing plant biogeography. For example, Leiberman *et al.* (1987) analyzed 31 piles of African elephant dung that together yielded a total of 449 seeds representative of 11 taxa from 9 plant families. The seeds were generally recovered in good condition, if not fully intact. Furthermore, every pile of dung was found to contain seeds, with the density of seeds per pile ranging from 4 to 40, and the number of species from 1 to 5, with a mean of 2.7 separate plant taxa. It was noted that some species were found to be ubiquitous and super abundant, while others were infrequent or absent from individual dung samples. Interestingly, seed frequencies among dung samples were not in complete agreement with the actual densities of particular tree species in the local forest census, therefore the specific composition of the dung was interpreted as a good indication of species selection and food preferences by elephants

(Lieberman *et al*., 1987). The 11 plant taxa ranged from small to large trees and one large liana (i.e. a woody vine). The fruits of these taxa range from drupes and berries of various types (fruits with single or multiple pits or seeds, encased in soft, pulpy edible tissues) to a fleshy winged pod, and a woody capsule with an arillate (a sweet, fleshy outer layer) seed. Fruit size ranged from 3 mm to as much as 18 cm in length or diameter (Lieberman *et al*., 1987; Table 10.1).

The morphological characteristics of the fruits and seeds documented in the Lieberman *et al*. (1987) study were found to be generally consistent with those traits associated with a "ruminant-rodent-elephant" syndrome (Janzen and Martin, 1982; Gautier-Hion *et al*., 1985) of seed dispersers, i.e. relatively large, dull-colored, indehiscent fruit with dry fibrous flesh and well-protected seeds (i.e. possessing outer coats that are hard, dense, rough, spiny, etc.). The hickory nuts from Page-Ladson are a good example of such fruits. However, a number of the fruit types identified in the Lieberman *et al*. (1987) study deviated somewhat from this idealized pattern, being relatively small or dehiscent, and with pulp texture varying from fibrous and tough to mealy and sticky, creamy, waxy, and soft and moist. Moreover, as the authors indicated, seed size varied from relatively small to very large (seed size for the most abundant species is 4 × 5.5 cm), and included some with a tough woody endocarp, but others that lack such mechanical protection. This general description – i.e. the extent of variability in fruit and seed types and sizes – basically also characterizes the Page-Ladson dung assemblage as it was described above. Interestingly, the fruit of the liana, *Strychnos aculeata*, found in the dung samples in the Lieberman *et al*. (1987; Table 10.1) study may be consumed by mammals with no harm, but the seeds are highly toxic, having evolved the strong alkaloid strychnine in the seed coats (Willis, 1985:1113) presumably as a chemical defense against herbivory (primarily predation by insects). This recalls the inferred toxicity (presumably so, based on extant forms) of the Page-Ladson wild gourd rinds.

Another study (Yumoto *et al*., 1995) employed dung analysis to compare the feeding behaviors of different mammals, including elephants (203 dung piles), in an African tropical rainforest. All together, 13 plant species were identified from the elephant samples; the seeds of seven were excreted exclusively by elephants and those of two plant species only by elephants and eastern lowland gorillas (the second largest frugivore in the particular forest environment). In general, these seeds were relatively large, or possessed a very thick pericarp, or a very hard, fibrous tissue surrounded the seeds, and one type of pod was reportedly poisonous. These are all features that tend to preclude all or most other animals as consumers or dispersers. Colors of the "elephant-exclusive" fruits ranged from black-brown to green, although the colors of all fruits consumed by elephants ranged into shades of yellow (Yumomo *et al*., 1995; Table 10.2). These characteristics led Yumoto *et al*. (1995) to suggest a refinement of the ruminant-rodent-elephant seed dispersal syndrome as the adaptation that: (1) prevents seeds from predation by small bovids (in this case, blue duiker, *Cephalophus monticola*) and rodents (African bush-tailed porcupine, *Atherurus africanus*, and emin's giant rat, *Cricetomys emini*), i.e. seeds having prohibitive mechanical (perhaps also chemical) defenses, (2) attracts no monkeys or birds (having dull color and drier or coarse flesh), and (3) allows them to be dispersed intact exclusively by elephants (being very large). Significantly, Yumoto *et al*. (1995) indicate that together the characteristics define fruits that have become specialized for dispersal by elephants, postulating three ways by which plants might benefit from having elephants as their primary seed dispersers: as large, wide-ranging mammals, elephants transport seeds over a broad area; they can convey large seeds that germinate into large seedlings with higher shade-tolerance; and they also create gaps and disturb dense vegetation cover, all of which creates suitable places for the germination of seeds and facilitates the successful growth of seedlings. Moreover, as Lewis (1987) pointed out, pre-ingestion and passing through an elephant's digestive tract, along with deposition of seeds in coarse, organic-rich dung piles beneficially alters the seed coat while simultaneously providing a microclimate highly favorable for seed germination and seedling growth.

Dudley (2000) examined the foraging behaviors of African bush elephants (*Loxodonta africana*) in a semiarid woodland – notably one that may approximate plant communities in the vicinity of Page-Ladson under the more arid conditions of late Pleistocene North Florida – with emphasis on the great potential in Africa for coevolved seed dispersal mechanisms involving elephants or elephant-like megaherbivores considering the lengthy history of proboscideans on that continent. Dudley (2000:556) pointed out that elephants are extraordinarily manipulative and vagile in their feeding behaviors, and their niche is functionally unique among extant mammals "in terms of the highly catholic nature of the diet and the spatial extent of the effective foraging zones (ca. 1 m below ground to >5 m above ground); these foraging parameters are not replicated within the niche of any other extant megaherbivore". The elephants in Dudley's study area reportedly often traveled 20–50 km or more in daily foraging treks within home ranges of 900–3000 km^2. Eighty percent of 123 dung piles analyzed contained seeds and/or partially digested fruit matter, for an average of 291 seeds per defecation event, representing 28 species of tree or shrub, one palm, and one herbaceous vine (Dudley, 2000; Tables 10.1 and 10.2). Interestingly, the most abundant and frequent types of seeds found among the dung samples were those of a wild melon (*Acanthosicyos naudinanus*, Cucurbitaceae, the same family as the Page-Ladson gourd) and a tree legume (*Acacia erioloba*). The seeds of woody plants found in the dung ranged in size from 1.0 to 5.0 cm in diameter, the largest being those of the palm (4.0–5.0 cm in diameter). As with some of the other studies described above, dung seed content varied with the phenology of individual plant species, i.e. it corresponded closely with the seasonal cycles and the timing of flowering and fruit production in the local vegetation. Moreover, some individual dung piles contained exceptional quantities of plant material, for example, nearly 5000 *Acacia* spp. seeds and a large quantity of undifferentiated pod/seed matter were associated with two defecation events by a single bull elephant (Dudley, 2000:558–559).

In view of all of the above and considering in particular the several traits outlined for the ruminant-rodent-elephant seed dispersal syndrome, the taxonomic diversity and the morphological characteristics of the fruits and seeds from the Page-Ladson samples are generally consistent with those documented by other researchers. Several of the plant taxa conform with those traits associated with the syndrome, for example, hickory nuts, acorns, and hazelnuts are all relatively large, dull-colored, indehiscent fruit with dry fibrous flesh and well-protected seeds, while others of the taxa deviate somewhat from the "model" pattern, which was true also of the studies of modern elephants. Aside from hickory nuts, most of the Page-Ladson dung taxa (i.e. the fruit targets of consumption) are relatively small; they exhibit a range of colors, though for the most part they are in fact muted (blue–black to pale peach/yellow/green) so generally conform with the "dull" end of the spectrum; and pulp texture varies from fibrous (e.g. Osage orange, wild gourd) to soft and moist (e.g. persimmon, hawthorn, plum, wild apple, grape, pokeweed, blackberry). In addition, seed size varied from relatively small to fairly large, and included some with relatively thick, tough seed coats or a spine-covered involucre (beechnut), but others that lack such mechanical protection aside from perhaps, hawthorn, with its armed twigs.

Perhaps the presence of the large (hawthorn, honey locust) and small (wild rose and/or blackberry) thorns in the Page-Ladson samples is consistent with the foliage-as-fruit hypothesis as we earlier suggested for the cypress cones. Likewise, the seeds of various herbaceous plants, including the emergents such as spatterdock and water lily, were likely to have been consumed incidentally to foraging on the stem and leaf tissues. This again would be consistent with the foliage-as-fruit hypothesis, although such other plant parts have not been identified.

Clearly, strong links and a complex co-evolutionary relationship exist between certain plants and large herbivores, including proboscideans, the former providing attractive edible fruits in exchange for transporting seeds. We may reasonably infer that the relationship existed also between mastodons and their native floras, and in fact as we have indicated, a number of plants native to the American continents today produce fruits that evidently are now anachronistically related to extinct megamammals. Barlow's (2000) *The Ghosts of Evolution* provides a thorough review of such taxa. Among these are several trees with relatively large fruit, for example, honey locust (*Gleditsia triacanthos*) with long, robust pods containing sweet pulp and tough, tooth-resistant seeds; Kentucky coffee tree (*Gymnocladus dioica*), another tree legume with large (ca. 10–25 cm long) red-brown leathery pods that enclose a slightly sweet pulp and hard, thick-walled seeds (note that the raw seeds are toxic to humans, at least [Little, 1980:524–525; Fergus, 2002:24]); Osage orange (*Maclura pomifera*) with large globular, densely fibrous, rather citrus-like fruits; and at least two tropical tree species, avocado (*Persea Americana*), an energy-rich fruit with a large hard bitter pit, and mombin (*Spondias mombin*), another large sweet, fleshy fruit encasing a hard, spiny pit, among others (Janzen and Martin, 1982; Janzen, 1985; Barlow, 2000, 2001). A notable sign of the anachronistic megafaunal association of these fruits is the fact that extant native fauna avoid or seldom consume them and may be unable to serve as effective seed dispersers. Moreover, the trunks, lower branches, and twigs of honey locust, various other tree legumes, Osage orange, and hawthorns (*Crataegus* spp., again, another potential member of this anachronistic assemblage) are all armed with stout thorns that protect the wood and leaves from predation, an adaptation presumably evolved to cope with megafauna browsers (Barlow, 2001), allowing fruits and seeds to be attractive and available for consumption while ensuring that the primary plant body and photosynthetic tissues remained intact. Hawthorn seeds and the spines, and possibly also Osage orange seeds were identified among the Page-Ladson samples. Some members of the cactus family may also exhibit anachronistic adaptations (spiny plant body, fruits relatively unprotected, arrayed high on upper lobes), and this has been suggested also of devil's claw (*Proboscidea* sp.), with its giant bur evolved to attach to large animals for dispersal (Janzen and Martin, 1982; Barlow, 2001). Finally, Janzen and Martin (1982) (see Barlow, 2000) have pointed out that wild bitter Cucurbitaceae – the gourd-bearing vines of the pumpkin and squash family – almost certainly represent an original adaptation for dispersal by megafauna, who would have avoided the highly bitter rind while consuming the less- or non-bitter flesh and seeds, later dispersing the relatively large seeds intact in their dung. Barlow (2000:211) in fact comments on the Page-Ladson *Cucurbita* seeds, agreeing that the plant fits the model of one with a close association with megafauna dispersers, elaborating that the pulp of such wild gourds may have served the plants effectively as "bait" that attracted large mammals and pointing out the frequent occurrence in living elephant dung (e.g. the wild melon mentioned above) of seeds belonging to various other genera in the Cucurbitaceae. Presumably, the somewhat tough, bitter rind – an effective deterrent to other faunal consumers, including insects – would have been readily overcome by mastodons, much as modern elephants in the Kalahari use their feet to gently pop open wild gourds and consume the flesh, avoiding the bitter rind. This, particularly noteworthy among the Page-Ladson samples are the wild gourd, the stout spines suggestive of locust trees, the spines and seeds (thus fruit) of hawthorn, and the possible Osage orange, as taxa that specifically have been hypothesized by Janzen and Martin (1982) to have anachronistic associations with megafauna.

Highly relevant to our research also are observations from modern elephant populations concerning dung volumes and gut transit time. According to Dudley (2000:558–559) and assuming a defecation rate of 14 dung piles/elephant/day, "The overall rate of elephant dung deposition within Hwange National Park is estimated to be about one million tons/annum (912,500 metric tones [sic]), assuming a population of 25,000 elephants, average of 23.39 years , and estimated dung production of 100 kg/elephant/d for an elephant of this age/size class , equivalent to a wet-weight dung deposition rate of ca. 62.5 g/m^2/year ," Similarly, Haynes (1991:88, citing Guy, 1975) indicates that an adult African elephant deposits on average 11 kg of dung every two hours, or 100–150 kg every day. These data show how readily the sinkhole at Page-Ladson could have contained such volumes of dung as we estimated and described above.

Dudley (1999, 2000) reports gut transit time as between 23 and 36 h for one tree legume (seeds and fruit), thus a potential dispersal distance of 20–30 km can be predicted for elephant-dispersed seeds in a dry woodland and savanna environment, which, to reiterate, is similar in several respects to late Pleistocene Florida (Hansen, this volume). This brings to mind the hazelnut and Osage orange, possibly also the wild gourd and the black haw (*Viburnum*) mentioned earlier, if in fact the late Pleistocene ranges of these plant species closely approximated their current ranges, which do not include northern Florida. One additional observation worth noting is that in summer a modern elephant's food intake is generally greater than in winter or during dry seasons, thus dung volume may vary seasonally (Guy, 1975; Haynes, 1991).

Finally, it is important to recognize that all browsers and grazers often ingest small seeds as they feed on the photosynthetic tissues of plants. Thus Janzen (1984) proposed his foliage-as-fruit hypothesis, in recognition that the foliage of small-seeded species in part may have had the same coevolutionary function for megafauna as fleshy fruit holds for them and obligate frugivores. Browsing on the leaves and stems of grasses and other herbaceous vegetation, or the leaves and other vegetative parts of woody plants, may incidentally result in the ingestion of small, relatively unattractive seeds and fruits that ultimately are dispersed by the animals. One example from our research might be the cypress cones among the Page-Ladson samples, the consumption of which could have been incidental to ingestion of the young green twigs and apical growth as abundant low quality browse. As we mentioned earlier, some of the other small seeds, including from plants growing in and around the sinkhole pond may fit this situation.

10.4.1.2 Extinct Megaherbivores

Some environments, as we have indicated, have occasionally allowed for the preservation of the stomach contents and dung of Pleistocene herbivores. Outside of North America, the preserved intestinal contents of extinct proboscideans have been reported for wooly mammoths (*Mammuthus primigenius*) in Russia (Tikhomirov, 1958; Olivier, 1982) and for *Haplomastodon* (Bryan *et al*., 1978) in Venezuela. Dung and intestinal remains of North American Pleistocene megaherbivores are well known from two main regions of the continent (Haynes, 1991; Fisher, 1996). In the west, dung of Pleistocene herbivores from the Colorado Plateau (Hansen, 1978, 1980; Davis *et al*., 1984, 1985; Mead *et al*., 1986; Mead and Agenbroad, 1989) is known from an array of species including Shasta ground sloth (*Nothrotheriops*), mammoth (*Mammuthus*), horse (*Equus*), and bison (*Bison*). These are preserved in xeric caves and are often found as complete dung boluses and mixed together in stratified layers. Mammoth dung from Brechan Cave (Davis *et al*., 1985) consisted of over 95% herbaceous tissue from grasses, sedges, and rushes; additional constituents from woody plants included birch, rose, saltbush, sagebrush, blue spruce, wolfberry, and dogwood. Recently, Hoefreiter *et al*. (2000, 2001) have demonstrated that it is potentially possible to detect a wider range of taxa consumed and to trace changes in the diets of extinct taxa, e.g. ground sloths, by combining the analysis of preserved plant particles with DNA recovered from individual fecal specimens.

The second region includes southern Ontario, the Midwest, and the northeastern United States where, as we described in the introduction to this chapter, intestinal contents have been found within the rib cages and pelvic regions of American mastodon skeletons preserved in peat bogs and other wetsite deposits (Bishop, 1921; Dreimanis, 1968; Laub, 1990; Haynes, 1991; Fox and Smith, 1992; Laub *et al*., 1994; Fisher, 1996; Saunders, 1996). To reiterate, these apparent gut contents are sometimes found to be quite voluminous and to occur in a cylindrical shape evidently conforming to the digestive tract at the time of the animal's death, and they are generally described as consisting predominantly of finely chopped or clipped sections of twigs and branch materials that often lack bark and are generally straw-colored or yellowish in aspect. In general, the intestinal contents indicate that boreal forest mastodons consumed a large proportion of the distal tips and outer branches of northern coniferous trees, based variously on the presence of wood, twigs, cones, and needles from spruce (*Picea* spp.), hemlock (*Tsuga* sp.), pine (*Pinus* sp.), red cedar (*Juniperus* sp.), fir (*Abies* sp.), and larch or tamarack (*Larix* sp.). Some studies report a small percentage of flowering plants in the samples as well, e.g. willow (*Salix* sp.) and other wetland vegetation, including aquatic pondweed (*Potamogeton* sp. [seeds]), and unidentified reeds and grass (Dreimanis, 1968; Fisher, 1996). The identification of conifers as having served as bulk forage is consistent with the Page-Ladson samples; we would note that both willow and pondweed were provisionally identified from among the samples we analyzed (Tables 10.5 and 10.6).

We briefly mentioned earlier the Burning Tree mastodon found in Ohio. Lepper *et al*. (1991) report a relatively diverse, non-coniferous diet for that particular mastodon, the gut contents having consisted largely of the leaves and twigs of unidentified broadleaved trees, as well as mosses and an apparently significant amount of low herbaceous growth. The latter is based on the presence of unidentified inflorescence fragments and an abundance of seeds identified or provisionally classified to four genera: sedges (Cyperaceae: *Carex*, *Cladium*), niads (*Najas* spp.), and the possible clover mentioned earlier (cf. *Trifolium* sp.); the sedges and niads, at least, are associated with wetland habitats. Smaller numbers of seeds identified as pondweed (*Potamogeton*), waterlilly (*Nymphaea*), and pigweed (*Amaranthus*) were also present; the first two are freshwater aquatics, and the latter generally represents dry-ground and disturbed habitats though some species occur in wetlands (Radford *et al*., 1968:423–427). Here again, the wetland and aquatic taxa mirror those identified from the Page-Ladson samples, given the presence in our samples of some of the same or similar taxa: pigweed (*Amaranthus* [cf.]), watershield (*Brasenia*), sedges (*Carex* spp., *Cyperus* sp.), and waterlilies (spatterdock [*Nuphar*] and waterlily [*Nymphaea*]), among others (Tables 10.5 and 10.6). This suggests that perhaps likewise mastodons at Page-Ladson consumed some of the emergent and damp-ground vegetation in and around the perimeter of the sinkhole pond, rather than these taxa necessarily being present among the samples due to simple seed release and deposition.

Based on the seasonal availability (fruit ripening periods) of the individual plant taxa, the Burning Tree mastodon would have consumed these plants and died in the late summer to early autumn (Lepper *et al*., 1991), a finding that was corroborated by analysis of seasonally formed dental laminations in the tusk (Fisher, 1994). Conversely, the remains of the more coniferous diets of other mastodons have been attributed to late autumn or winter foraging (Laub *et al*., 1994; Fisher, 1996), much as we infer for Page-Ladson. Based on this evidence, and considering the aforementioned on seasonal variability in the diets of extant elephants, there may have been sufficient diversity in the mastodon diet to allow for seasonal fluctuations. For example, the more nutritious non-coniferous plants were perhaps more heavily consumed during favorable times, while the bulk of the mastodons' food intake was likely to have consisted of less nutritious coniferous forage that was available throughout the year (in this case, conifers specifically meaning the soft terminal growth of cypress trees, even after leaf fall, and perhaps as much as anything because the trees commonly grew around the pond fringe).

The discussion earlier about cypress trees and growth cycles underscores the inherent difficulties of trying to discern a seasonal signal from dung or gut contents, as Guthrie (1990:12, 14) observed concerning the Dima mammoth and efforts to ascertain the time of year when death occurred. Regarding Page-Ladson, the situation is further complicated since rather than dealing with the season and death of a single individual, we seek to identify any evidence suggesting annual periodicity of visits based on collective dung remains representing multiple individuals over a period of years. Nevertheless, a strong fall signal for site visits on the part of mastodons appears to be a solid conclusion for Page-Ladson, though it does not necessarily negate their presence in and around the area at other times of the year. Specifically, the presence of mature cypress cone scales and twigs evidently bearing few or no leaves, combined with predominantly fall ripening periods for the nut and vine taxa provides a strong indication of mastodon foraging in the latter part of the year. This autumn signal of the plant materials is consistent with evidence of migratory patterns for mastodons found at the Page-Ladson site that have been reconstructed from strontium and oxygen stable isotopic signatures of growth increments in tooth enamel, all of which suggests that Florida mastodons migrated seasonally between the Gulf Coast into Georgia and perhaps as far as the Appalachian region (Hoppe *et al*., 1997; Hoppe and Koch, this volume; also see Fox and Fisher, this volume for further discussion). (Strontium isotopes also indicate that mammoths appear not to have had the same migratory routes as mastodons and were perhaps more stationary.) Moreover, Fisher and Fox (this volume) concluded from tusk growth increments in tusk dentin that the season of death of one mastodon from Page-Ladson (UF 148667) occurred sometime in the autumn, further corroborating the presence of mastodons in the area based on the dung constituents.

Interestingly, Fisher (1996) suggested that in the Northeast region mastodons concentrated on deciduous trees and wetland vegetation during the mid-autumn, while coniferous material became more important later in the season. Our evidence potentially indicates something similar with regard to southeastern mastodons, who perhaps consumed proportionately more of the various fruits and nuts that were available in late summer through middle fall, and then likewise emphasized a local conifer – in this case, cypress trees – following the peak period of fruit and nut availability for other taxa.

Northern Florida is the third region that has revealed the presence of preserved digested food remains of Pleistocene herbivores, which seem in general to represent primarily mastodon diets. In fact, these remains come from two localities, both relic sinkhole deposits in the Aucilla River that evidently were visited repeatedly by mastodons and other herbivores over a period of years or decades. The sinkhole at Page-Ladson, first reported by Webb and Newsom (1991) and Webb *et al.* (1992), contains dung deposits dating to 12,000–13,000 B.P., while the Latvis–Simpson site has produced strikingly similar material dating back to 32,000 B.P. (Mihlbachler, 1998). Preliminary analyses of the dung from the latter site indicate once again an overwhelming abundance of cypress woody growth and cone scales, and otherwise some of the same nuts and fruits, e.g. wild grapes and wild gourds as were identified from Page-Ladson. Likewise, the Latvis–Simpson samples indicate that foraging activities by mastodons in the area occurred during later months of the year. In general, the mastodon dung from Florida indicates a somewhat different diet from mastodon populations inhabiting the Pleistocene boreal and mixed conifer-deciduous forests of the North, though they are more or less consistent with the plant materials associated with the Missouri mastodon discovered by Koch (1841) that possibly, but not certainly, represents dung or stomach contents, and the Burning Tree mastodon from Ohio, as described above. Moreover, as we have indicated, it is important to reemphasize that the Florida dung deposits are effectively composite dung samples, i.e. the result of multiple defecation events over a period of time, and not individual dung boluses or the gut contents, i.e. the last meals, directly associated with individual mastodon skeletons such as are the other cases. As such, the Aucilla River deposits containing heavy concentrations of dung may be more indicative of the general diet of the local mastodon population, including individuals of all ages and both sexes, rather than the diet of a single individual. In this respect, they resemble the deep, extensive mammoth dung deposits preserved in caves in the American west, e.g. Brechan Cave noted above, reflecting seasonal use of the sites over several years (or short-term use by larger groups) (Haynes, 1991:88–89). Likewise, if the site was regularly visited over an extended period of time – i.e. seasonally revisited over a period of years – the diet reflected in the overall dung sample provides an indication of preferred forage for at least part of the year (however unspecified the period of time) versus simple individual consumption events.

10.5 Conclusions

Assuming that the material discussed in this chapter has been correctly identified as the remains of plants ingested and deposited by mastodons, we infer that heavy mastodon activity occurred within, around, and in the vicinity of the sinkhole at the Page-Ladson site approximately 12,000 years ago. This activity seems to have been concentrated or occurred exclusively during the autumn months. Most likely, the sinkhole was a shallow pond that mastodons used as a wallow and source of freshwater over an extended period of time. Most likely, a minor increase in the local water level, possibly caused by a small spring, turned what was once a marshy bog (considering the deeply buried peat deposits) into a shallow pond, thus attracting heavy use by mastodons (and possibly other ungulates and megaherbivores such as giant ground sloth), resulting in a massive influx of dung deposition.

The evidence of this wallow scenario is reminiscent of modern ponds and wallows in both African and Asian game parks that contain elephants, rhinos, and other large-bodied ungulates with dung strata. In dry or seasonally dry savanna environments, the seasonal availability of water heavily influences the social behavior, feeding range, seasonal movements, and biomass distribution (Western, 1975; Haynes, 1991, 2002) of large herbivores. Likewise, Fisher and Fox's (this volume) growth increment study of the Page-Ladson mastodon suggests that seasonal moisture or nutritional stress might have played a causal role in migratory patterns. While the social behavior of mastodons can never be known, large numbers of mastodons visiting the same water resource imply that at least some degree of social interaction must have taken place in this species. Even solitary megaherbivores exhibit a higher degree of social interaction at watering holes (Owen-Smith, 1988), including sexual-related behavior such as intermale competition. Sinkholes such as this may have served as social loci for mastodon populations where individual males, small female groups (i.e. mother–infant pairs), or combinations of both carried out social interactions. If water sources were confined to chains of sinkhole ponds during the drier portions of the year, feeding territories would have radiated for many kilometers beyond these water sources.

The seasonal fluctuation of water availability, as well as the condition and availability of plant forage, provides viable explanations for large-scale population movements. For example, regular population movements could have been influenced by the impact that high densities of mastodons would have had on their habitat, i.e. the condition of the local forests and extent of remaining forage. Dense numbers and concentrations of proboscideans are capable of greatly disturbing and modifying habitats (Naiman, 1988; Haynes, 2002), as we have indicated. Thus, the possible large-scale seasonal movements of the mastodon populations away from the area on a temporary basis theoretically would have reduced any negative impacts on local vegetation and maintained a sustainable habitat favorable for browsing mastodons, much as was described earlier regarding African elephant habitat. In general, large bodied herbivores such as proboscideans are capable of bulk feeding on abundant low quality forage such as woody twigs, bark or grass, in part as a direct result of their body size. Consequently, the material consumed by mastodons in North Florida resembles that of living browsing elephants in terms of the overall composition, if not also some of the basic dietary elements (fruits and nuts representing essential minerals and carbohydrates).

While the mastodons evidently browsed heavily in bottomland cypress forest near local water sources such as the sinkhole ponds of the Aucilla River, they undoubtedly fed from a diversity of local habitats, with some of the plant taxa possibly indicative of this variety, in particular the pokeweed and perhaps a few others such as wild plum that may have come from drier upland environments. We would add that while the bulk of the feeding was perhaps rather unselective, i.e. intensive browsing from the distal growth of trees but particularly cypress – there are suggestions of more selective foraging behaviors. Mastodons may have preferentially browsed acorns and hazelnuts, as well as persimmon, hawthorn, plum, and wild grape fruits, and the seeds and flesh of wild gourds, avoiding the bitter rinds. Moreover, such selection and the potential nutritional value of some of these plant taxa suggest that this diet was essentially a healthy diet composed of a relatively wide variety of plant species. The apparently healthy nature of the localized late summer–fall–winter diet of southeastern (i.e. Page-Ladson) mastodons is, again, consistent with Fisher and Fox's (this volume) suggestion from the tusk growth increments that periods of nutritional stress occurred during a time well removed from the time of the autumn death, and hence the time of the deposition of the dung. The overall nature of the forage provides an indication that at 12,000 years ago southeastern mastodon populations, at least, were reasonably healthy and consumed a nutritious diversity of foods from different habitats. There is no reason to suspect – at least based on the sources of data discussed here – that local populations were impoverished or starving.

References

Barlow, C. 2000. *The Ghosts of Evolution: Nonsensical Fruit, Missing Partners, and other Ecological Anachronisms*. Basic Books, New York, NY.

——. 2001. Ghost Stories from the Ice Age: some plants are hunted by large mammals from another era. *Natural History* 110(7):62–67.

Beriault, J., R. Carr, J. J. Stipp, R. Johnson, and J. Meeder. 1981. Archaeological salvage of the Bay West Site, Collier County, Florida. *The Florida Anthropologist* 34:39–58.

Bishop, S. C. 1921. The Temple Hill (Orange County, NY) mastodon. *Science* 54:1391.

Bodmer, R. E. 1990. Fruit patch size and frugivory in the lowland tapir (*Tapirus terrestris*). *Journal of Zoology* 219:457–467.

——. 1991. Strategies of seed dispersal and seed predation in Amazonian ungulates. *Biotropica* 22:255–261.

Brown, J. G. and A. D. Cohen. 1985. Palynologic and petrographic analyses of peat deposits, Little Salt Spring. *National Geographic Research* 1:21–31.

Bryan, A. L., R. M. Casamiquela, J. M. Cruxent, R. Gruhn, and C. Ochsenius. 1978. An El Jobo mastodon kill at Taima-taima, Venezuela. *Science* 200:1275–1277.

Buss, I. O. 1990. *Elephant Life: Fifteen Years of High Population Density*. Iowa State University Press, Ames.

Calhoun, A. J. K. 1999. Forested wetlands. In M.L. Hunter, Jr. (ed.), *Maintaining Biodiversity in Forest Ecosystems*, pp. 300–331. Cambridge University Press, Cambridge, UK.

Cheney, T. A. 1872. The Chantauqua mastodon. *American Naturalist* 6:178–179.

Chin, K. 1995. Lessons from leavings. *Natural History* 104(6):67.

Clausen, C. J., A. D. Cohen, C. Emiliani, J. A. Holman, and J. J. Stipp. 1979. Little Salt Spring, Florida: a unique underwater site. *Science* 203:609–613.

Cushing, F. H. 1897. A preliminary report on the exploration of the ancient key dweller remains on the Gulf Coast of Florida. *Proceedings of the American Philosophical Society* 35(153).

Davis, O. K., L. Agenbroad, P. S. Martin, and J. I. Mead. 1984. The Plesitocene dung blanket of Bechan cave, Utah. In H. H. Genoways and M. R. Dawson (eds.), *Contributions in Quarternary Vertebrate Paleontology in Memorial to John E. Guilday*, pp. 267–282. Special Publication of Carnegie Museum of Natural History, 8.

Davis, O. K., J. I. Mead, P. S. Martin, and L. D. Agenbroad. 1985. Riparian plants were a major component of the diet of mammoths of southern Utah. *Current Research in the Pleistocene* 2:81–82.

Decker-Walters, D., T. Walters, W. Cowan, and B. Smith. 1993. Isozymic characterization of wild populations of *Cucurbita pepo*. *Journal of Ethnobiology* 13(1):55–74.

Delcourt, P. A. and H. R. Delcourt. 1993. Paleoclimates, paleovegetation, and paleofloras during the late quaternary. In Flora of North America Editorial Committee (eds.), *Flora of North America North of Mexico, Volume 1*, *Introduction,* pp. 71–94. Oxford University Press, Oxford, UK.

Dinerstein, E. 1989. The foliage-as-fruit hypothesis and the feeding behavior of South Asian ungulates. *Biotropica* 21:214–218.

Doran, G. H. (ed.). 2002. *Windover: Multidisciplinary Investigations of an Early Archaic Florida Cemetery*. University Press of Florida, Gainesville.

Doran, G. H. and D. N. Dickel. 1988. Multidisciplinary investigations at the Windover Site. In B. A. Purdy (ed.), *Wetsite Archaeology*, pp. 263–289. Telford Press, Caldwell, New Jersey.

Dreimanis, A. 1967. Mastodons, their geologic age and extinction in Ontario, Canada. *Canadian Journal of Earth Sciences* 4:663–675.

——. 1968. Extinction of mastodons in eastern North America: testing a new climatic-environmental hypothesis. *The Ohio Journal of Science* 68(6):257–272.

Dudley, J. P. 1999. Seed dispersal of *Acacia erioloba* by African bush elephants in Hwange National park, Zimbabwe. *African Journal of Ecology* 37:375–385.

——. 2000. Seed dispersal by elephants in semiarid woodland habitats of Hwange National Park, Zimbabwe. *Biotropica* 32(3):556–561.

Dunbar, J. S., S.D. Webb, and D. Cring. 1989. Culturally and naturally modified bones from a Paleoindian site in the Aucilla River, North Florida. In R. Bonnichsen (ed.), *Bone Modification*, pp. 473–497. University of Maine at Orono Press, Orono.

Eisenberg, J.H. 1989. *Mammals of the Neotropics, Volume 1. The Northern Neotropics*. University of Chicago Press, Chicago, Illinois.

Elias, T.S. 1980. The complete Trees of North America: Field guide and Natural History. Van Nortrand Reinhold Company, New York, New York.

Ewel, K. C. 1990. Swamps. In R. L. Myers and J. J. Ewel (eds.), *Ecosystems of Florida*, pp. 281–323. University of Central Florida Press, Orlando.

Fergus, C. 2002. *Trees of Pennsylvania and the Northeast*. Stackpole Books, Mechanicsburg, Pennsylvania

Fisher, D.C. 1994. Evidence for butchery of the Burning Tree Mastodon. In W. S. Dancey (ed.), *Evidence for Butchery of the Burning Tree Mastodon*, pp. 43–57. The Ohio Archaeological Council, Columbus, Ohio.

——. 1996. Extinction of proboscideans in North America. In J. Shoshani and P. Tassy (eds.), *The Proboscidea: Evolution and Paleoecology of Elephants and Their Relatives*, pp. 296–315. Oxford University Press, Oxford.

Fox, J. W. and C. B. Smith. 1992. Introduction: historical background, theoretical approaches, and proboscideans. In J. W. Fox, C. B. Smith, and K. T. Wilkins (eds.), *Proboscidean and Paleoindian Interactions*, pp. 1–14. Baylor University Press, Waco, Texas.

Fragoso, J. M. V. 1997. Tapir-generated seed shadows: scale-dependent patchiness in the Amazon rain forest. *Journal of Ecology* 85:519–529.

Garland, E. B. and J. W. Cogswell. 1985. The Powers Mastodon site, Van Buren County, Michigan. *The Michigan Archaeologist* 31:3–39.

Gautier-Hion, A., J. M. Duplantier, R. Quris, F. Feer, C. Sourd, J. P. Decoux, G. Dubost, L. Emmons, C. Erard, P. Hecketsweiler, A. Moungazi, C. Roussilhon, and J. M. Thiollay. 1985. Fruit characteristics as a basis of fruit choice and seed dispersal in a tropical forest vertebrate community. *Oecologia* 65:324–337.

Gobetz, K. E. and S. R. Bozarth. 2001. Implications for late Pleistocene mastodon diet from opal phytoliths in tooth calculus. *Quaternary Research* 55:115–122.

Godfrey, R. K. and J. W. Whooten. 1979. *Aquatic and Wetland Plants of the Southeastern United States. Monocotyledons*. The University of Georgia Press, Athens.

——. 1981. *Aquatic and Wetland Plants of the Southeastern United States. Dicotyledons*. The University of Georgia Press, Athens.

Graham, R. W. and E. L. Lundelius, Jr. 1984. Coevolutionary disequilibrium and Pleistocene extinctions. In P. S. Martin and R. G. Klein (eds.), *Quaternary Extinctions: A Prehistoric Revolution*, pp. 223–249. University of Arizona Press, Tuscon.

Green, J., G. Semprebon, and N. Solounias. 2003. Reconstructing the dietary habitats of Florida mastodons via low-magnification stereomicroscopy. *Journal Vertebrate Paleontology* 23(Supplement):57A.

Green, J., G. Semprebon, and N. Solounias. 2005. Reconstructing the paleodiet of Florida Mammut americanum via low-magnification stereomicroscopy. *Palaeogeography, Palaeoclimatology, Palaeoecology* 223(1–2):34–48.

Grimm, E. C., G. L. Jacobson, Jr., W. A. Watts, B. C. S. Hansen, and K. A. Maasch. 1993. A 50,000-year record of climate oscillations from Florida and its temporal correlation with the Heinrich Events. *Science* 261:198–200.

Gross, H. 1951. Mastodon, mammoth, and man in America. *Bulletin of the Texas Archaeological and Paleontological Society* 22:101–131.

Gustafson, C. E., D. Gilbow, and R. D. Augherty. 1979. Manis mastodon site: early man on the Olympic Peninsula. *Canadian Journal of Archaeology* 3:157–164.

Guthrie, R. D. 1990. *Frozen Fauna of the Mammoth Steppe: The Story of Blue Babe*. University of Chicago Press, Chicago, Illinois.

Guy, P. R. 1975. The daily food intake of the African elephant, *Loxodonta africana* Blumenbach, in Rhodesia. *Arnoldia Rhodesia* 7(26):1–8.

Hansen, R.M. 1978. Shasta ground sloth food habits, Rampart Cave, Arizona. *Paleobiology* 4(3):302–319.

——. 1980. Late Pleistocene plant fragments in the dungs of herbivores at Cowboy Cave. In J. D. Jennings (ed.), *Cowboy Cave*, pp. 179–189. University of Utah Anthropological Papers, 104.

Hartnagel, C. A. and S. C. Bishop. 1922. The mastodon, mammoths and other Pleistocene mammals of New York State. *New York State Museum Bulletin* 241–242:110 pp.

Haynes, G. 1991. *Mammoths, Mastodonts, and Elephants*. Cambridge University Press, Cambridge, UK.

——. 2002. *Early Settlement of North America: The Clovis Era*. Cambridge University Press, Cambridge, UK.

Henry, O., F. Feer, and D. Sabatier. 2000. Diet of the lowland tapir (*Tapirus terrestris* L.) in French Guiana. *Biotropica* 32(2):364–368.

Hoefreiter, M., H. N. Poinar, W. G. Spaulding, K. Bauer, P. S. Martin, G. Possnert, and S. Paabo. 2000. A molecular analysis of ground sloth diet though the last glaciation. *Molecular Ecology* 9:1975–1984.

Hoefreiter, M., D. Serre, H. N. Poinar, M. Kuch, and S. Paabo. 2001. Ancient DNA. *Nature Reviews (Genetics)* 2:353–359 [www.nature.com/reviews/genetics].

Hoppe, K. A., P. L. Koch, and R. Carlson. 1997. The strontium isotope ratios of late Pleistocene mammoths and mastodons from Florida: evidence of migration. *Journal of Vertebrate Paleontology* 17 (Supplement 3):53A.

Jackson, S. T., D. R. Whitehead, , and G. D. Ellis.1986. Late-glacial and early Holocene vegetational history at the Kolarik mastodon site, northwestern Indiana. *The American Midland Naturalist* 115(2):361–373.

Janzen, D. H. 1984. Dispersal of small seeds by big herbivores: foliage is the fruit. *American Naturalist* 123:338–353.

——. 1985. Spondias mombin is culturally deprived in megafauna-free forest. *Journal of Tropical Ecology* 1:131–155.

Janzen, D. H. and P. S. Martin. 1982. Neotropical anachronisms: the fruits the gomphotheres ate. *Science* 215:19–17.

Judd, W. S., C. S. Campbell, E. A. Kellogg, P. F. Stevens, and M. J. Donoghue. 2002. *Plant Systematics: A Phylogenic Approach, Second Edition*. Sinauer Associates, Inc., Sunderland, Massachusetts.

King, J. E. and Saunders, J. J. 1984. Environmental insularity and the extinction of the American Mastodont. In P. S. Martin and R. G. Klein (eds.), *Quaternary Extinctions: A Prehistoric Revolution*, pp. 315–39. University of Arizona Press, Tuscon.

Koch, A. 1841. *Description of Missourium or Missouri leviathan*. Prentice and Weisinger Printers, Lousville Kentucky.

Koch, P. L., K. A. Hoppe, , and S. D. Webb, 1998. The isotopic ecology of late Plesitocene mammals in North America, Part 1: Florida. *Chemical Geology* 152:119–138.

Kushlan, J. A. 1989. Freshwater marshes. In R. L. Myers and J. J. Ewel (eds.), *Ecosystems of* Florida, pp. 324–363. University of Central Florida Press, Orlando.

Kurz, H. and R. K. Godfrey. 1962. Trees of North Florida. University of Florida Press, Gainesville.

Laub, R. S. 1990. The Hiscock site (western New York): recent developments of Pleistocene and early Holocene interest. *Current Research in the Pleistocene* 7:116–118.

——. 1996. The masticatory apparatus of the American mastodon (*Mammut americanum*). In K. M. Stewart and K. L. Seymour (eds.), *Paleoecology and Paleoenvironments of Late Cenozoic Mammals: Tributes to the Career of C.S. (Rufus) Churcher*, pp. 375–405. Univeristy of Toronto Press, Toronto.

Laub, R. S., C. A. Dufort, and D. J. Christensen. 1994. Possible mastodon gastrointestinal and fecal contents from the late Plesitocene of the Hiscock Site, Western New York State. In E. Landing (ed.), *Studies in Stratigraphy and Paleontology in Honor of Donald W. Fisher*. *New York State Museum Bulletin* 481:135–148.

Laws, R. M. 1970. Elephants as agents of habitat and landscape change in East Africa. *Oikos* 21:1–15.

Lepper, B. T., T. A. Frolking, D. C. Fisher, G. Goldstein, J. E. Sanger, D. A. Wymer, J. G. Ogden, III, and P. E. Hooge. 1991. Intestinal contents of a late Plesitocene mastodont from midcontinental North America. *Quarternary Research* 36(1):120–125.

Lewis, D. M. 1987. Fruiting patterns, seed germination, and distribution of *Sclerocarya caffra* in an elephant-inhabited woodland. *Biotropica* 19(1):50–56.

Lieberman, D., M. Lieberman, and C. Martin. 1987. Notes on seeds in elephant dung from Bia National Park, Ghana. *Biotropica* 19(4):365–369.

Little, E. L. 1980. *Field Guide to North American Trees: Eastern Region*. National Audubon Society, Inc., Alfred A. Knopf, Inc., New York.

Maglio, V. J. 1972. Evolution of mastication in the Elephantidae. *Evolution* 26:638–658.

Mead, J. I. and L. D. Agenbroad. 1989. Pleistocene dung and the extinct herbivores of the Colorado Plateau, southwestern USA. *Cranium* 6(1):29–44.

Mead, J. I., L. D. Agenbroad, O. K. Davis, and P. S. Martin. 1986. Dung of *Mammuthus* in the arid southwest, North America. *Quarternary Research* 25:121–127.

Middleton, B. A. and D. H. Mason. 1992. Seed herbivory by nilgai, feral cattle, and wild boar in the Keoladeo National Park, India. *Biotropica* 24(4):538–543.

Mihlbachler, M. C. 1998. Mastodon and digesta from Little River, North Florida. *Current Research in the Pleistocene* 15:116–118.

Naiman, R. J. 1988. Animal influences on ecosystem dynamics. *Bioscience* 38:750–752.

Nelson, G. 1994. *The Trees of Florida : A Reference and Field Guide*. Pineapple Press, Sarasota, Florida.

Newsom, L. A. 1987. Analysis of botanical remains from Hontoon Island (8Vo202), Florida: 1980–1985 excavations. *Florida Anthropologist* 40(1):47–84.

——. 1994. Archaeobotanical data from Groves Orange Midden (8Vo2601), Volusia County, Florida. The *Florida Anthropologist* 47(4):404–417.

Newsom, L. A. 2002. The paleoethnobotany of the Archaic mortuary pond. In G. H. Doran (ed.), *Windover: Multidisciplinary Investigations of an Early Archaic Florida Cemetery*, pp. 191–210. University Press of Florida, Gainesville.

Newsom, L. A. and C. M. Scarry. 2006. Homegardens and mangrove swamps: pineland archaeobotanical research. In K. Walker and W. Marquardt (eds.), *The Archaeology of Pineland: A*

Coastal Southwest Florida Village Complex, A.D. 100–1600. Institute of Archaeology and Paleoenvironmental Studies Monograph 3. Florida Museum of Natural History, Gainesville.

Newsom, L. A., S. D. Webb, and J. S. Dunbar. 1993. History and geographic distribution of *Cucurbita pepo* gourds in Florida. *Journal of Ethnobiology* 13(1):75–97.

Nordlie, F. G. 1988. Rivers and springs. In R. L. Myers and J. J. Ewel (eds.), *Ecosystems of Florida*, pp. 392–425. University of Central Florida Press, Orlando.

Olmos, F., R. Pardini, R. L. P. Boulhosa, R. Bürgi, and C. Morsello. 1999. Do tapirs steal food from palm seed predators or give them a lift? *Biotropica* 31(2):375–379.

Olivier, R. C. D. 1982. Ecology and behaviour of living elephants: bases for assumptions concerning the extinct wooly mammoth. In D. M. Hopkins. J. V. Matthews, Jr., C. E. Schweger, and S. B. Young (eds.), *Paleoecology of Beringia*, pp. 291–305. Academic Press, New York, New York.

Oltz, D. F. and R. O. Kapp. 1963. Plant remains associated with mastodon and mammoth remains in central Michigan. *The American Midland Naturalist* 70(2):339–346.

Owen-Smith, N. 1987. Pleistocene extinctions: the pivotal role of megaherbivores. *Paleobiology* 13(3):351–362.

——. 1988. *Megaherbivores: The Influence of Very Large Body Size on Ecology*. Cambridge University Press, Cambridge, UK.

Platt, W. J. and M. W. Schwartz. 1988. Temperate hardwood forests. In R. L. Myers and J. J. Ewel (eds.), *Ecosystems of Florida*, pp. 194–229. University of Central Florida Press, Orlando.

Purdy, B. A. 1987a. Investigations at Hontoon Island (8Vo202), An archaeological wetsite in Volusia County, Florida: an overview and chronology. *The Florida Anthropologist* 40(1):4–12.

——. 1987b. In B. A. Purdy (ed.), *Wetsite Archaeology*, Telford Press, Caldwell, New Jersey.

——. 1991. *The Art and Archaeology of Florida's Wetlands*. CRC Press, Boca Raton, Florida.

Radford, A. E., H. E. Ahles, and C. R. Bell. 1968. *Manual of the Vascular Flora of the Carolinas*. The University of North Carolina Press, Chapel Hill.

Rosas, F. C. W., J. A. S. Zuanon, and S. K. Carter. 1999. Feeding ecology of the giant otter. *Pteronura brasiliensis*. *Biotropica* 31(3):502–506.

Salas, L. A., and T. K. Fuller. 1996. Diet of the lowland tapir (*Tapirus terrestris L.*) in the Tabaro River Valley, southern Venezuela. *Canadian Journal of Zoology* 74:1444–1451.

Sánchez, B., J. L. Prado, and M. T. Alberdi. 2004. Feeding ecology, dispersal, and extinction of South American Pleistocene gomphotheres (Gomphotheriidae, Proboscidea). Paleobiology 30(1):146–16.

Saunders, J. J. 1996. North American mammutidae. In J. Shoshani and P. Tassy (eds.), *The Proboscidea: Evolution and Paleoecology of Elephants and Their Relatives*, pp. 271–279. Oxford University Press, Oxford.

Shoshani, J., D. C. Fisher, J. M. Zawiskie, S. J. Thurlow, S. L. Shoshani, W. S. Benninghoff, and F. H. Zoch. 1989. The Shelton mastodon site: multidiscipilinary study of a late Pleistocene (Twocreekan) locality in southeastern Michigan. *Contributions from the Museum of Paleontology, The University of Michigan* 27(14):393–436.

Smith, B. D., C. W. Cowan, and M. P. Hoffman. 1992. Is it an indigene or a foreigner? In B. D. Smith (ed.), *Rivers of Change: Essays on Early Agriculture in Eastern North America*, pp. 67–100. Smithsonian Institution Press, Washington, DC.

Sreekumar, P. G. and M. Balakrishnan. 2002. Seed dispersal by the sloth bear (*Melursus ursinus*) in South India. *Biotropica* 34(3):474–477.

Stoutamire, W. P. and W. S. Benninghoff. 1964. Biotic assemblage associated with a mastodon skull from Oakland County, Michigan. *Papers of the Michigan Academy of Sciences, Arts and Letters* 49:47–60.

Thorne, R. F. 1993. Phytogeography. In Flora of North Amercia Editorial Committee (eds.), *Flora of North American, Volume 1, Introduction*, pp. 132–153. Oxford University Press, Oxford, UK.

Tikhomirov, B. A. 1958. Natural conditions and vegetation in the mammoth epoch in northern Siberia. *Problems of the North* 1:168–188.

Tobler, M. W. 2002. Habitat use and diet of Baird's tapirs (*Tapirus biardii*) in a montane cloud forest of the Cordillera de Talamanca, CostaRica. *Biotropica* 34(3):468–474.

Ward, D. B. 1979. Okeechobee gourd. In D. B. Ward (ed.), *Rare and Endangered Biota of Florida, Volume 5, Plants*, pp. 81–83. University of Florida Press, Gainesville.

Ward, D. B. and M. C. Minno. 2002. Rediscovery of the endangered Okeechobee gourd (*Cucurbita okeechobeensis*) along the St. Johns River, Florida, where last reported by William Bartram in 1774. *Castanea* 67:201–206.

Warren, J. C. 1855. *The Mastodon giganteus of North America*. John Wilson, Boston, MA.

Watts, W. A. and B. C. S. Hansen. 1988. Environments of Florida in the late Wisconsin and Holocene. In B. A. Purdy (ed.), *Wet Site Archaeology*, pp. 307–323. The Telford Press, Caldwell, New Jersey.

Webb, S. D. 1992. A brief history of new world Proboscidea with emphasis on their adaptations and interactions with man. In J. W. Fox, C. B. Smith, and K. T. Wilkins (eds.), *Proboscidean and Paleoindian Interactions*, pp. 15–34. Baylor University Press, Waco, Texas.

Webb, S. D. and L. Newsom. 1991. Diet of *Mammut americanum* in late Pleistocene of Florida. *Journal of Vertebrate Paleontology (Abstracts)* 11:60A.

Webb, S. D., J. Dunbar, and L. A. Newsom. 1992. Mastodon digesta from North Florida. *Current Research in the Pleistocene* 9:114–116.

Western, D. 1975. Water availability and its influence on the structure and dynamics of a savannah large mammal community. *East African Wildlife Journal* 13:265–286.

Wharton, B. R., G. R. Ballo, and M. E. Hope. 1981. The Republic Groves Site, Hardee County, Florida. *The Florida Anthropologist* 34(2):59–80.

Whitehead, D. R., S. T. Jackson, M. C. Sheehan, and B. W. Leyden. 1982. Late-glacial vegetation associated with caribou and mastodon in central Indiana. *Quarternary Research* 17:241–257.

Willis, J. C. 1985. *A Dictionary of the Flowering Plants and Ferns, Student Edition (Eighth Edition)*. Cambridge University Press, Cambridge, UK.

Wunderlin, R. P. 1998. *Guide to the Vascular Plants of Florida*. University Press of Florida, Gainesville.

Wunderlin, R. P. and B. F. Hansen. 2000. *Flora of Florida, Volume 1: Pteridophytes and Gymnosperms.* University of Florida, Gainesville.

Yumoto, T., T. Maruhashi, J. Yamagiwa, and N. Mwanza. 1995. Seed-dispersal by elephants in a tropical rain forest in Kahuzi-Biega National Park, Zaire. *Biotropica* 27(4):526–530.

Chapter 11

Mastodon Tusk Recovery

S. DAVID WEBB
Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.

11.1 Introduction

The single most notable discovery of the Aucilla River Prehistory Project's fall season in 1993 was a complete tusk of an American Mastodon, *Mammut americanum*, catalog UF 150701. This brief chapter narrates the conditions and context attending its recovery and the preliminary laboratory analyses that were pursued at the Florida Museum of Natural History during the next two years. More detailed studies of this same tusk, subsequently conducted at the University of Michigan Museum of Paleontology, are presented in Chapter 12 by Fisher and Fox.

11.2 Recovery from the River

The initial discovery of this large *Mammut americanum* tusk came on October 23 as two divers routinely trowelled sediments from within a 2 × 3 m grid about 6 m below the water surface. This excavation unit, known as Test F, level 23, was subsequently

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 333–341

considered to be the lower part of stratigraphic Unit 3. The long axis of the tusk trended northward beyond the grid into the west bank of the river. In order to continue exposing the tusk, field protocol required that a new vertical excavation, 2 × 3 m, be opened immediately to the north of the tusk. This entailed a full day of additional work. The *in situ* tusk is pictured first in its discovery phase and secondly in its fully uncovered status on the river bottom (see Figs. 11.1 and 11.2).

The sediments in which the tusk occurred consisted of massive clayey peat. Subsequent study of these peaty sediments showed that they were digesta of a large herbivore, most probably *Mammut americanum*. This mastodon digesta hypothesis and the constitution of the peat are fully discussed in Chapter 10 by Newsom and Mihlbachler. Seven closely corroborative carbon dates, based on four individual gourd seeds (*Cucurbita pepo*), two wood specimens, and a sample of bone collagen from the jugal of *Palaeolama mirifica*, all occurring in the digesta, gave an average uncalibrated date of 12,425 ± 35 ^{14}C B.P. (see Chapter 4 by Webb and Dunbar). A small sample of peat hand picked from the hollow end of the tusk and immediately submitted for an AMS date yielded a slightly older date of 12,940 ± 70.

When the tusk was received on the riverbank and gently laid out in five adjacent sections, two striking features were noted. First, within about 5 min, the exposed surfaces of each successive piece changed color from light tannish orange to a dark chocolate brown. Presumably this represented oxidation of iron and other minerals present in the tusk dentin. The rate of color change beneath the surface of the tusk is unknown, but subsequent internal views a week later revealed approximately the same dark color.

A second unexpected set of features was soon noted on the most proximal piece of the tusk. There was an elaborate set of grooves girdling one side of the tusk. It was also observed that this set of marks coincided with a subtle change from a darker colored

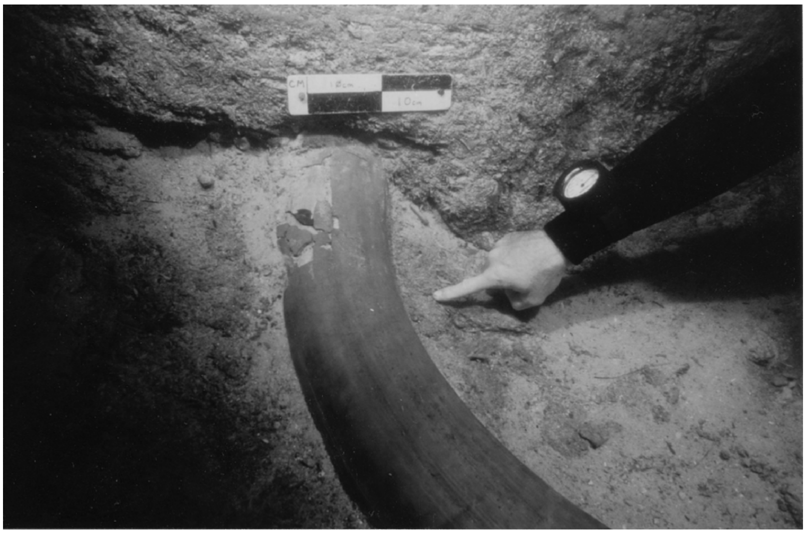


Figure 11.1 Proximal half of tusk, UF 150701, exposed on river bottom. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Figure 11.2 Complete tusk exposed on river bottom, seen from above. Note gray color of proximal (alveolar) portion, nearer camera, in comparison to more orange tone of the rest of the tusk. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

region of tusk dentine to a lighter colored region nearer the proximal end. These features are evident in the close up picture of that region in Fig. 11.3. The color change evidently marked the distal end of the alveolar region of the tusk, where it had emerged from the premaxillary bone during the animal's life. This prompted the hypothesis that these circumferential grooves might be cutmarks delivered by Paleoindians removing the tusk from the skull. From that moment forward the ARPP was determined to investigate the question of whether this tusk might have been an object of human procurement.

11.3 Laboratory Methods

11.3.1 Tusk Preservation

The immediate concern as the tusk was transported from the riverbank to the vertebrate paleontology laboratory, besides protecting it from any physical damage, was to keep it wet. Each tusk segment was well wrapped in several layers of polyethylene and burlap which were frequently moistened. Subsequent chemical conservation in the

Figure 11.3 Close view of cutmarks at transition from alveolar (on right) to rest of tusk. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project. Photo by Aucilla River Prehistory Project.

laboratory consisted of submerging the tusk segments in sequential baths of increasing concentrations of alcohol each for a week. They were then soaked for two weeks in polyethylene glycol to consolidate the dentine lamellae within the tusk. These were then slowly dried to ambient room conditions in a moisturized chamber. Even so desiccation cracks and voids appeared in interior parts of the tusk during subsequent storage in museum cabinets within the air-conditioned collection area.

The specimen was cataloged as UF 150701. Those parts not subjected to further analysis were cushioned in polyurethane foam and stored in open shelving within the collection of vertebrate paleontology.

11.3.2 Tusk Measurements

The conserved tusk was loosely assembled and the shortest straight distance from worn distal tip to feather-edged proximal end was measured, using an extended anthropometer. The diameter of the tusk was measured at ten places between the distal tip and the proximal end using a Mitutoyo dial calipers.

11.3.3 Tusk Sectioning

Each tusk segment, except the piece from the distal end, was parasagitally sectioned. This entailed making a vertical planar cut, following the gentle spiral curve of the tusk axis. The segments were labeled A through E, from proximal to distal. The distal segment including the worn tip region was the longest and the best preserved. It was not sectioned. One half of each of the other four segments was set aside as the voucher half. In the study half, five cross-sectional cuts were made as follows: one proximal and one distal cut in segment A; one proximal in C; and one proximal and one distal cut in D. The tusk was hand-fed to the blade of a thin bladed diamond table saw. The operator fed each of the four segments extremely slowly in order to avoid heating.

The five cross-sectional samples were submitted to Spectrum Petrographics of South Jordan, Utah for further processing. They placed the sections on glass slides and polished them. They either included the complete tusk radius from each section or, if the section were too fragile, they made a composite set of pieces to cover the whole radius. They polished each slide using odorless kerosene as lubricant to a thickness of 20 µm and lightly embedded each in clear epoxy resin with no cover slip. One polished section from the distal end of segment A sampled approximately a dozen years of dentinal growth.

11.3.4 Taxonomic Identification

The relatively straight shape of the tusk suggested from the beginning that it might represent an American Mastodon. And its substantial size suggested that it might be a male. In the following year students in the vertebrate paleontology lab applied the more definitive method of identification developed by Fisher *et al*. (1998), based on the angle between Schreger lines as measured within the cross section of a proboscidean tusk. Schreger lines are the three-dimensionally “woven” bundles of dentin that give a characteristic herringbone-like pattern to proboscidean tusk material. These are illustrated in Fig. 11.4.

11.3.5 Studies of Circumferential Grooves

The set of six deep grooves girdling segment A of the tusk near its distal end was photographed. There did not appear to be any important difference in preservation or depth of these grooves as they traversed approximately 90º around the lateral side of the tusk. The most proximal groove, however, appeared slightly deeper and more continuous than the others. A white silastic impression of the set of grooves was taken on

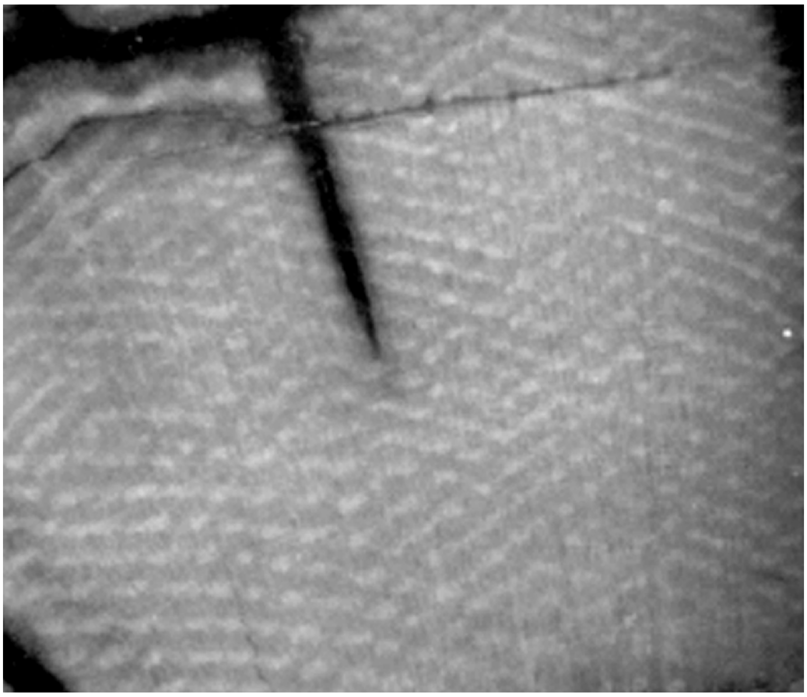


Figure 11.4 Schreger bands on transversely cut and polished section near distal end of tusk segment A. Exposed surface is about 3 cm wide. Photo by Aucilla River Prehistory Project.

the tusk's lateral face. And this "peel" was used to make SEM micrographs of the grooves as reversed to positive features as shown in Fig. 11.5.

Control studies were undertaken on the homologous region of a tusk from a recently euthanized old bull African elephant. Students in the vertebrate paleontology lab made experimental cuts and grooves. These consisted of cuts inflicted by trowels, sharp tempered steel knives and newly knapped knives of high-quality chert, as a basis of comparison with the ancient grooves. One set of cuts was made on the outer circumference of a dry segment of the modern tusk material and another set was made identically on a tusk segment that had been soaked for 48 h in water.

11.4 Results

11.4.1 Tusk Measurements

The overall length of the tusk, taken as the chord of a gentle arc, is 229 cm, or somewhat over 7 feet. The longest of the five segments was the tip and distal region labeled segment E. It measured approximately 64 cm. The largest diameter, taken near the

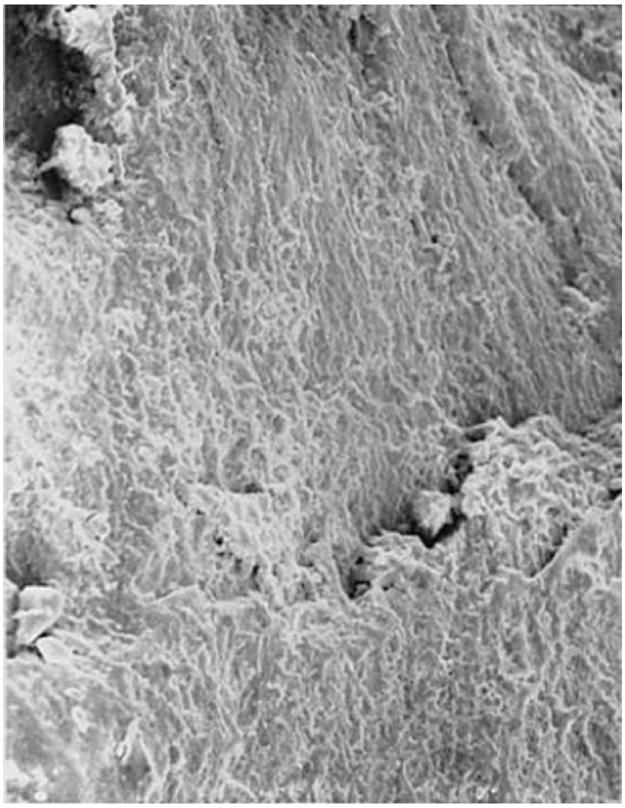


Figure 11.5 Scanning electron micrograph of cutmark on tusk, UF 150701. Taken near center of prominent groove near proximal (right) side of set shown in Fig. 11.3. Photo by Aucilla River Prehistory Project.

presumed alveolar border close to the probable cut marks, is about 15.3 cm. More proximal measurements, which might be expected to have been slightly greater, were compromised by substantial warping of the thin-walled dentine shell of that portion of the tusk. The least diameter measured was 76 cm and this was taken about 51 cm from the tip, just past the heavily worn, distal portion of the tusk.

11.4.2 Tusk Sectioning

The important results of tusk section studies appear in the following two chapters. Fisher counted 21 annual growth bands in the sectioned parts of the tusk, and it is estimated that the unsectioned segment from the tip represented more than a decade. At least an additional decade worth of dentin must have been worn and broken from the tip earlier in its life history. Thus the particular male mastodon that owned this tusk is estimated to have lived at least 40 years.

11.4.3 Taxonomic Identification

The gross form of the tusk with its relatively straight arc prompted an early, tentative assignment in the field to *Mammut* rather than to *Mammuthus* or *Cuvieronius*, the only other proboscideans that are known to have lived in Florida during the Pleistocene. It was of some importance, however, to make a more reliable determination of the taxonomy of this isolated tusk.

The most reliable method for tusk identification depends on the angles between Schreger bands (“woven” dentin bands). Such studies were undertaken by Espinoza and Mann (1993) and further refined by Fisher *et al*. (1998). Three determinations were made on the polished thin sections of tusk cross sections such as that shown in Fig. 11.2. Measurements of the angles between concave bands within the transverse cross sections gave results of 129°, 132°, and 133°. They were thus consistently within the range characteristic of *Mammut americanum* and well above that of *Mammuthus*, which generally ranges below 100° (Fisher *et al*., 1998).

11.4.4 Circumferential Grooves

The set of six associated grooves was studied from the positive impressions of white silastic peels described above. Despite some shrinkage cracks on all surfaces of the tusk, these grooves showed as deep, sharp-edged and “fresh”. The ancient grooves were closely comparable to those made by steel knives and chert knives on the modern control tusk, and much deeper and sharper than the cuts attempted with a trowel. There was little or no difference between equivalent sets of dry cuts and wet cuts.

11.5. Discussion

Discovery of an isolated tusk of a mature male mastodon has led through a number of analyses to a remarkably detailed set of inferences regarding its life, its death, and its environment. The discussion in this chapter focuses primarily on the possible significance of the set of circumferential grooves near the proximal end of the tusk.

An important clue in this investigation is the placement of that set of grooves near the point at which the tusk emerged from the alveolus (socket) within the cranium. It seems unlikely that the mastodon itself could have produced such grooves especially at such a great distance (about 2 m) from the tusk tip. The most likely scenario to explain this location involves an attempt to remove the tusk from its socket. And that is indeed what must have happened shortly before the tusk reached its site of deposition within a peaty pond.

Analysis by SEM photos of the grooves suggests that they are of the steep-walled type previously shown by Shipman *et al*. (1984) to be compatible with lithic cuts involving human tool use. The set of six near parallel grooves was evidently developed during the same bout of activity by the same object or a similar set of objects. The fact that they extend about 90º around the circumference of the tusk near its maximum diameter is not compatible with the mode of delivery of some large carnivore such as a dire wolf or sabercat. But it is a pattern that could be delivered by the flexibility of the human forearm and wrist producing an arcuate sawing motion.

11.6 Conclusions

Discovery of the right upper tusk of a large male mastodon in stratigraphic Unit 3 provided the largest of about three dozen specimens of that species recovered from the Page-Ladson site. Recognition of a set of long, sharp circumferential cuts near the proximal end of the tusk raised the question of how they might have been inflicted.

A reasonable scenario, compatible with the known facts about this tusk, is that it was cut from the connective tissue around its alveolar border, probably by a human hand grasping a sharp lithic tool. The tusk was then removed from the skull by strong twisting action using the leverage of its entire 7-foot length. This hypothesis gains support from other associated evidence of human activity also accumulated in Unit 3 at this same site (see Chapter 8 by Webb and Simons and Chapter 14 by Dunbar).

The value to contemporary Paleoindians of acquiring this large tusk is clear from the fact that large numbers of ivory tools have been recovered in north Florida rivers, most notably the Aucilla River. Hemmings *et al*. (2004) present figures and brief descriptions of nine distinct types of ivory tools recovered from Florida rivers, a majority of them in the Aucilla River. The largest of these tool types, ranging up to lengths of at least 40 cm, sometimes incorrectly known as “foreshafts”, is represented by more than 50 specimens from north Florida. Their abundance and the significant manufacturing skills they required indicate that they were an important part of the Paleoindian economy. For this reason, we infer that Paleoindians in this region regularly sought to acquire large tusks as raw material for spear shafts and other ivory-based tools.

References

Espinoza, E. O. and M. J. Mann. 1993. History and Significance of the Schreger Pattern in Proboscidean Ivory Characterization, *Journal of American Institute of Conservation* 32:241–248.

Fisher, D. C., J. Trapani, J. Shoshani, and M. S. Woodford. 1998. Schreger angles in Mammoth and Mastodon Tusk Dentin, *Current Research Pleistocene* 15:105–107.

Hemmings, C. A., J. S. Dunbar and S. D. Webb. 2004. Florida’s Early Paleoindian Bone and Ivory Tools, pp. 88–92, *in* B. T. Lepper and R. Bonnichsen (eds.), *New Perspectives on the First Americans*, Texas A&M Press, College Station, TX.

Shipman, P., D. C. Fisher and J.J. Rose. 1984. Mastodon Butchery: Microscopic Evidence of Carcass Processing and Bone Tool Use, *Paleobiology* 10:358–365.

Chapter 12

Five Years in the Life of an Aucilla River Mastodon

DANIEL C. FISHER[1] AND DAVID L. FOX[2]
[1]Museum of Paleontology and Department of Geological Sciences, University of Michigan, Ann Arbor, MI 48109-1079, USA.
[2]Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455–0129, USA.

12.1 Introduction

The tusks of mastodons, mammoths, and other proboscideans are accretionary structures that record, in the fashion of a stratigraphic section, numerous time-dependent parameters relevant to the living animal that grew them. Their lack of *in vivo* remodeling and their frequent accumulation of growth sequences that are several decades long make them ideal archives of biological and environmental data. Methods for extracting

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 343–377

and interpreting these data are still under development (e.g. Fisher, 1996, 2001; Hoppe *et al.*, 1999; Fox, 2000), and we are just beginning to explore the application of these methods to proboscideans of different regions and time periods. In this spirit of exploration, we undertake examination of a portion of a tusk-record representing a brief interval in the life of a single American mastodon (*Mammut americanum*), from a region and a time period that are interesting in their own right. We cannot yet claim generality for the observations reported here, but they at least expand the coverage achieved in prior work. In doing so, they offer an opportunity to discover new patterns of association between environmental variability and organismal response.

Our focus is on documenting the pattern of variation in rate of addition of new dentin to the tusk (i.e. rate of dentin apposition), measured normal to the surface to which it is added. Then we compare this pattern to variation in the oxygen isotope composition of phosphate in dentinal hydroxyapatite. The oxygen isotope record varies with temperature and moisture and thus registers the seasonal schedule of tusk growth. We also relate these aspects of growth rate and composition to measurements of increasing tusk length and to other isotope measurements (see Chapter 13 by Hoppe and Koch). Our goals are to use the pattern of variation in oxygen isotope composition to diagnose the scale of annual increments of tusk dentin and help to characterize the seasons that comprise the annual cycles recorded in this tusk. This information will allow us to quantify tusk growth rates for part of one animal's life and to characterize the climatic and environmental setting in which this individual lived.

The tusk we analyzed is UF 150701, from collections of the Florida Museum of Natural History, at the University of Florida, Gainesville. It represents a large male mastodon, *M. americanum*, recovered from the Page-Ladson site, on the Aucilla River, in Taylor County, northwestern Florida. It was associated with a rich fauna of both aquatic and terrestrial vertebrates (see Chapter 8 by David Webb and Simons). Seven carbon dates from the fine-grained, organic-rich silty sand of Unit 3 yield an average age of 12,425 ^{14}C BP.

This tusk is one of those analyzed and discussed in Chapter 13 by Hoppe and Koch. It is also from the same assemblage that produced evidence of Florida mastodons migrating seasonally northward into the southern Apalachians (Hoppe *et al.*, 1999). In addition, this tusk shows apparent cutmarks, at the approximate location of the alveolar margin, interpreted by David Webb in Chapter 11 as evidence of butchery. This specimen thus stands at the confluence of several interesting issues. Beyond simply providing a record of one individual and its environment, tusk analyses have a bearing on questions such as the seasonal timing of migratory movements of mastodons, and the human procurement of mastodons.

12.2 Methods

12.2.1 Sample Procurement

The source of material utilized both by Hoppe and Koch and by us was a fragment from the proximal end of the tusk, in an anatomically ventrolateral position, i.e. near the "outside curve" of the tusk spiral. It was about 26 cm long, bounded along one edge by a radial fracture and along the other by a longitudinal cut. Its chord width expands irregularly from about 3 cm externally, at its distal end, to almost 6 cm at its proximal end. The curvature of the fragment suggests that the tusk may be from the right side of the animal. The concave, "inner" surface of the fragment (uppermost in Fig. 12.1) is a portion of the well-preserved wall of the tusk pulp cavity, the last part of the tusk to be mineralized prior to death. The exterior surface at the proximal end of the fragment is the cementum exterior, i.e. the outer surface of the tusk itself. However, for most of the length of the fragment, the cementum has spalled off, leaving traces of the dentin–cementum interface and areas of fractured dentin immediately internal to this.

As commonly happens in non-permineralized material, desiccation following excavation has produced significant volume loss. At the proximal end of the tusk,

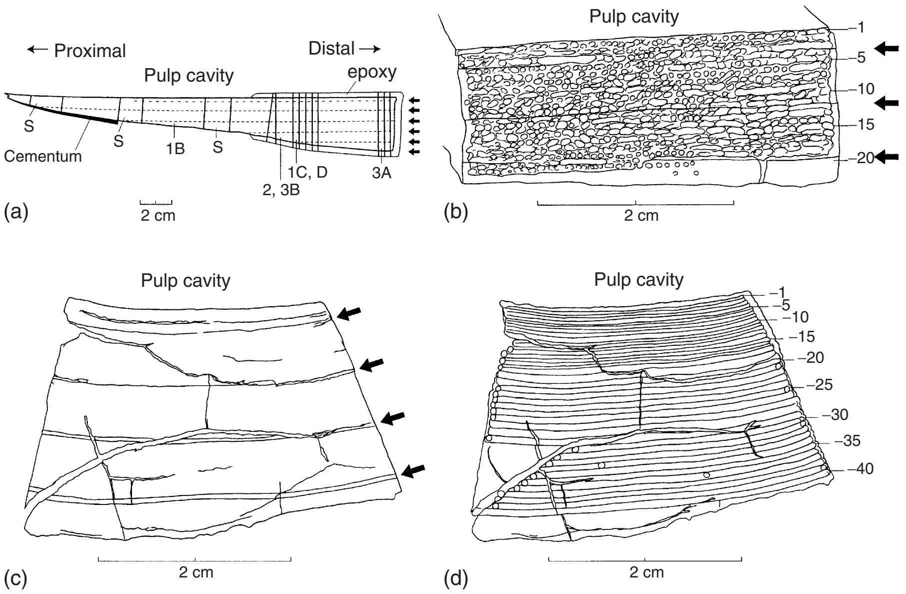


Figure 12.1 (a) Schematic diagram of fragment from the proximal end of the tusk, showing location of sampled areas. S, sample blocks removed by Hoppe and Koch; alphanumeric labels (e.g. 1B) specify figures in this paper where parts of the specimen are illustrated. Dashed lines marked by arrows at right represent first-order features traceable on the fragment (the one nearest the pulp cavity is less clearly marked than the others). (b) *Camera lucida* drawing of longitudinal section sampled by Hoppe and Koch for isotope analysis of carbon and nitrogen from collagen and carbonate oxygen from hydroxyapatite. Arrows indicate "thin, white layers", which are one aspect of the first-order pattern shown as dashed lines in (a). (c) *Camera lucida* drawing of polished transverse section from a more distal position on the fragment (see a), showing the last 3+ years of dentin apposition. Arrows at right indicate sets of one or more white layers that correspond to white layers in (b) and to dashed lines in (a). (d) *Camera lucida* drawing of the same slab shown in (c), after removal of the sample-series used for isotope analysis of phosphate oxygen from hydroxyapatite.

where there is a large surface-to-volume ratio, this change is accommodated with only minor radial fracturing. However, moving toward the distal portion of even the small fragment studied here, the surface-to-volume ratio decreases enough that desiccation fractures have developed more extensively, displacing the otherwise continuous record of growth history (irregular vein-like structures in Fig. 12.1c,d).

Hoppe and Koch's sampling was limited to the proximal portion of this fragment, where desiccation-induced breakup of the record had not occurred and where preservation of organic material was best. They removed three sample blocks (S in Fig. 12.1a) adjacent to the longitudinally sawn surface and serially sampled the distal-most of the intervening areas. However, the dentin thickness available in this part of the fragment was only sufficient to give their serial samples access to an interval of time that we estimate at about two years. Even the distal-most block of dentin they removed appears not to have extended much beyond the third year prior to death. We wanted to relate our samples to those of Hoppe and Koch, but we also wanted access to a longer time interval. Since organic preservation was not crucial for our study, we focused on the distal part of the fragment.

Leaving the area sampled by Hoppe and Koch unmodified, we filled fractures with epoxy resin and then embedded the rest of the distal portion of the fragment in a thin layer of epoxy. We cut the embedded and unembedded portions apart. Then, using a Buehler Isomet low-speed saw with a diamond-wafering blade, we made a series of transverse cuts, normal to the surface of the pulp cavity. Only when these cuts were complete could we tell where we would obtain the best growth record. For the growth increment profile of the last three years of life, and for oxygen isotope analyses, we chose a sampling location near the proximal end of the embedded portion of the fragment, where fractures involved minimal displacement and did not compromise the continuity of the record. Unfortunately, the last year or two of life *were* interrupted by fractures near the distal end of the fragment, but this sampling position provided access to two additional years formed before those preserved at the more proximal sampling location. That is, the wedge of dentin increases in thickness and in the duration of its temporal record as one moves distally. We therefore used thin sections from the distal end of the fragment to extend the growth increment profile earlier in time.

12.2.2 Enhancement of First-order Incremental Features

Examination of the radial, longitudinal fracture along one edge of the tusk fragment, and of many of the cut surfaces, revealed faint, linear features interpretable as representing some brief change in the character of growth increments. These appeared as extremely thin, white layers, outcropping on untreated surfaces. Several were visible at intervals that could plausibly represent years, based on comparisons with previously studied material (e.g. Fisher, 1988, 1990), but they were faint enough for their interpretation to remain tenuous. Toward the distal end of the fragment, where organic material was less well preserved and where the dentin had a chalky appearance, these features were even less clearly marked.

Subtle contrasts in physical properties such as porosity are part of the range of traits that sometimes vary in an annually repeating fashion and contribute to the most inclusive scale of repetitive, structural, and compositional variation in the hierarchical system of incremental features that characterizes proboscidean dentin (Fisher, 1987). Referring only to "level" within this hierarchical system, and not to any particular periodicity (i.e. time-value of increments), these coarsest features comprise "first-order" patterns in tusk structure, with "second-order" and "third-order" reserved for finer levels in the hierarchy. Table 12.1 illustrates some of the relations of these and other aspects of tusk structure, showing how different physical modalities (e.g. topography of the dentin–cementum interface and dentin composition) may be organized into the same physical units and how superficially similar patterns (e.g. dark–light couplets) may occur at different spatial scales. Most details of Table 12.1, including the typical number of repetitions of a pattern within higher-order units, can be treated as descriptive characterizations of tusk organization, whereas the time-value of organizational units is clearly a matter of interpretation. These interpretations have been tested previously and will undergo additional scrutiny in this work. Nonetheless, at the price of some wordiness, we often use adjectives such as "first-order" instead of the simpler "annual" in order to indicate what is, and what is not, being taken for granted.

Table 12.1 Relations between features and terms used for the organization of increments in tusk dentin, with specific application to UF 150701, Mammut americanum

Physical feature	*Spatial scale (mm)*	*Hierarchical level*	*Time value (repeat no.)*
Dark–light couplets, with pigmented epoxy ("narrow bands") Repeating pattern of prominent 2° increments, "faint, linear features" and "thin, white layers" Repeating pattern of conspicuous variation in 2° increment thickness Repeating pattern of constriction of dentin–cementum interface Repeating pattern of variation in oxygen isotope composition Repeating pattern of variation in collagen carbon and nitrogen isotopes	5–6 (T[1]) 52–55 (L[2])	First-order (1°)	One year, annual (N/A)
Dark–light couplets, in thin section (with or without pigmented epoxy) Repeating pattern of differential extinction under crossed nicols Repeating pattern of fine ridges at dentin–cementum interface	0.1–0.3 (T) 1–3 (L)	Second-order (2°)	Two weeks, circadiseptan (ca. 26 2°/1°)
Dark–light couplets, in thin section (without pigmented epoxy)	0.014 (T)	Third-order (3°)	One day, circadian (ca. 14 3°/2°)

[1] Thickness.
[2] Length.

As described elsewhere (Fisher, 2001), first-order patterns are sometimes more easily visualized following treatments that interact differentially with tusk dentin that has differing properties. On this specimen, we were able to increase visual contrast between two components of the first-order cycle of dentin variation by impregnation with a low-viscosity epoxy resin (Buehler "Epo-Thin") to which red pigment was added. We first removed as much as possible of the cutting oil used in the Isomet saw, by dilution with acetone and prolonged evaporation. Pigmented, catalyzed resin, under vacuum, was then poured over the polished surfaces of 5-mm thick dentin slabs, from a magnetically activated device enclosed within the vacuum chamber. Dentin and plastic were then returned to ambient pressure. After allowing about 15 min for the plastic to flow into the dentin, the slabs were removed from the resin reservoir. After the resin polymerized, transverse surfaces were polished again to reveal the enhanced contrast.

12.2.3 Second-order Incremental Features

Second-order incremental features of tusk dentin were studied on thin sections made without prior epoxy impregnation (Fisher, 1988) and on a second set treated with the red plastic described above. Both sets were made from transverse, polished surfaces oriented normal to the wall of the pulp cavity. Thin sections were examined at 40X, both with and without crossed polars, using a Leitz Laborlux petrographic microscope.

An image analysis system running OPTIMAS 5.2 (Optimas Corp., Bothell, WA) was used to record increment number and thickness, with data exported to a spreadsheet to compile profiles. Transects were set up normal to incremental features within each field of view. Automated feature extraction based on luminance profile was "trained" using a representative second-order feature and was then allowed to mark luminance minima that met selected criteria of breadth and disparity from local background values. This was followed by manual editing to exclude obvious errors (e.g. fractures with luminance characteristics similar to growth lines) and to make adjustments based on lateral variation in manifestation of growth lines. Data from each field of view were exported, and the thin section was then translated so that the last feature of a previous field of view became the first feature of the next field of view. Printouts of each field of view were used for annotations regarding preservation and qualitative features.

Data on second-order increment thickness were first plotted by sequential increment number (i.e. ordinal position within the growth sequence) to check for cyclic variation in increment thickness and determine the number of second-order increments within any cycles that seemed likely candidates for years. Independently, the number of second-order increments within structurally identified first-order increments was noted, as well as the relation of first-order features to changes in second-order increment thickness. Second-order increment thickness profiles were then plotted relative to cumulative increment thickness to place the growth history into a spatial reference frame (ultimately, distance from the pulp cavity) rather than the implicitly temporal reference frame of increment number. This domain shift is necessary in order to relate growth history to compositional variation, which is sampled in the spatial domain (also relative to distance from the pulp cavity). Finally, a smoothed (three-point moving average) increment thickness profile was computed to reveal general patterns of variation more clearly.

12.2.4 Oxygen Isotope Analyses

Sampling of oxygen isotope composition was undertaken on a highly polished (5 μm laevigated alumina in kerosene) transverse surface (Fig. 12.1c,d) of a 5-mm thick slab of dentin, following impregnation by pigmented epoxy. Enhanced contrast on first-order and second-order features visible under stereomicroscopic observation guided manually directed milling of samples. A 0.6-mm carbide bit, held in a stationary dental drill, removed samples as the specimen slid horizontally on the microscope stage. Each sample consisted of 40–50 mg of powder from multiple passes of the bit, between which the stage was raised to allow the bit to plunge more deeply into the specimen. Powder produced by each pass was collected into a numbered sample vial, and the specimen surface was cleaned with compressed air between samples. Milling continuous sample paths optimized sample recovery and reduced the chance of intersample contamination and time averaging.

The sampling protocol was designed to process representative aliquots of all tusk dentin deposited in the last 3+ years of life (judged initially by first-order features only, but later confirmed by all analyses). For most of the two chronologically earliest of these years, sample spacing was "full-bit" (ca. 0.6 mm), but for the remainder of life, spacing was reduced to "half-bit" (ca. 0.3 mm, plunging deeper to achieve desired mass) to increase temporal resolution during the interval critical for determining season of death. We implemented this design by starting at the coarser resolution, near a well-marked dentin increment, just outside the point at which we would shift to finer resolution. The first sample path (−19 in Fig. 12.1d) was the hardest to control, because sample powder accumulated directly on the surface on which the increment "guidelines" were exposed. However, two sample paths at the coarse width were sufficient to provide a recess that collected most of the powder produced while subsequent sample paths were milled. We then switched to the finer resolution, continuing to the surface of the pulp cavity. We subsequently returned to just outside the starting position and continued "backward in time", away from the pulp cavity, until an adequate interval of time had been covered.

Each sample position was measured along a radial transect using an ocular reticle in the stereomicroscope. We recorded the distance from each edge of each sample path to a reference position (a narrow scratch placed along the epoxy margin of the sample slab). Several reference positions were required, but all were later converted to distance from the pulp cavity. Each sample composition was attributed to a position midway between the two edges of the sample path. Fractures that displaced the entire sequence were subtracted out; the spatial reference frame thus refers to unfractured dentin thicknesses.

Samples of dentin were pretreated to remove any collagen matrix that was preserved. This began by soaking in 2 ml of 2–3% NaOHCl (Clorox) for 24 h, followed by rinsing five times in distilled water. Samples were then soaked in 0.125 M NaOH for 24 h and again rinsed five times in distilled water. After pretreatment, samples were prepared for phosphate oxygen isotope measurement following the method of O'Neil *et al.* (1994), with minor modifications. Samples were digested in 2 ml of 2 M HF for 24–36 h, during which time each was agitated in a sonication bath for 1–2 h. After the pH of the solution was adjusted with 1.5 ml of reagent grade (29% aqueous solution) NH_4OH, samples were vacuum filtered to remove CaF_2 that precipitates during digestion. The PO_4 was isolated by addition of silver amine solution (0.2 M $AgNO_3$, 0.35 M NH_4NO_3, 0.74 M NH_4OH, 0.342 ml/mg sample) and precipitation of Ag_3PO_4 at approximately 70°C. The Ag_3PO_4 crystals were weighed into 6 mm o.d. quartz tubes and combined with a stoichiometric amount of spectrographically pure graphite (0.014316 mg C/mg Ag_3PO_4). The tubes were degassed at high vacuum and the Ag_3PO_4 heated to 500°C to drive off water trapped in and on the crystals. The sealed tubes were then heated to 1400°C for 1.75 min to evolve CO_2 from the reaction of the Ag_3PO_4 with the graphite. The $\delta^{18}O$ of the CO_2 was measured in the University of Michigan Stable Isotope Laboratory on a Finnigan MAT Delta-S isotope ratio mass spectrometer. Analytical precision of the analyses is better than ±0.2%, based on repeated measurements of a laboratory standard of African elephant molar enamel.

12.3 Results

12.3.1 Enhancement of First-order Increments

Pigmented, low-viscosity resin entered dentinal tubules where they intersected the polished dentin surface. If dentinal tubules had been consistently oriented relative to the plane of section, a homogeneous effect might have been expected, but proboscidean dentin is characterized by the "Schreger pattern" (Espinoza and Mann, 1993), which appears on transverse sections of mastodon tusk dentin as a "checkerboard" or lattice-like pattern of dark and light regions (Trapani and Fisher, 2003). This pattern reflects spatial variation in the period and phase of undulation of dentinal tubules within radial planes (Miles and White, 1960). Penetration of resin varied with tubule orientation, so the most pronounced effect of impregnation by pigmented epoxy was increased visibility of the Schreger pattern itself. However, less resin appears to have entered along narrow zones associated with the "faint, linear features" (or "thin, white layers") described in Section 12.2.2, leaving them lighter under reflected-light observation, relative to broader, intervening zones (Fig. 12.2a). Under transmitted-light observation, used for thin section analysis, resin penetration reduced scattering of light, increasing transparency, and leaving the narrow zones darker than the inter-

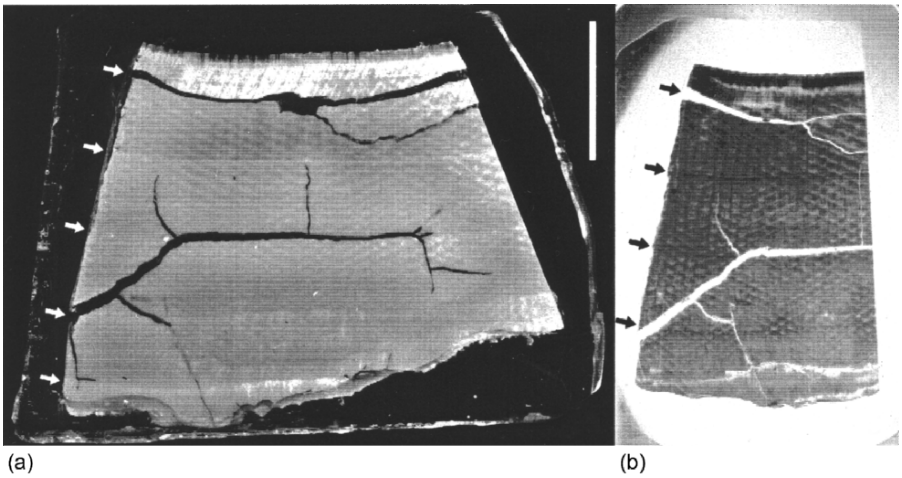


Figure 12.2 Photographs of transverse dentin cross section in reflected (a) and transmitted (b) light, following impregnation by pigmented epoxy resin. Scale bar = 1 cm (applies to both a and b). Samples originate from proximal end of embedded region of the tusk fragment (see Fig. 12.1a). Arrows at left of each image indicate narrow bands highlighted by epoxy. Photo by Aucilla River Prehistory Project.

vening broad zones (Fig. 12.2b). After this treatment, dark–light couplets that repeated on a spatial scale of 5–6 mm were plainly evident.

One of these narrow bands highlighted by epoxy can be discerned at about 2 mm from the surface of the pulp cavity, but it is not as pronounced as others. It may be observed in Fig. 12.2a,b, but a narrow fracture runs along part of its extent, a slightly larger fracture is situated between it and the pulp cavity, and a still larger fracture lies just to the outside of it. These fractures allowed clear epoxy to enter prior to treatment with pigmented epoxy, reversing (to a variable degree) the pattern of contrast seen on most such features. In Fig. 12.2a (uppermost arrow), this "narrow band" is a discontinuous dark line on a light background, and in Fig. 12.2b, it shows up only as a short segment of light on a dark background. More typical in contrast and appearance are narrow bands that lie at about 8, 14, and 19 mm from the pulp cavity (Fig. 12.2a,b), and at about 24 (Fig. 12.2a) and 29 mm from the pulp cavity. These bands (dashed lines in Fig. 12.1a), or more precisely, the couplets of which they are the most conspicuous component, constitute first-order elements in the hierarchical system of dentin increments and are excellent candidates for annual features.

Stereomicroscopic examination of the "faint, linear features" and "thin, white layer[s]" with which "narrow bands" are associated shows these features to consist of one or more layers, each of which is about the thickness expected for a thin second-order increment (ca. 0.1 mm). The layers stand out not only by their light color (in reflected light), but also by their sharp delineation from adjacent material. When there is more than one such layer within a narrow band, they typically differ in strength of definition, bringing up the issue of how to decide on a threshold for their recognition and enumeration. Our provisional resolution, admittedly subjective, is to count those features that were "easy to draw" during production of the camera lucida drawings in Fig. 12.1b,c. On this basis, the feature located 2 mm from the pulp cavity is clearly single. It can be traced from the embedded region, where it appears at the position of our isotope sample-7 (Fig. 12.1c,d), to the longitudinal surface that was serially sampled by Hoppe and Koch. There it appears between their samples-3 and -4 (Fig. 12.1b). Proximal to this, it becomes difficult to recognize in reflected light.

The feature at about 8 mm from the pulp cavity, in the embedded portion of the specimen (included in our isotope sample-20), is likewise single and can be traced all the way to the dentin–cementum interface near the proximal end of the tusk fragment. At the position of Hoppe and Koch's serial sampling, it is a single layer located between their samples-11 and -12, but even across the proximodistal distance they sampled, it (and their sample paths) converges slightly toward the layer located 2 mm from the pulp cavity.

The feature at about 14 mm from the pulp cavity (in our isotope sample-29) includes two conspicuous layers in the embedded portion of the fragment (Fig. 12.1c), but when traced proximally, one of these fades out, leaving only a single layer (Fig. 12.1b; between Hoppe and Koch's samples-19 and -20) to continue to the dentin–cementum interface, at about the distal extent of remaining cementum. This feature is located closer to the pulp cavity where Hoppe and Koch sampled it (between their samples-19 and -20 but partly included in sample-20) than where we did, and it converges even more notably toward the pulp cavity along the length of their sample paths than did the layer between their samples-11 and -12.

The feature at about 19 mm from the pulp cavity (in our isotope sample-39) also includes two conspicuous layers where we studied it (Fig. 12.1c), but it reaches the dentin–cementum interface distal to Hoppe and Koch's serial sampling. Additional features at about 24 and 29 mm from the pulp cavity appear to be single layers and extend to the dentin–cementum interface within the embedded portion of the fragment.

A final spatial association that was recognized following treatment with pigmented epoxy is that the course of fractures passing through the dentin frequently appears to have been controlled in part by the location of "narrow bands" following "white layers". Loci of fracture initiation (seen in cross section as the widest parts of epoxy-filled fractures) show no such association and were presumably controlled by stress fields set up by moisture loss from the surfaces of the fragment (exterior, pulp surface, and radial fractures). Where fractures propagated at a high angle to incremental features, they often passed through the latter without deflection, but as fractures continued (in the direction of their narrow terminations), they often turned to follow "white layers". The two largest fractures shown in Fig. 12.1c come from the left margin, curve inward, and then follow the features at 8 and 14 mm from the pulp cavity.

12.3.2 Increment Thickness Profile

Measurements of successive second-order increment thicknesses from two different, but overlapping, three-year intervals are presented in Fig. 12.3. The first graph covers the chronologically earliest years analyzed in this study, recorded in thin sections

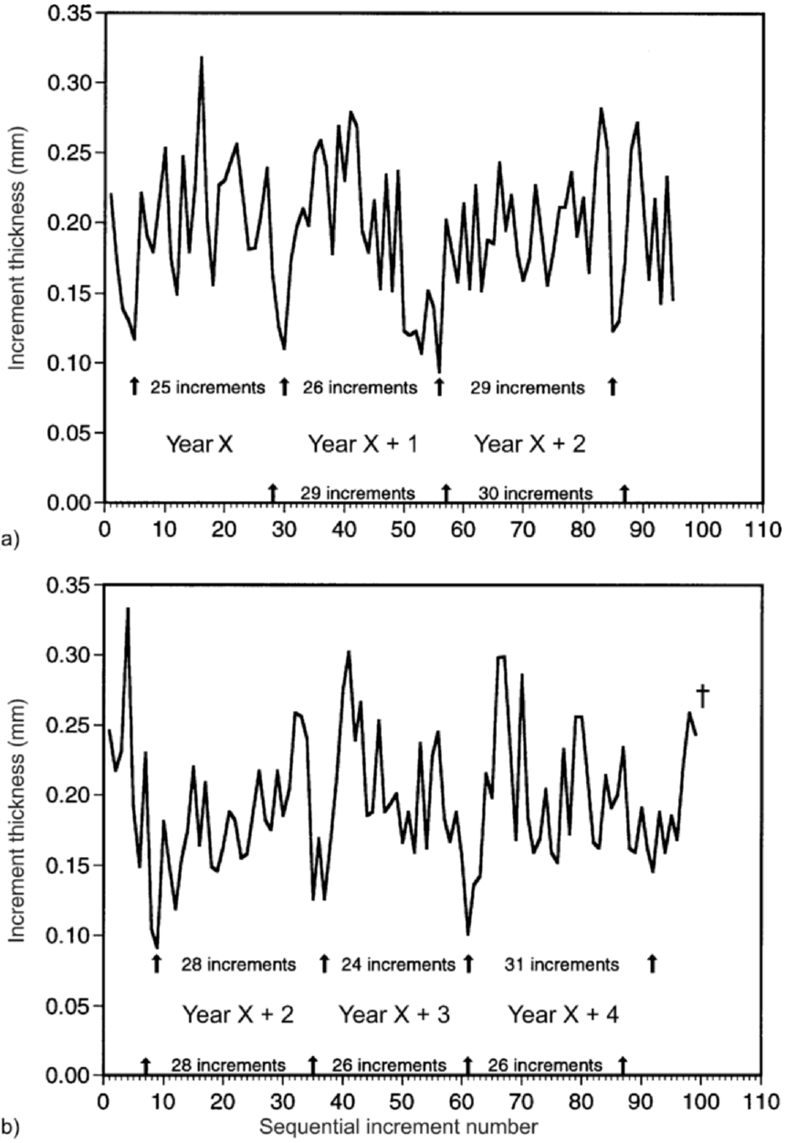


Figure 12.3 Thickness profiles for second-order dentin increments from tusk UF 150701. Upper row of small arrows below plot indicates positions of annual minima in second-order increment thickness; number of intervening increments is noted for each year. Lower row of small arrows below plot indicates positions of prominent incremental features that appear to repeat on an approximately annual basis; number of intervening increments is noted for each year. Years in life are noted below graph, and time of death is marked by a small dagger symbol above curve. (a) Profile measured on a thin section derived from the proximal end of the embedded region of the tusk fragment (see Fig. 12.1a). (b) Profile measured on a thin section derived from the distal end of the tusk fragment.

derived from the distal end of the tusk fragment (see index diagram in Fig. 12.1a). This profile is truncated after nearly 100 increments because of fractures that disrupted the sequence, and because the same time interval was much better preserved at the more proximal location recorded in Fig. 12.3b (see Fig. 12.1a). The second graph (Fig. 12.3b) also covers about 100 increments, but these extend all the way to the pulp cavity, at which the last second-order increment is incomplete (not terminated by a luminance minimum and not including the usual number of third-order features) and therefore not graphed. Each of these increment profiles shows several local minima in increment thickness (indicated by the upper row of small arrows) at intervals of approximately 26 (24–31) second-order increments. These increment thickness minima are also closely associated with one or more prominent second-order increments (bounded by darker than usual luminance minima, as viewed in reflected light, on the polished surface of the thin section or the slab from which it was cut). Positions of the most prominent of these (assessed visually) are marked by the small arrows just above the *x*-axis. They too are thus separated by about 26 (26–30) second-order increments.

An obvious question is whether the "prominent second-order increments" marked by arrows along the *x*-axes in Fig. 12.3 are the same features as the "white layers" associated with "narrow bands" highlighted by pigmented epoxy. Checking this is less straightforward than it might seem, as it involves finding landmarks that can be located in both transmitted and reflected light and judging features that often appear different under these contrasting conditions of observation. In general, the correspondence seems to be imperfect. Whereas only one or two white layers occur per narrow band, there are often several prominent second-order increments in the same portion of the dentin sequence. As with white layers themselves, choosing an appropriate threshold for enumeration is non-trivial, and we simply defaulted to marking only the most prominent one. Moreover, whereas each white layer appears to consist of an entire second-order increment, recognition of prominent increments involves the "growth lines" bounding them; the arrows along the *x*-axes of Fig. 12.3 thus mark positions *between* increments. In view of this difference in criteria and nature of units, it is not surprising that the correspondence treated here is not an exact identity, but it is nonetheless faithful to within a few increments.

The correspondence between white layers and local minima on the second-order increment profiles is likewise not exact, but it is very close. White layers appear to be among the thinnest in the sequence, and their pattern of recurrence is highly regular. In some cases, white layers seem to precede local minima, although this difference is greatest for the white layer nearest the pulp cavity, where the minimum is not pronounced. White layers seem to be more closely associated with increment thickness minima than are prominent increments. They were described above as either single or double (i.e. either one or two per narrow band), and it is notable that single white layers are associated with single minima, whereas double white layers occur in parts of the sequence where several nearby increments, separated by slightly thicker ones, vie for minimal status.

In summary, we observe close, but inexact, relations among several kinds of first-order features. We hesitate to consider any one of the most highly localized of these features (e.g. white layers) as the "golden spike" that should take precedence over others in denoting boundaries between first-order increments, although minima in second-order increment thickness have been used in this manner previously (Fisher, 1987). An alternative is to use a less highly localized feature, the narrow bands highlighted by pigmented epoxy, for this purpose (Fisher, 2001). These have the advantage of being traceable even where thin sections have not been analyzed. Dark bars above the *x*-axis of the $\delta^{18}O_p$ profile (Fig. 12.5) discussed below indicate the positions of these features relative to the pulp cavity, at the proximodistal position on the tusk fragment from which our isotope samples derive.

Previous work on mastodon tusk growth has interpreted first-, second-, and third-order increments as having periods of about one year, two weeks, and one day, respectively (e.g. Fisher, 1987, 1988; Koch *et al.*, 1989; see also Table 12.1). This interpretation is discussed further below, but we use it here as a working hypothesis, facilitating efficient description of the intervals of time represented by various aspects of the tusk record. We thus refer to the intervals bounded by "narrow bands" and associated features as years. Because we do not know the age of this animal at death, we number the first such interval "Year X", and the following ones "Year X + 1" and so forth, up to the last full year of life.

The first-order features highlighted by pigmented epoxy, together with prominent second-order increments and white layers, can be traced across the tusk fragment as indicated by the dashed lines in Fig. 12.1a. They provide unambiguous links by which the profiles in Fig. 12.3a,b can be correlated (at the scale of years), and on this basis, Year X + 2 on each is identified as the same interval of time. For reasons discussed below, we retain the Year X + 2 profile from Fig. 12.3a, terminating the first profile at its increment 84 and picking up the second profile at its increment 34. This point was chosen because it was easily correlated based on luminance attributes and relative position on the profile itself.

Given the above correlation, the composite increment thickness profile for the entire sequence analyzed is shown in Fig. 12.4a. As explained in Section 12.2.3, the reference frame (*x*-axis) for this profile is transformed to the spatial domain by plotting increment thicknesses relative to cumulative increment thickness, as in Fig. 12.4b. For consistency with the directionality of time, our position values increase in the growth direction, and to reflect the reference status of the surface of the pulp cavity, we reserve for it the value of 0.

The five years displayed here show variable second-order increment thicknesses that nonetheless remain relatively close to mean thickness (= 0.20 mm; standard deviation = 0.061) for most of the year. Brief episodes of reduced increment thickness recur at approximately annual intervals, but most of these last for no more than about three second-order increments, or about six weeks. These downward excursions of the profile are relatively pronounced, in the sense that rate of dentin apposition is generally depressed by more than one standard deviation below mean increment thickness (i.e. below 0.139 mm). Only the last increment thickness

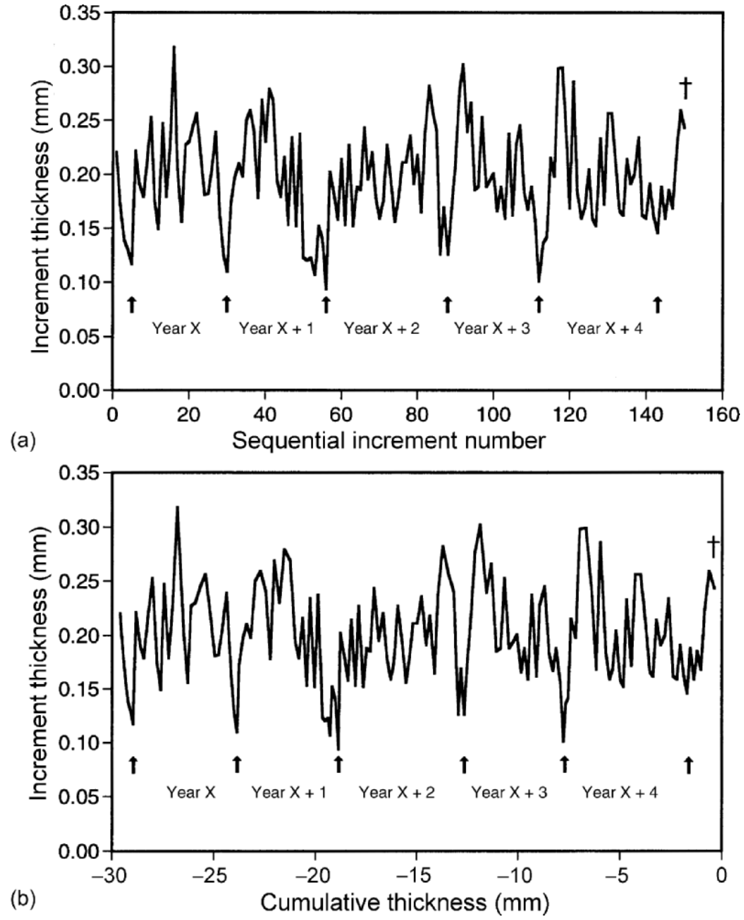


Figure 12.4 Composite second-order increment thickness profile from Fig. 12.3a,b; symbols as in Fig. 12.3. (a) Second-order increment thickness graphed relative to increment number (increments numbered sequentially in order of formation, over a period >5 year, ending at death). (b) Second-order increment thickness graphed relative to cumulative dentin thickness, measured backward (hence, the negative values), in millimeters, from the surface of the pulp cavity (distances uncorrected for increment taper near cementum).

minimum (near 2 mm from the pulp cavity) is less extreme than this, and yet it comes close. In all cases, minima are followed by a rapid return to some of the highest values of the entire profile. The smoothed version of this profile (Fig. 12.4c) highlights some of these longer-term characteristics, at the expense of short-term variability.

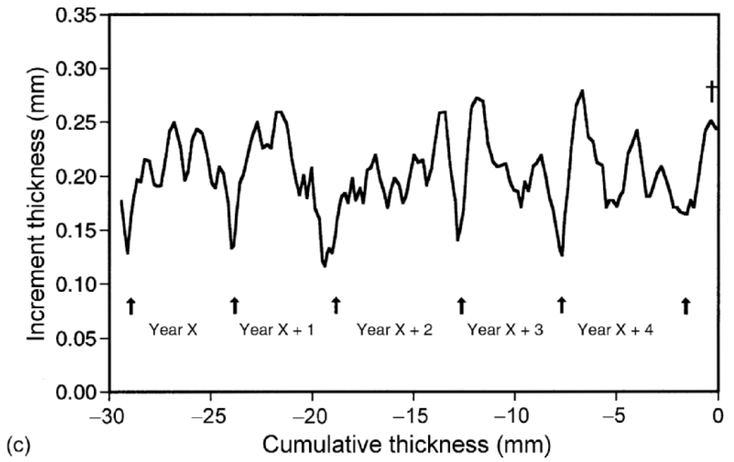


Figure 12.4 (*Continued*) (c) Second-order increment thickness graphed as a three-point moving average of the data shown in (b).

12.3.3 Rate of Tusk Length Increase

Rate of tusk length increase is best measured along the dentin–cementum interface. However, a combination of fractures and cementum spalling has left little of this surface intact. The proximal-most ‘feather-edge’ of the original tusk has been broken away, and with it went any external expression of the first-order feature at 2 mm from the pulp cavity. The penultimate first-order feature, at 8 mm from the pulp cavity, intersects the dentin–cementum interface near the current proximal margin of the fragment, where it is expressed as a sharp topographic discontinuity (periradicular annulation) visible through the thin layer of cementum that has been deposited at that position. This topographic feature is too fine to show up in Fig. 12.1a, but its position is indicated by the proximal termination of the next-highest dashed line on the diagram. First-order features formed before this are also expressed topographically, as low annulations involving minor (<1 mm relief), transient constrictions of tusk diameter, followed by return to the former curvature. Using these, the length increment for Year X + 3 can be directly measured as 52 mm, and for Year X + 2, we estimate a length increment of 55 mm. Preservation of this fragment is inadequate to go further, except to note that its entire length and the number of first-order increments encountered, are consistent with increment lengths between 50 and 60 mm.

12.3.4 Oxygen Isotope Profile

Oxygen isotope compositions are presented in Table 12.2 and plotted relative to each sample’s distance from the pulp cavity in Fig. 12.5. The total range of variation is just 3‰ from a low of 18.7‰ to a high of 21.7‰. Periodicity of variation is not

Table 12.2 Data on isotope composition of phosphate oxygen ($\delta^{18}O_p$ in ‰ VSMOW) from the last years of life of UF 150701, Mammut americanum, *listed by sample number and distance from pulp cavity*

Sample	*Distance (mm)*	$\delta^{18}O_p$	*Sample*	*Distance (mm)*	$\delta^{18}O_p$
–1	–0.2	19.0	–21	–8.9	21.0
–2	–0.5	19.5	–22	–9.5	20.7
–3	–0.7	18.9	–23	–10.1	21.4
–4	–1.0	18.7	–24	–10.7	20.9
–5	–1.4	–	–25	–11.2	20.6
–6	–1.7	20.6	–26	–11.8	19.6
–7	–2.0	20.5	–27	–12.3	20.4
–8	–2.3	20.7	–28	–12.9	20.7
–9	–2.9	20.0	–29	–13.5	21.7
–10	–3.4	19.7	–30	–14.0	21.6
–11	–4.1	19.3	–31	–14.5	20.4
–12	–4.6	19.5	–32	–15.0	19.7
–13	–4.9	19.7	–33	–15.5	19.7
–14	–5.2	20.1	–34	–16.1	20.0
–15	–5.6	19.8	–35	–16.7	20.3
–16	–6.0	19.5	–36	–17.4	20.4
–17	–6.3	19.9	–37	–18.0	20.1
–18	–6.9	20.1	–38	–18.6	21.0
–19	–7.6	21.4	–39	–19.3	21.1
–20	–8.3	21.6	–40	–19.9	19.7

conspicuous when the oxygen isotope profile is viewed in isolation (i.e. just the lower, longer curve in Fig. 12.5, for $\delta^{18}O_p$). However, adding the first-order features (narrow bands) highlighted by pigmented epoxy, as is done through display of the short, solid bars just above the *x*-axis of Fig. 12.5, draws attention to a pronounced regularity. Each bar, measured on the same 5-mm slab from which isotope samples were milled, coincides with a local maximum along the isotope profile. The converse does not hold, although it could be argued that all of the more prominent local maxima are associated with bars. In this sense, oxygen isotope compositions join structural features in distinguishing first-order patterns for this tusk.

The first (Year X + 2) and third (Year X + 4) of the 3+ years displayed on the profile for phosphate oxygen show very similar internal structure. Starting at one of the narrow bands marked by bars, they show the highest value of the year, decline to a local minimum (at roughly one quarter of the way through the year), rise slightly to a local maximum (roughly half way through the year) well below the annual maximum, fall to the annual minimum (at roughly three quarters of the way through the year), and then rise again to the next year's initial maximum. The second (Year X + 3) of these years is similar except that the secondary maximum is somewhat higher in value and the relative values of the two minima are reversed. All three years are characterized by rather asymmetrical profiles involving two cycles of rising and falling values per year.

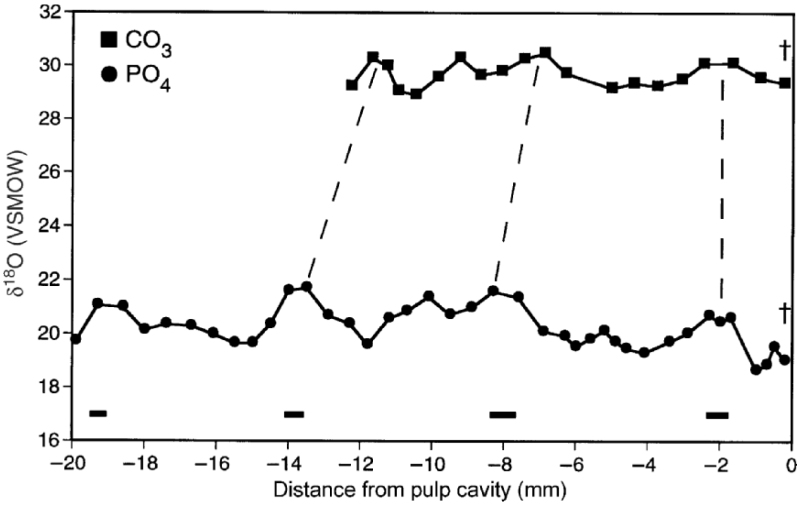


Figure 12.5 Profiles of variation in oxygen isotope composition of dentinal hydroxyapatite relative to distance from pulp cavity. Lower profile, through solid dots, shows data reported here for phosphate oxygen. Bars below curve indicate positions of narrow bands highlighted by pigmented epoxy (measured to the nearest 0.1 mm). Upper profile, through solid squares, shows Hoppe and Koch's data for carbonate oxygen. Dashed lines represent white layers, anchored on each profile in the position they occupy relative to each sample series and distance from the pulp cavity.

12.4 Discussion

12.4.1 Reproducibility of Structural Increments

Before becoming immersed in details of interpretation, it is important to confirm the reproducibility of our structural observations from one part of the tusk fragment to another and among observers. The white layers and associated topographic features can be traced with the naked eye or with low-power, reflected-light magnification. On the embedded part of the specimen, narrow bands, white layers, and prominent second-order increments can be seen on cut and polished surfaces, whether of thick or thin sections. We regard the first-order features of this specimen as essentially self-evident under any careful inspection. Treatment with pigmented epoxy has enhanced contrast on these features, but its effects clearly follow boundaries defined by physical properties of original dentin increments.

Preservation of second-order increments was excellent in most parts of this specimen. The main challenge in marking them for data export was that in some areas, they were difficult to distinguish from intervening third-order increments. Criteria for distinguishing second-order increments emphasize their boundaries – luminance minima that are darker, broader, and more laterally continuous than those bounding third-order increments (Fisher, 1987). Second-order increments may also be recognized by counting included third-order features, of which mastodon tusks usually show about 14. In areas where second- and third-order increments were difficult to distinguish, it was because of some conflicts between these normally compatible criteria. In this study, such conflicts were often adjudicated on the basis of features evident in one field of view, although in principle, it is preferable to range broadly across an entire thin section or even among sections. It was useful in some cases to compare thin sections of the same interval, with and without pigmented epoxy. Third-order increments were better resolved without epoxy penetration, consistent with earlier findings (Fisher, 1988). For counting their number within provisionally recognized second-order increments, thin sections without pigmented epoxy (usually observed without crossed nicols) were most useful. However, the tendency for third-order features to be obliterated by epoxy penetration was useful in that it often left second-order luminance minima relatively unchanged, making them easier to pick out (especially when observed with crossed nicols, suggesting that changes in crystallite orientation may be involved in second-order increment boundaries).

Second-order increments obviously require more detailed observation than first-order increments and thus offer more opportunities for error. However, the broad features of second-order increment profiles allow limited scope for reinterpretation. Our duplicate profiles for the end of Year X + 1 through the beginning of Year X + 3 serve as examples. Nearly a month separated the data collection sessions on which these were recorded, and although each was reviewed for consistent application of recognition criteria for second-order increments, no effort was made to reconcile the parts of the profiles that overlap temporally. The first notable difference between the profiles is that increments 50–55 of Fig. 12.3a are quite thin, whereas increments 1–6 of Fig. 12.3b are relatively thick. On reviewing printouts of the images analyzed, the thinner increments seen on the 12.3a profile are indeed present on images for 12.3b. They were not marked because this thin section was darkly stained in this area, as is common near the cementum-dentin interface, where this profile began. Third-order features were therefore obscure and could not be integrated into increment marking decisions. This portion of the 12.3b profile had been noted as problematic, and the 12.3a version of this interval is clearly preferable. Even so, the increment thickness minimum between Years X + 1 and X + 2 is common to the two profiles. Indeed, most of Year X + 2 is similar in these profiles. Increments tend to be thinner in 12.3b than 12.3a, but this is a general feature of observations near the dentin–cementum interface (see below); in this respect the 12.3a profile is more representative of this interval elsewhere in the tusk. Moreover, increments observed in this area on the thin section used for 12.3a were simply clearer than in the thin section used for 12.3b. This may be because of distance from the dentin–cementum interface, local variation in preservation, or differences in epoxy penetration during thin section production. In any case, both profiles show a distinctive "W-shaped" section (spanning nine increments) midway through the year, and both indicate generally increasing values of increment thickness, with a pronounced rise just before the minimum that marks the end of Year X + 2. Matches in the profiles again become more tenuous near the end of 12.3a, but this is where fractures begin to interfere on this thin section, rendering 12.3b preferable. The point at which we spliced the profiles was chosen to combine the clearest and most representative parts of each.

12.4.2 Periodicity of Structural Increments

Evidence for the periodicity of incremental features of proboscidean dentin has been presented previously (e.g. Fisher, 1987; Koch *et al.*, 1989), but this specimen corroborates earlier arguments. We will show that first-order features represent annual cycles and that third-order cycles approximate daily increments. We start by considering first-order features apart from other levels in the hierarchy. Massive structures such as tusks might be expected to display spatially repetitive, layered organization related to fracture inhibition, elasticity, or other physical attributes. Such patterns could be spatially periodic without necessarily being temporally periodic. The three-dimensional development of the Schreger pattern may be a prime example of such a phenomenon. However, the Schreger pattern has repeating elements in all three dimensions of its spatial organization (radial, ad/abaxial, and proximodistal), of which at most one could represent a temporal sequence. Furthermore, each of the differently oriented 'layers' of the Schreger pattern intersects the appositional surface of dentin at a high angle, whereas only layers that parallel developmental loci (in an accretionary system such as tusk dentin) could plausibly represent a time series reflecting systemic changes. First-order features have this requisite relation to an appositional surface.

It is conceivable that repeated co-occurrence of many, independently recognizable structural and compositional changes could arise due to complex modulation of an appositional system, resulting in spatially periodic, but temporally aperiodic structure. Biomechanical consequences could give rise to selection for such a pattern, and could be involved as well in maintaining a pattern that was temporally periodic in nature. The critical question is whether observed features could be generated by a temporally aperiodic mechanism. We may not know enough about the mechanism of dentin apposition to evaluate whether spatially periodic but temporally aperiodic modulation of structure is possible, but this is where stable isotope data come to the fore. All previous work on variation in stable isotope composition of mineralized tissues has interpreted it as reflecting composition of body fluids (Longinelli, 1984; Luz *et al.*, 1984), which in turn is a function of the environmental availability of isotopes. For oxygen in particular, the dominant control on environmental availability is meteoric water, the oxygen isotope composition of which is dependent largely on temperature (Rozanski *et al.*, 1993; Dansgaard, 1996) and at mid- to high-latitudes, varies seasonally. This temporally periodic signal in meteoric water composition is available for incorporation in organisms – indeed, it will be incorporated unless behavior and physiology combine to dampen it. Generating a spatially periodic structure from a temporally aperiodic signal requires a growth mechanism unlike any known today (e.g. growth rate constrained to vary inversely to waiting-time to the next environmental perturbation). The entire field of sclerochronology (Steuber, 1996) is based on a simpler, less *ad-hoc*, growth model. Spatial structure may be, indeed usually is, related non-linearly to temporal structure, but the two are coupled via growth rates that vary as a function of environmental state, which in turn has a temporally periodic component.

Isotope composition of phosphate oxygen is widely accepted as being resistant to diagenetic alteration (Tudge, 1960; Kolodny *et al.*, 1983), so the profile observed here is likely to have characterized the environment encountered by the living animal. Although oxygen isotope "cycles" occur at wavelength-scales of roughly 3 and 6 mm, only the 6-mm scale matches the pattern of structural features such as white layers and narrow bands. Following the arguments above, this pattern of first-order spatial variation is best interpreted as reflecting temporal variation with a dominant periodic component. For an animal of this body size and general ecology, the most likely period for such temporal variation is annual.

This argument is independent of second- and third-order features, but bringing them into the picture is helpful. Variation in second-order increment thickness confirms first-order increment identification, and the product of number of third-order features within second-order features and number of second-order features within first-order features is close enough to 365 to support the hypothesized time-value of increments at all three levels. Variation in numbers of features recorded here probably represents a combination of error in feature discrimination and real variability in the timing of environmental shifts in consecutive years. The five years studied here, as represented on the composite profile (Fig. 12.4a) by intervals between increment thickness minima, include, in sequence, 25, 26, 29, 24, and 31 second-order increments. The number most disparate from 26 (31) is bounded on the closing end by the least well-marked minimum (in terms of contrast from neighboring values), and this is also the position at which a white layer most clearly preceded the minimum. Using prominent second-order increments to mark this year's boundaries yields 26 increments. The two other most disparate values in the above series, 29 and 24, are adjacent to each other and are complementary in the sense that a single two-week shift in one of the times of lowest rate of dentin apposition could have been responsible for most of their disparity. We made no concerted effort in this study to evaluate number of third-order features per second-order feature, but inspection of the best preserved portions of the sequence suggests that this is usually about 14, as reported initially for mastodon tusks (Fisher, 1987; Koch, 1989; Koch *et al.*, 1989). Recent work has indicated different numbers of included features for mastodon cheek teeth and mammoth tusks, *contra* Fisher (1996). Nonetheless the number of third-order features per second-order feature is still a multiple of seven, and the number of third-order features per first-order feature is still about 365 (Fisher, 2001; Fisher and Fox, submitted).

12.4.3 Rate of Dentin Apposition

Inferences about rate of dentin apposition depend on measuring increment thickness, and "true thickness" is measured perpendicular to a tangent to the appositional surface. We describe our thin sections as "normal to the surface of the pulp cavity", but given the geometry of cones, this is strictly true only along one radius. However, for a narrow sector of dentin such as this specimen presents, the error in orientation is <5°, and the cosine correction factor yields a value within measurement error. Transects for increment thickness profiles were usually run down the middle of thin sections, keeping them normal to growth lines, so no correction of measured values was needed. Positions of our isotope samples, however, were measured along the margin of the sample slab, where measured values are slightly greater than true thickness (only measured values are used in Fig. 12.5 and Table 12.2).

Increment thickness can be biased by the location on the tusk at which it is measured. In compiling composite, second-order increment thickness profiles on other specimens, it has become clear that although increments maintain nearly constant thickness over most of their extent, they taper toward both the tusk axis and the dentin–cementum interface. This effect is most notable within about 10% of the proximodistal distance from the increment-cone apex or from its proximal margin. In a given transverse section, this translates approximately into an effect recognized "within two years" of the tusk axis or cementum, becoming stronger as these limits are approached. Year X + 2 was affected by this factor in the thin section profiled in Fig. 12.3b, but probably not in Fig. 12.3a. In the former thin section, Year X + 2 had a thickness between second-order increment thickness minima of only 5.0 mm, but in the thin section that yielded 12.3a, this same dimension was 5.8 mm. Applying the same percentage increase (116%) to Year X would change it from the 5.1 mm observed in Fig. 12.4b to 5.9 mm. Reflecting the gradational nature of this reduction in increment thicknesss, we propose that a smaller correction factor (108%) be applied to years recorded one year away from the cementum (Years X + 1 and X + 3), but that no correction is necessary for years recorded farther from the cementum (Year X + 4), yet still not within the tapering zone near the tusk axis. These modifications of observed thickness (Table 12.3) help ensure that increments sampled at different positions are compared on a common basis. The magnitude of correction needed for a given tusk is a function of its geometry, for which we currently have limited control on this specimen, but the corrections offered should mitigate this problem.

Accepting the time-value of increments proposed in Table 12.1 allows direct conversion of increment thicknesses to rates of dentin apposition. The corrected first-order increment thicknesses discussed above thus yield rate estimates at an annual scale. A good indication that our corrections are of about the right magnitude is that the total composite (Fig. 12.4) corrected thickness (30.1 mm, Table 12.3), for the time interval under consideration, is nearly the same as the total thickness (30.0 mm) measured directly on a slab from the distal portion of the tusk fragment, where no correction for increment taper is necessary other than for Year X (penultimate column of Table 12.3). Year-by-year differences between corrected first-order increment thicknesses and directly measured first-order increment thicknesses in Table 12.3 are mostly due to use of second-order increment thickness minima to demarcate years in the former, and narrow bands in the latter. Average values for the 5-year period are nearly identical. Likewise, use of white layers or prominent second-order increments for year boundaries would have given slightly different annual values, without changing the long-term average. Over the span of time studied here, there is no systematic trend toward higher or lower annual rates, as

Table 12.3 Annual rates of dentin apposition and tusk length increase for the last years of life of UF 150701, Mammut americanum

Year	*Composite 1° thickness ($2°_{min}$, mm)*	*Increment-Taper correction (%)*	*Corrected composite 1° thickness ($2°_{min}$, mm)*	*Distal location, 1° thickness (n.b., mm)*	*Tusk length increment (mm)*
X	5.1	116	5.9	5.2	57 (c)
X + 1	5.0	108	5.4	5.5	52 (c)
X + 2	5.8	N/A	5.8	5.4	55 (e)
X + 3	4.9	108	5.3	6.3	52
X + 4	6.1	N/A	6.1	5.6	59 (c)
5-Yr total	26.9	N/A	28.5	28.0	275
5-Yr average	5.4	N/A	5.7	5.6	55
X + 5 (NC)	1.6	N/A	1.6	2.0	19
Total	28.5	N/A	30.1	30.0	294

1° – first-order.
$2°_{min}$ – second-order increment thickness minimum.
n.b. – narrow band.
N/A – not applicable.
NC – not complete.
c – calculated from corrected 1° thickness.
e – estimated due to incomplete preservation.

expected for a mature, healthy individual that has not yet entered a senescent decline. These annual rates are within the range previously observed for male mastodons (a gender assignment supported by the length and girth of this tusk at its base).

At the scale of second-order increments, rates of dentin apposition average 0.20 mm/fortnight over the entire interval studied (uncorrected thicknesses; or 0.21 mm/fortnight, corrected thicknesses over the five complete years). Each year includes only one interval of a few fortnights in which rates are lower than one standard deviation below the mean, and the seasonal occurrence of this interval is highly constrained (i.e. the number of second-order increments between such intervals is relatively constant). Excursions to values greater than one standard deviation above the mean are also limited in duration, but their position within years (and the number of second-order increments between them) is not constant. Maximal rates of apposition occur near mid-year in Years X and X + 1, late in Year X + 2, and early in Years X + 3 and X + 4. These patterns of short-term variation suggest that for most of the year, resources were broadly dependable, though not highly predictable, but that at one time of the year, there were highly predictable shortages.

Average rates of dentin apposition for this tusk are toward the upper end of the range of rates observed on mature male mastodons from the Great Lakes region. Such examples include ca. 0.15 mm/fortnight for the Pleasant Lake and Grandville mastodons (Fisher, 1987, 1996); ca. 0.18 and 0.20 mm/fortnight for two Hiscock mastodons (Fisher, 1988); ca. 0.22 mm/fortnight for the Parker and Farview mastodons (Fisher, 1996). We note three main differences between Great Lakes region mastodons and this individual: (1) rates measured on a fortnightly scale are more seasonally variable in the north (lower lows and higher highs); (2) the northern low-rate interval (interpreted there as winter) lasts for a greater portion of the year than the annual low-rate intervals of this mastodon; and (3) the northern annual profile is more sinusoidal than "hump"-shaped. These differences are not surprising given our qualitative sense for the impact of latitude on climate and forage conditions, even in the late Pleistocene.

12.4.4 Rate of Tusk Length Increase

Data on tusk length increase are barely adequate to treat separately, but they warrant reporting, if only to serve as a basis for comparison with other studies. A simple model of tusk geometry would suggest that tusk length increase is nothing more than an alternative manifestation of dentin apposition, magnified in proportion to the obliquity of intersection of the appositional surface and the dentin–cementum interface. However, as discussed recently (Fisher, 2001), there may be considerable independent variation in these two aspects of tusk "growth". Dentin apposition without proportional length increase is common during low-growth-rate intervals and is a factor in the development of periradicular annulations such as often mark first-order increments in tusk length. The cause of these features requires further study, but deficiency of dietary protein may be a contributing factor (Fisher, 2001). Periradicular annulations on this specimen coincide spatially and temporally with minima in second-order increment thickness. They are not strongly developed, compared to some tusks from the Great Lakes region, but this may simply reflect the brevity of the insult to the animal's physiology with which they are associated. Even if subtle, they mark two length increments listed in Table 12.3. For Year X + 2, the first-order length increment is 9.5 times the first-order thickness increment, whereas for Year X + 3, the relevant factor is 9.8. Calculated values in Table 12.3 assume a factor of 9.65. They are intended only to show that the length of the tusk fragment is compatible with the number of first-order increments recognized, and to indicate approximately the magnitude of increments expected.

Second-order length increments are not well enough displayed on this fragment to evaluate their similarity to second-order thickness increments. In addition, with only two first-order length increments preserved directly, we cannot say anything about trends or year-to-year variability that was not already evident in thickness data. We can, however, compare the estimated average first-order length increment (ca. 55 mm) for these five years to length increments in other male mastodons of this approximate age at death. Length increments, more than thickness increments, show a tendency to decline in value with increasing age (Figs. 30.6a and 30.8 in Fisher, 1996). Prior to our analyses, DCF examined the entire tusk from which this fragment was extracted. Inspection of transverse breaks and longitudinal cuts along the tusk revealed first-order increment traces representing 21 years in the part of the tusk proximal to an unsawn tip section. The distal end of the tusk showed a flake scar from tip fracture, partly obliterated by wear. The remaining tip section almost certainly included 10 years, and probably more, making the animal >31 years old at death. At this age, the Pleasant Lake mastodon, in Michigan, was also producing first-order tusk length increments of 50–60 mm, down from 90–100 mm at an age of 17–27. These five years of the Aucilla mastodon are comparable in this respect to material from the Great Lakes region.

12.4.5 Seasonal Variation in Oxygen Isotope Composition

Our data on the isotope composition of phosphate oxygen offer intriguing hints about the climate and environment encountered by the Aucilla mastodon. Only one value (for sample-5) is missing due to loss during sample processing, and this appears most likely to have had a composition falling between the preceding local maximum and the following minimum. The low range of variation, both within and among years, is not unexpected for a relatively low-latitude setting, not far removed from the Gulf of Mexico, the ultimate source of the water to which this animal would have had access in its food and drink. Despite the low total range of values, the regularity of the profile from year to year strongly supports the annual nature of first-order structural increments. The presence of this pattern in phosphate oxygen makes it exceedingly unlikely that it represents a diagenetic artifact.

Seasonal attribution of parts of the annual cycle observed here is much more difficult than determining which repeating units represent years. Most prior studies have dealt with higher-latitude settings and have focused on drinking water as the carrier of a seasonally variable signal in oxygen isotopes. In such areas, summer precipitation is relatively enriched in the heavier isotope of oxygen (^{18}O), and winter precipitation is strongly depleted (Rozanski *et al.*, 1993). This seasonal contrast is produced by a combination of temperature of evaporation of water vapor, temperature of condensation of precipitation, cumulative history of depletion through condensation from an airmass, and contributions to local precipitation from airmasses with different evaporation–condensation histories (Grootes, 1993; Rozanski *et al.*, 1993). These factors interact in a complex, yet relatively predictable fashion in the seasonally shifting weather patterns of temperate to high-latitude continental interiors. If the local hydrological system includes ponds and streams dominated by surface runoff, and if mammals use these sources for drinking water, teeth undergoing mineralization will to some degree record this seasonally varying environmental signal. In such a system, summer, or the summer–autumn boundary is found at the peaks on the isotope profile, and winter, or the winter–spring boundary, in the valleys (Koch *et al.*, 1989; Stuart-Williams and Schwarcz, 1997; Fricke *et al.*, 1998; Fisher and Fox, in press; Fisher *et al.*, 2003).

What can be expected, however, in a low-latitude, coastal to piedmont setting such as that sampled here? Geographic proximity to the evaporative source of water vapor makes it less likely that airmasses with contrasting water vapor compositions will develop. Since temperature variation also tends to be less pronounced in such an environment, these factors combine to leave composition of precipitation relatively invariant. This problem is compounded if mammals derive some or all of their drinking water from sources such as larger rivers, lakes, or other groundwater-dominated systems in which even seasonally variable compositions of precipitation tend to be averaged out. This is an issue regardless of the initial variability in precipitation. One possibility is that evaporation from drinking water sources will generate seasonally variable intake that could be recorded in teeth. Evaporation can of course occur under a wide range of conditions, but its contribution may be especially significant under the same conditions that lead to low variability in isotope composition of precipitation. During a dry season, increased evaporative losses of the lighter isotope (^{16}O) push the oxygen isotope composition of drinking water toward higher values, producing "evaporative enrichment" of the heavier ^{18}O. In contrast, during a wetter season, water would be minimally displaced from the starting composition of near-source precipitation.

The focus on drinking water in the discussion above is based on calculations (Koch, 1989; Bryant and Froelich, 1995) that most of the oxygen in body fluids, especially in large mammals, comes from this source. The other major source is food, where herbivores get a great deal of oxygen through free water in plant tissues (plant-water). Although plant-water contributes less to the oxygen budget than does drinking water, it might be critical for understanding seasonal changes in oxygen isotope composition when drinking water is seasonally invariant. The possible role of plant-water is two-fold. First, its oxygen isotope composition tends to track the composition of recent precipitation in an area (Yakir, 1992), providing (if present in precipitation) a seasonally variable source, even if drinking water sources retain only a highly dampened signal. Second, evapotranspiration in plants provides a seasonally variable mechanism of fractionation that could enhance a signal present in precipitation (Sternberg *et al.*, 1989) or generate a signal from an invariant starting composition.

Under these circumstances, seasonal changes in humidity and local rates of evaporation and evapotranspiration might make a greater difference than precipitation. An evaporation-dominated (rather than temperature- or airmass-dominated) seasonal cycle of oxygen isotope compositions also fits well with profiles showing two highs and two lows per year, as ours do. Subtropical climates commonly have two dry seasons – one more severe than the other – and two rainy seasons per year. Our default preference would be to assume that a midsummer drought would be most severe, pushing water compositions to the highest values of the year. Our profiles would then suggest, in addition, autumn and spring wet seasons, bracketing a winter dry season of only moderate severity. However, it is also possible that if summers are humid enough, they might entail less evaporative enrichment than would a dry winter. In this case, the positions of winter and summer on our profiles would be reversed, with spring and autumn following suite. Until additional data allow us to choose between these interpretations with greater confidence, we consider it preferable to speak simply of an annual "dry season", punctuating a year that is otherwise more moderate, with two wetter seasons bracketing a slightly drier season.

Additional insight into environmental conditions encountered by this animal is gained by comparing the oxygen isotope profile to the second-order increment thickness profile. This still does not solve the problem of assigning a precise season to the oxygen isotope maximum, but it does draw attention to a profound difference between this specimen and those from temperate settings: Aucilla's second-order increment thickness minima coincide with the *highest* oxygen isotope values in each year, not the *lowest*. Even in temperate conditions, reduced rate of dentin apposition is presumably not a direct consequence of low temperature, but rather of reduced availability and/or quality of food. We likewise suspect that this animal's annual minima in rate of dentin apposition are indications of nutritional stress, even if only moderate and reversible. Their association with oxygen isotope highs supports interpretation of the latter as drought-induced, not simply reflections of higher temperature. As a variant on this theme, we have considered the possibility that water shortage might have a direct impact on nutrient intake or assimilation by proboscideans either by restricting gut passage rate or by making it more difficult to maintain an appropriate internal environment for the gut microflora (Fisher *et al.*, 2003).

The above comments are framed in terms of a sedentary population, but mastodons in this area may have been seasonally mobile (Hoppe *et al.*, 1999). This mobility could affect the isotope profile recorded in a tusk, not to mention tusk growth rates, but because the scale of migration remains an open issue, treatment of a single region is a good starting point.

12.4.6 Comparison with Other Compositional Variation

The first requirement for comparing our results to those of Hoppe and Koch is to establish the spatial scale of their sampling, rather than treating only the pattern of changing values from one sample to the next. Using dial calipers under a stereomicroscope, we measured the distance to the pulp cavity from each edge of each of their sample paths, near its distal end. Because the surface they sampled was inclined 13° from normal to the pulp cavity surface, we corrected these distance values to represent "true thickness", and then attributed each isotope value to a position midway between the leading and trailing edges of its sample path, as we had done for our samples. This is the basis for positioning their profile for $\delta^{18}O_c$ relative to our profile for $\delta^{18}O_p$ in our Fig. 12.5.

However, comparing results with only this information would be like trying to make sense of our Fig. 12.5 without the dashed lines. It would appear that there was a moderately close relation between profiles in the last year, but progressively worse comparability backward in time. Other means of correlating the spatial scale of Hoppe and Koch's sampling to that of our own must be considered, because their sampling extends into the zone ("two years from the cementum") of tapering dentin increments, where distance from the pulp cavity is no longer a satisfactory index of time.

The most precise key to link our sample series with that of Hoppe and Koch is the set of white layers discussed previously. These appear as solid lines in the camera lucida drawings of Fig. 12.1b, c, and d and can be traced clearly on the original specimen. The dashed lines in Fig. 12.5 represent these white layers in that each end of a dashed line is shown at the distance from the pulp cavity and position in the sample sequence that it has in the appropriate sampling area. The dashed lines in Fig. 12.5, like those in Fig. 12.1a, follow individual incremental features and thus are equivalent to "timelines", linking temporally equivalent points in different sampling areas. Although intervening second-order increments cannot be traced as easily, they clearly "parallel" the white layers.

We now observe a very close match between the profiles in Fig. 12.5, with every significant change in one being duplicated qualitatively in the other. One of Hoppe and Koch's values (sample-9) is missing (like our sample-5), but it is not in a position to be critical. The displacement between the two profiles is normal for the different fractionations of carbonate and phosphate oxygen relative to body water (Bryant *et al.*, 1996; Iacumin *et al.*, 1996).

The similarity of these profiles suggests little diagenetic modification of either carbonate or phosphate oxygen values. There is a difference in total range of values between the two profiles, which could be taken as evidence of diagenesis. However, we suspect this largely reflects a difference in sampling strategies. Hoppe and Koch appear to have used the white layers as guidelines in sampling, but they left significant portions of the layer intact, between their samples. We, on the other hand, generally included a given white layer in one sample and did not leave any zone unrepresented. We then encountered our highest oxygen values in samples that included white layers. Hoppe and Koch thus appear to have analyzed smaller amounts of the most enriched material. There is also a slight difference in sample spacing, with our more closely spaced samples possibly providing greater resolution of extreme values, but this difference is not dramatic. Finally, we appear to have had greater temporal control in sample removal, mainly because our dentin slab could slide across a solid surface, whereas they had to control an irregular fragment during drilling. Despite these differences, we observe essentially the same patterns.

Using the same correlation between sample scales developed above, we turn now to other analyses presented by Hoppe and Koch. Figure 12.6 shows their profile of variation in δ^{15}N from collagen. As they discuss thoroughly, nitrogen isotope values

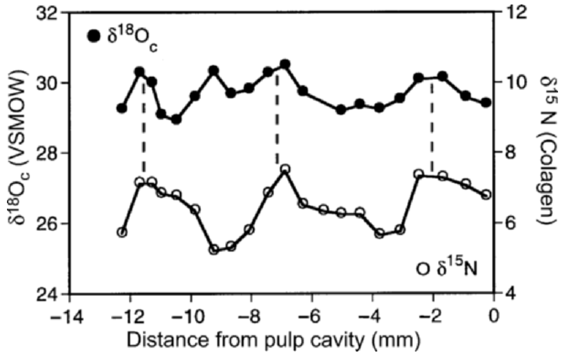


Figure 12.6 Profiles of variation in oxygen isotope composition of hydroxyapatite carbonate (as in Fig. 12.5) and nitrogen isotope composition of dentinal collagen, measured by Hoppe and Koch (this volume, Chapter 13). Both profiles are plotted relative to distance from the pulp cavity near the distal end of their sample paths (same samples used for each analysis; see Fig. 12.1b). Dashed lines indicate positions of white layers. Each peak on the nitrogen profile corresponds to first-order features such as white layers, narrow bands, and minima in second-order increment thickness and coincides with a peak on the carbonate oxygen profile.

may indicate an animal's position along one axis of variation in dietary composition, reflecting the distinct nitrogen isotope values typically found in certain plan groups. Alternatively, nitrogen isotope values may be an indication of levels of nutritional (protein) stress, with higher values marking greater stress, when an animal is forced to metabolize some of its own protein reserves (Koch, 1998). The relation between the nitrogen isotope profile and other features discussed in this study is displayed in Fig. 12.6 by juxtaposing it with the $\delta^{18}O_c$ profile determined by Hoppe and Koch from the same samples, with both plotted on the spatial scale developed for the $\delta^{18}O_c$ profile in Fig. 12.5. Dashed lines marking white layers are repeated here, in the now-familiar position, under each peak in $\delta^{18}O_c$.

The pattern observed for nitrogen is a rapid rise to maximal values, which are in turn associated with white layers, prominent second-order increments, narrow bands, minimal second-order increment thicknesses, and maximal oxygen isotope values. This is followed by a more gradual fall to the lowest values of the year. Unlike the oxygen isotope profile, there is only one cycle of rising and falling nitrogen isotope values per year. The sharp rise occurs at the time of year provisionally interpreted as a dry season, based on elevated oxygen isotope values and declining second-order increment thicknesses. Each of the three peaks recorded in the profile (which lasts about two and a half years) differs in the trajectory of decline, suggesting some more prompt, and some more protracted, returns to lower levels of nutritional stress. It is also interesting, admitting the danger of over-interpreting the profiles, that the first two nitrogen peaks show less protracted declines and are associated with parts of the second-order increment profile (near the beginnings of Years X + 3 and X + 4, respectively) that show high rates of dentin apposition early in the year, indicating relatively sharp improvement of foraging conditions immediately following the time of worst foraging. The last nitrogen peak, with a more protracted decline, is associated with a broader than usual low stretch on the second-order increment profile, and a return to higher rates of dentin apposition that, while notable, is not as dramatic as in the two previous years.

Hoppe and Koch's data on carbon isotope composition are plotted relative to distance from the pulp cavity in Fig. 12.7. Again, the 21 samples and their relations to other aspects of tusk structure and composition are the same as established for the nitrogen and carbonate oxygen profiles. The $\delta^{13}C$ composition of carbonate in hydroxyapatite (Fig. 12.7a) is, surprisingly for a mastodon, in a range associated with a predominantly C_4 diet (Koch, 1998), but we leave the broader implications of this for discussion by Hoppe and Koch. Most interesting for our analysis is that there is marked cyclicity in this profile. Carbonate carbon values are generally high in association with white layers, second-order increment thickness minima, and their attendant phenomena, and then generally decline through the rest of the year. No decline is evident following the last white layer, at 2 mm from the pulp cavity, but since this part of the year shows some variability in both Years X + 3 and X + 4, we cannot determine whether the beginning of Year X + 5 is really significantly different. A missing value for sample-9 compounds this problem, as Year X + 4 could look more like Year X + 3 if the missing value were intermediate between those for samples-8 and -10, or more like Year X + 5 if it were higher than that for sample-10. On the scale of variation between

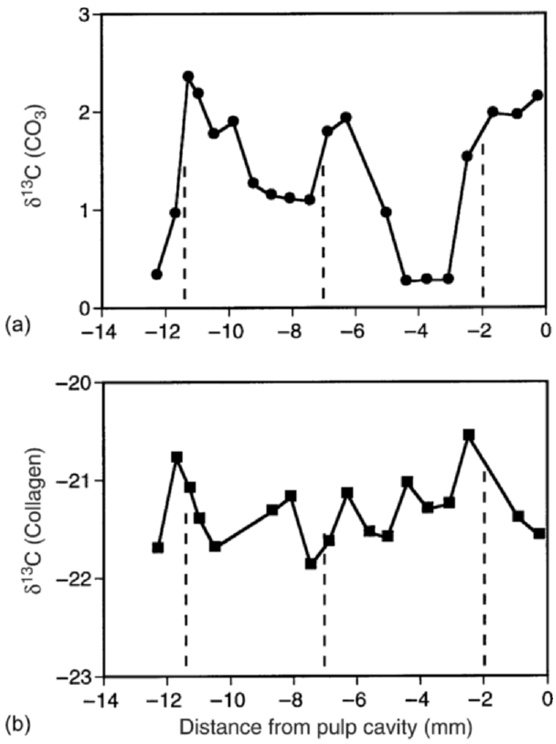


Figure 12.7 Profiles of carbon isotope composition of hydroxyapatite carbonate (a) and collagen (b), measured by Hoppe and Koch (this volume, Chapter 13). Both profiles are plotted relative to distance from the pulp cavity near the distal end of their sample paths (same samples used for each analysis in this figure and in Fig. 12.6; see Fig. 12.1b). Dashed lines indicate positions of white layers.

pure C_3 and pure C_4 diets, all of this variation is perhaps modest. Still, the strong, annual pattern displayed by the profile, with a shift toward more extreme C_4 values at, and following, the time of minimal rates of dentin apposition, suggests that we are seeing some indication of an annual cycle of changes in foraging behavior.

The only data that appear to be out of accord with other observations on this specimen are those for carbon isotopes in collagen (Fig. 12.7b). The range of compositions preserved is smaller than observed for carbonate carbon, but more important, it represents a C_3-dominated diet (factoring in the different displacement expected between diet on the one hand and carbonate vs. collagen on the other). Although the collagen carbon results are more in line with other analyses of mastodon diet (Koch *et al.*, 1998), they offer a different result than came from carbonate carbon. Different compositions for these two reservoirs of carbon are not impossible. Ambrose (1998) has argued that collagen carbon reflects mainly the carbon isotope composition of dietary components that happen to be relatively protein rich, while carbonate carbon tends to average the carbon isotope compositions of all dietary components. This would then imply that protein-rich elements in the diet of this animal were C_3 plants, even though the bulk diet was strongly weighted toward C_4.

Whatever the meaning of the magnitude of values observed, their pattern of variation is another matter. Like other compositional profiles studied here, the profile for collagen carbon shows "cycles", but these appear to be relatively short-term fluctuations that bear no consistent relation to the first-order cycles in all other modalities. By itself, this does not mean that the variation recorded is not an original attribute of the organism, but it shows a pattern that is at present unmatched by any other.

12.4.7 Season of Death

As noted above, use of seasonal designations native to temperate climates is difficult and possibly irrelevant in a tropical or subtropical climate. The principal distinction we can make at this time is between a short, dry season in which a state of moderate nutritional stress develops, and a longer, more moderate season in which a series of wet–dry–wet intervals repeat annually.

Prior studies of season of death in mastodons (Fisher, 1987, 1988) have reckoned time within the year relative to the most consistently recognizable point in the annual cycle. Since the greatest temporal resolution that can be routinely used for determining season of death derives from analysis of second-order increments in thin section, a reference point that is evident in that context is needed. For specimens from temperate settings, this is the annual, second-order increment thickness minimum, which is there taken as the winter–spring boundary. For most years in the specimen studied here, the second-order increment thickness minimum would be an even better reference point, because the zone of thin increments is more highly localized within the year than was the case in the Great Lakes region. We therefore favor a reference point (effectively a mammutid "New Year's Eve") located at this time of the year, even though it almost certainly does not represent a "winter–spring boundary".

Unfortunately, the last, second-order increment thickness minimum in this specimen is the least characteristic feature of its type on this specimen. This increment thickness minimum occurs at about 1.7 mm from the pulp cavity, whereas the nearby white layer, most prominent second-order increment (marked by the last arrow along the *x*-axis in Fig. 12.3b), and narrow band occur at about 2.0 mm. Compositional profiles also corroborate the location of the last, first-order feature at about 2.0 mm. Although we generally favor use of the second-order increment thickness minimum, it may not be the best choice in this case.

As noted above, death comes part-way through a second-order increment. Counting back to the second-order increment thickness minimum, we see eight complete increments; continuing back to the location of the most prominent second-order increment nearby, we get to a total of 12 complete increments. Depending on which of these reference points is used, death occurred four to six months into Year X + 5, and our preference for using the point at 2.0 mm implies that the six month figure better represents the timing of death relative to the normal seasonal cycle. Death is clearly not associated with the short, stressful dry season. Following the last one of these it experienced, there was time to return to more moderate oxygen isotope values, higher rates of dentin apposition, lower nitrogen isotope values, and lower isotope values for carbonate carbon. This should have been a time of the year when the animal was in good condition, and there is no suggestion, either in rates of dentin apposition or nitrogen isotopes, of protracted morbidity prior to death.

In these respects, this animal's death is similar to autumn deaths in the Great Lakes region (Fisher, 1987). It is thus intriguing that David Webb (Chapter 11) has observed evidence of butchery on this tusk. With only one individual, it is perhaps premature to speculate on general patterns, but these observations at least raise the question of what similarities or differences will come to characterize the mastodons and mammoths of this region, and whether these are stable through time.

12.4.8 Season of Migration

Studies of strontium isotope compositions by Hoppe *et al.* (1999) and Hoppe and Koch (Chapter 13), offer compelling evidence that some or all mastodons from the Page-Ladson site migrated seasonally toward the north. Their most direct record of such behavior was from the enamel of a mastodon molar (UF 148668), investigated through serial microsampling. The strontium isotope profile from this molar demonstrates relatively long intervals with the composition typical of areas further to the north, in the southern Apalachians, interspersed with much shorter intervals with the composition typical of northwestern Florida itself. At least for those years of that individual, seasonal allocation of time in different areas greatly favored the north. We would like to determine the season of the year at which this migration took place. It goes without saying that the animal studied here died in the south, but when during the year did it make the trek north, and when did it return? The most direct solution would be to repeat the strontium isotope study on this tusk (UF 150701), or alternatively to study oxygen isotope patterns on the molar (UF 148668). However, pending such analyses, can we make any predictions?

We start by assuming that the two-year sequence of enamel analyzed by Hoppe and Koch shows a typical pattern for other years and other individuals. Although questionable, this hypothesis is testable in the future if not now. We take for granted that both years show equally short episodes of low values, although the duration of the second episode (where the profile terminates) is not constrained by higher values following it. We next assume that apposition of enamel occurs at a sufficiently constant rate that we can use the spatial domain in which the profile is recorded as a proxy for the temporal domain. We have been careful not to conflate these in our own analyses, partly to draw attention to the *possibility* of significant differences and partly because we do not know, a priori, whether the differences will be great enough to matter. Given the relatively even rate of apposition we have demonstrated for tusk dentin (observable as the lack of dramatic profile shifts between Figs. 12.4a and b), this assumption is not unreasonable for molar enamel. We next evaluate the duration (thickness) of the interval showing low (Floridian) strontium isotope values relative to the duration (thickness) of the interval showing high (Appalachian) values, which yields a conservative estimate of 1:3, that is, three months on Florida soil and nine months in the Apalachians, with the possibility that the Florida stay was even more brief.

Although UF 150701 died in Florida, we do not know whether it had just arrived, or was about to depart for the north when its stay was indefinitely extended. Nothing within this range of possibilities, however, is compatible with it having experienced its last episode of reduced rate of dentin apposition on Florida soil, because that episode, together with its last drought, and its last time of nutritional stress, occurred four to six months prior to death. The events that mark its “New Year’s Eve” must therefore have taken place in the Apalachians (reducing geography in this binary fashion), and must have in some sense been a prelude to its trip south.

This interpretation clearly requires testing, but even if it is corroborated, multiple scenarios may explain the patterns observed. Perhaps mastodons such as this one stayed in the north until the developing dry season began to compromise seriously the availability or quality of vegetation, or the availability of water in upland areas. They may have then started south, remaining under some nutritional stress (high nitrogen values) along the way, until resources of the coastal area became available. Within a short time of their arrival, however, the seasonal cycle brought amelioration of conditions in the north, allowing their return to what may have been, for them, more generally productive habitat.

We have also considered the possibility that the depression in tusk growth rate does not reflect poor conditions in one area (drought in the north), leading to a subsequent migration, but rather, that it reflects the migration itself. If this were a “forced march” southward, there might be limited opportunity to forage along the way, but the presence of only one episode of reduced rate of dentin apposition per year (and per migratory round trip) suggests that the return northward was less demanding. If the depression in tusk growth rate were a “forced march” northward, there would be inadequate time prior to death to “squeeze in” nine months of Appalachian strontium. The “forced march southward” model may be worthy of additional consideration, but it is only marginally compatible with the constraints suggested by our assumptions. That is, if migration occurred four to six months prior to death, and the stay in Florida was only three months in duration, this animal should not have been where he was, when he was. If subsequent analyses indicate that some of these constraints need to be relaxed, the “forced march southward” model could regain some standing, but at present, we prefer “drought in the north”.

Another approach to evaluating these hypotheses would be to consider the Aucilla River mammoths. If the depression in tusk growth rate reflects migration, and Aucilla mammoths were sedentary, as their low strontium values suggest (Hoppe *et al.*, 1999), we would not expect mammoths to show the growth rate reduction observed here. If mammoths do show the same pattern of tusk growth, without encountering higher strontium values, then either growth rate depression is something other than migration (e.g. dry-season forage reduction) or mammoths migrated, but stayed within the coastal strontium province.

12.5 Conclusions

Records of tusk growth and compositional profiles for almost five and a half years of an adult male, late Pleistocene mastodon from northwestern Florida portray an animal in good health until the time of its death. Despite living in a relatively low-latitude setting, not far, on a continental scale, from coastal environments, this tusk records annual cycles that include clear, seasonal patterns of variation in tusk growth rate, dentin structure, and isotope composition of phosphate oxygen. These patterns suggest a sub-tropical climate with one moderately severe dry season per year, and a secondary, less severe dry interval, each bracketed by times of relief from moisture stress. The more severe dry season culminated in moderate nutritional stress and reduced tusk growth rate, presumably reflecting limited availability or quality of food and/or water. The animal died at a time in this seasonal cycle that was well removed from the time of most severe conditions. Assuming this animal migrated seasonally to the north, as has been proposed for other mastodons from this site, the time of greatest stress occurred in a location remote from its place of death. Further studies of this and other specimens may determine whether these patterns are typical for this species and region. In addition, comparisons between mastodons and mammoths may help to elucidate how these two proboscidean taxa dealt with their respective environments and with the growing presence of humans in this ecosystem.

12.6 Acknowledgments

We greatly appreciate the opportunity to work on this specimen, thereby extending our own familiarity with these animals and times. David Webb graciously hosted DCF during a visit that initiated this project, and provided encouragement and information toward its completion. Paul Koch and Kathryn Hoppe facilitated the study as well through exemplary generosity with their data, allowing us to develop a much fuller picture of this animal than would have been possible otherwise. Kacey Lohmann and Lora Wingate made the facilities of the University of Michigan Department of Geological Sciences’ Stable Isotope Laboratory available to us, without which we would not have been able to undertake this work. We also owe much to the dedication and care of Scott Beld, research assistant, who produced all thin sections and collected all of the second-order increment thickness data. Bonnie Miljour produced several of the illustrations with her usual skill and speed.

References

Ambrose, S. H., 1998. Implications of 24 controlled diet experiments for diet reconstruction with carbon isotopes of bone collagen & carbonate, *J. Vert. Paleont.* **18**(Suppl. to 3):24A.

Bryant, J. D. and Froelich, P. N., 1995. A model of oxygen isotope fractionation in body water of large mammals, *Geochimica et Cosmochimica Acta* **59**:4523–4537.

Bryant, J. D., Koch, P. L., Froelich, P. N., Showers, W. J., and Genna, B. J., 1996. Oxygen isotope partitioning between phosphate and carbonate in mammalian apatite, *Geochimica et Cosmochimica Acta* **60**:5145–5148.

Dansgaard, W., 1996. Stable isotopes in precipitation, *Tellus* **16**:436–468.

Espinoza, E. O. and Mann, M. J., 1993. The history and significance of the Schreger pattern in proboscidean ivory characterization, *J. Amer. Inst. Conservation* **32**:241–248.

Fisher, D. C., 1987. Mastodont procurement by Paleoindians of the Great Lakes Region: hunting or scavenging? in: *The Evolution of Human Hunting* (M. H. Nitecki and D. V. Nitecki, eds.), pp. 309–421, Plenum Press, New York.

Fisher, D. C., 1988. Season of death of the Hiscock mastodonts, *Bulletin of the Buffalo Society of Natural Sciences* **33**:115–125.

Fisher, D. C., 1990. Age, sex, and season of death of the Grandville mastodont, *Michigan Archaeologist* **36**:141–160.

Fisher, D. C., 1996. Extinction of proboscideans in North America, in: *The Proboscidea: Evolution and Palaeoecology of Elephants and Their Relatives* (J. Shoshani and P. Tassy, eds.), pp. 296–315, Oxford University Press, Oxford.

Fisher, D. C., 2001. Season of death, growth rates, and life history of North American mammoths, in: *Proceedings of the International Conference on Mammoth Site Studies* (D. L. West, ed.), pp. 121–135, University of Kansas Publications in Anthropology **22**, Lawrence.

Fisher, D. C. and Fox, D. L., In press. Season of death of the Dent mammoths: distinguishing single from multiple mortality events, *From the Dent Prairie to the Peaks of the Rockies: Recent Paleoindian Research in Colorado* (R. H. Brunswing and B. L. Pitblado, eds.), pp. 169–208, Colorado University Press.

Fisher, D. C., Fox, D. L., and Agenbroad, L. D., 2003. Season of death of *Mammuthus columbi* from Hot Springs, South Dakota, USA, in: *Advances in Mammoth's Research, Proceedings of the Second International Mammoth Conference, Rotterdam*, 16–20 May 1999 (J. W. F. Reumer, J. de Vos, and D. Mol, eds.), Deinsea **9**:117–133.

Fisher, D. C., Trapani, J., Shoshani, J., and Woodford, M. S., 1998. Schreger angles in mammoth and mastodon tusk dentin, *Curr. Res. Pleistocene* **15**:105–107.

Fox, D. L., 2000. Growth increments in *Gomphotherium* tusks and implications for late Miocene climate change in North America, *Palaeogeography, Palaeoclimatology, Palaeoecology* **156**:327–348.

Grootes, P. M., 1993. Interpreting continental oxygen isotope records, in: *Climate Change in Continental Isotopic Records*, Geophysical Monograph 78 (P. K. Swart, K. C. Lohman, J. McKenzie, and S. Savin, eds.), pp. 37–46, American Geophysical Union.

Hoppe, K. A., Koch, P. L., Carlson, R. W., and Webb, S. D., 1999. Tracking mammoths and mastodons: reconstruction of migratory behavior using strontium isotope ratios, *Geology* **27**:439–442.

Iacumin, P., Bocherens, H., Mariotti, A., and Longinelli, A., 1996. Oxygen isotope analyses of co-existing carbonate and phosphate in biogenic apatite: a way to monitor diagenetic alteration of bone phosphate? *Earth and Planetary Science Letters* **142**:1–6.

Koch, P. L., 1989. Paleobiology of late Pleistocene mastodonts and mammoths from southern Michigan and western New York, Ph.D. dissertation, University of Michigan.

Koch, P. L., 1998. Isotopic reconstruction of past continental climates, *Annual Review of Earth and Planetary Science* **26**:573–613.

Koch, P. L., Fisher, D. C., and Dettman, D. L., 1989. Oxygen isotope variation in the tusks of extinct proboscideans: a measure of season of death and seasonality, *Geology* **17**:515–519.

Koch, P. L., Hoppe, K. A., and Webb, S. D., 1998. The isotopic ecology of late Pleistocene mammals in North America, Part 1. Florida, *Chemical Geology* **152**:119–138.

Kolodny, Y., Luz, B., and Navon, O., 1983. Oxygen isotope variations in phosphate of biogenic apatite, I: fish bone apatite – rechecking the rules of the game, *Earth and Planetary Science Letters* **64**:398–404.

Longinelli, A., 1984. Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research? *Geochimica et Cosmochimica Acta* **48**:385–390.

Luz, B., Kolodny, Y., and Horowitz, M., 1984. Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water, *Geochimica et Cosmochimica Acta* **48**:1689–1693.

Miles, A. E. W. and White, J. W., 1960. Ivory, *Proceedings of the Royal Society of Medicine* **53**:775–780.

O'Neil, J. R., Roe, L. J., Reinhard, E., and Blake, R. E., 1994. A rapid and precise method of oxygen isotope analysis of biogenic phosphate, *Israel Journal of Earth Science* **43**:203–212.

Rozanski, K., Araguás-Araguás, L., and Gonfiantini, R., 1993. Isotopic patterns in modern global precipitation, in: *Climate Change in Continental Isotopic Records*, Geophysical Monograph 78 (P. K. Swart, K. C. Lohman, J. McKenzie, and S. Savin, eds.), pp. 1–36, American Geophysical Union.

Sternberg, L. S. L., Mulkey, S. S., and Wright, S. J., 1989. Oxygen isotope ratio stratification in a tropical moist forest, *Oecologia* **81**:51–56.

Steuber, T., 1996. Stable isotope sclerochronology of rudist bivalves: growth rates and late Cretaceous seasonality, *Geology* **24**:315–318.

Stuart-Williams, H. Le Q. and Schwarcz, H. P., 1997. Oxygen isotopic determination of climatic variation using phosphate from beaver bone, tooth enamel, and dentine, *Geochimica et Cosmochimica Acta* **61**:2539–2550.

Trapani, J. and Fisher, D. C., 2003. Discriminating proboscidean taxa using features of the Schreger Pattern in tusk dentin, *Journal of Archaeological Science* **30**:429–438.

Tudge, A. P., 1960. A method of analysis of oxygen isotopes in orthophosphate – its use in the measurement of paleotemperatures, *Geochimica et Cosmochimica Acta* **18**:81–93.

Yakir, D., 1992. Variations in the natural abundance of oxygen-18 and deuterium in plant carbohydrates, *Plant, Cell and Environment* **15**:1005–1020.

Chapter 13

The Biogeochemistry of the Aucilla River Fauna

KATHRYN A. HOPPE[1] and PAUL L. KOCH[2]
[1]Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305, USA.
[2]Department of Earth Sciences, 1156 High St., University of California, Santa Cruz, Santa Cruz, CA 95064, USA.

13.1 Introduction

Ecosystems in the late Pleistocene differed dramatically from the ones we know today, particularly in their striking diversity and abundance of large mammals. North America alone supported a wide range of now globally or locally extinct taxa, including several families of proboscideans, giant ground sloths, glyptodonts, equids, camelids, and tapir, as well as surviving taxa such as deer and bison (Kurtén and Anderson, 1980). Although reconstructing fossil ecosystems is often problematic, the survival of some Pleistocene species allows us to compare paleobiological reconstructions with modern observations. We can thus assess the precision of any proxy used, which in turn allows us to evaluate the accuracy of paleoecological reconstructions.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 379–401

Accurately reconstructing the biology of extinct taxa is essential not only for assessing paleoecological relationships, but also for evaluating many extinction hypotheses. Historically, two opposing sets of theories have been argued to explain the Pleistocene extinction. One set of theories blames this extinction directly on human hunters (e.g. Churcher, 1980; Martin, 1984), while the other invokes climatic and/or ecological changes associated with deglaciation (e.g. Graham and Lundelius, 1984; Guthrie, 1984). More recently, it has been suggested that extinctions resulted from the combined stress of hunting and ecological changes, some of which may have been indirectly caused by early humans (Owen-Smith, 1988; Haynes, 1991; Miller *et al*., 1999). Researchers on all sides of this debate frequently make complex assumptions about the biology of extinct fauna, many of which cannot be tested using traditional morphological or taphonomic methods.

The Aucilla River fauna, with its abundance of well-preserved specimens from both late glacial and full glacial times, provides an unprecedented opportunity to test several theories about the paleoecology of extinct species. We analyzed the chemistry of tooth enamel from several extinct taxa, including equids, llamas, mammoths, mastodons, and tapir, as well as from deer, which have survived into the present. The stable isotope ratios of carbon ($\delta^{13}C$) were used to reconstruct the diets of each individual and the degree of dietary specialization of each species. Oxygen isotope ratios ($\delta^{18}O$) were used to examine climatic variability. Finally, strontium isotope ratios ($^{87}Sr/^{86}Sr$) were used to examine the migration patterns of mammoths and mastodons.

13.1.1 Carbon Isotopes and Diet

One possible source of environmental stress for herbivores is the disruption of existing floral communities (Graham and Lundelius, 1984; Guthrie, 1984). If extinct fauna had relatively restricted dietary preferences, they may have been subject to dietary stress as a result of these changes (Graham and Lundelius, 1984; King and Saunders, 1984; Miller *et al*., 1999). In order to evaluate this possibility, we must first reconstruct the diets of extinct animals by distinguishing between browsers (animals with diets consisting primarily of trees, shrubs, and/or herbs), grazers (animals with diets consisting of >90% grass), and generalized intermediate feeders. Traditionally, the diets of extinct herbivores have been reconstructed through analysis of tooth morphology and/or comparison with modern analogs. However, such reconstructions may be misleading, especially when applied to taxa that have few modern analogs, such as proboscideans or equids. For example, MacFadden *et al*. (1999) used $\delta^{13}C$ values and tooth microwear to examine the diets of several Miocene equids with high crowned teeth, which are conventionally associated with a grazing diet; they found that some of these equids were browsers or intermediate feeders. Even when analysis of tooth morphology precisely reflects the average diet of a species, it cannot yield information about dietary differences between individuals, or track short-term dietary fluctuations. We therefore used the $\delta^{13}C$ values of tooth enamel to reconstruct the diets of each individual.

The $\delta^{13}C$ value of a herbivore's tooth enamel, which is formed of carbonated hydroxylapatite [$Ca_{10}(PO_4,CO_3)_6(OH,CO_3)_2$], reflects the average $\delta^{13}C$ value of plants consumed during tooth formation (Ambrose and Norr, 1993). The $\delta^{13}C$ value of each plant in turn depends primarily on its photosynthetic pathway (O'Leary, 1981, 1988). Plants with a C_3 metabolism (most trees, herbs, and cool climate grasses) have highly negative $\delta^{13}C$ values, which today average approximately −27 ± 3%. Plants with a C_4 metabolism (warm/dry climate grasses and sedges) display less negative $\delta^{13}C$ values averaging approximately −13 ± 2% (O'Leary, 1981, 1988; Koch *et al*., 1991). A third group of plants, which includes primarily succulents, uses CAM photosynthesis, which yields $\delta^{13}C$ values that vary between these two extremes (Ehleringer, 1989). However, northern Florida was covered with mainly forests and prairies during the glacial (Watts *et al*., 1992; Watts and Hansen, 1994). Thus, only a minor percent of the flora were likely to have been CAM plants.

Since the $\delta^{13}C$ value of tooth enamel directly reflects the average $\delta^{13}C$ value of an herbivore's diet, this proxy can be used to reconstruct that diet (Lee-Thorp and van der Merwe, 1987). In the wild, the $\delta^{13}C$ values of herbivore teeth are fractionated by approximately +13.5% relative to dietary values (Bocherens *et al*., 1996; Cerling *et al*., 1997; Koch, 1998a). Thus, in warm/dry regions the tooth enamel of modern grazers averages approximately 0.5%. Modern browsers typically average −13.5%, whereas mixed-feeders display intermediate values (Lee-Thorp and van der Merwe, 1987, 1991; Bocherens *et al*., 1996; Cerling *et al*., 1997).

However, several additional factors must be considered when using the $\delta^{13}C$ values of teeth to reconstruct the detailed diet of prehistoric herbivores. For example, atmospheric $\delta^{13}C$ values have changed with time, correlating with changes in ice volume (Marino *et al*., 1992). These fluctuations result in corresponding shifts in the $\delta^{13}C$ values of plants and ultimately herbivores. The values of late glacial and full glacial herbivores would thus be shifted by +0.5 to +1.1%, relative to modern animals (Koch *et al*., 1998).

Additionally, the $\delta^{13}C$ values of C_3 plants exhibit systematic differences among and within ecosystems. For example, plants from open habitats display less negative $\delta^{13}C$ values than plants from closed-canopy forests due to differences in light levels and the recycling of respired CO_2 (Vogel, 1978; Medina and Minchin, 1980). The $\delta^{13}C$ values of herbivores reflect these differences; van der Merwe and Medina (1991) found that browsers from dense forests displayed values ~4% more negative than browsers from open woodlands. The $\delta^{13}C$ values of C_3 plants also vary systematically among different life forms (i.e. functional groups). For example, evergreen trees have $\delta^{13}C$ values up to 3% more positive than sympatric deciduous trees, which may be 2–5% more positive than herbs growing at ground level (Medina and Minchin, 1980; Brooks *et al*., 1997). These differences may be reflected in the $\delta^{13}C$ values of browsers that preferentially forage on different plants or at different heights in the canopy. However, such variations are relatively small compared to the difference between C_3 and C_4 vegetation.

13.1.2 Oxygen Isotopes and Environmental Variability

The root causes of many ecological shifts are often thought to be changes in climatic factors such as temperature or the evaporation/precipitation balance. The $\delta^{18}O$ values of herbivore tooth enamel may record such climatic fluctuations; enamel $\delta^{18}O$ values correlate with the values of ingested water, which consists of drinking water and plant water (Ayliffe *et al.*, 1992; Bryant and Froelich, 1995). The $\delta^{18}O$ values of these sources often correlate with those of meteoric water. The $\delta^{18}O$ of meteoric water, in turn, varies on both a geographic and temporal scale. In temperate and high-latitude regions, the mean $\delta^{18}O$ value of meteoric water correlates with mean temperatures, with low $\delta^{18}O$ values in cold regions and high values in warmer regions (Dansgaard, 1964; Rozanski *et al.*, 1993). At each location, the $\delta^{18}O$ of meteoric water also varies seasonally, with low values in cold months and high values in warm months. For example, at Hatteras, NC (the best well-documented site close to Florida), the $\delta^{18}O$ of modern precipitation varies by ~4.5% (Koch, 1989b).

The $\delta^{18}O$ values of plant waters and tissues also vary regionally; plants derive their water from soil moisture, which tracks the $\delta^{18}O$ values of precipitation (Förstel, 1978; DeNiro and Epstein, 1979; Saurer *et al.*, 1997). However, plant waters may be enriched in ^{18}O due to transpiration, with the degree of enrichment varying from ~0%, when relative humidity is high, to >20% when relative humidity is low (Förstel, 1978). Plant tissues also show a slight increase not only in $\delta^{18}O$ values, but also in $\delta^{13}C$ values as conditions become drier (Saurer *et al.*, 1997).

The $\delta^{18}O$ values of tooth apatite will reflect environmental variations in the $\delta^{18}O$ values of meteoric waters and ingested plant waters. Since tooth enamel forms by accretion without remodeling, it can record seasonal variations in the $\delta^{18}O$ values of water (and the $\delta^{13}C$ values of plants) ingested by an animal (Fricke and O'Neil, 1996; Sharp and Cerling, 1998). Isotopic variations in teeth have been used to reconstruct tooth growth rates, as well as seasonal cycles in environmental $\delta^{18}O$ values (Koch *et al.*, 1989; Fisher and Fox, Chapter 12). Comparison of the $\delta^{18}O$ and $\delta^{13}C$ values of a tooth may provide additional information; if relative humidity varied seasonally, or if an animal migrated between relatively wet and dry environments seasonally, then $\delta^{13}C$ values should correlate with $\delta^{18}O$ values. Additionally, intraspecies comparison of bulk enamel $\delta^{18}O$ values may help identify individuals that lived under different climatic regimes. High variability at a site can mean either that the site is time-averaged (e.g. containing a mixture of glacial and interglacial individuals) or that some of the animals at the site are non-residents (Stuart-Williams *et al.*, 1996; Koch *et al.*, 1998).

13.1.3 Strontium Isotopes and Migration

It has been proposed that climatic changes may force animals to alter established movement patterns. Changes in migratory behavior factor into many extinction hypotheses, especially those relating to the extinction of proboscideans. For example, Churcher (1980) suggested that human hunters preyed on mammoths as they crossed natural traps during seasonal migrations of up to 2400 km one way. Additionally, Owen-Smith (1988) and Haynes (1991) proposed that climate/habitat change caused animals to reduce their range sizes, which in turn resulted in an increased vulnerability to human hunters.

If proboscideans migrated in order to escape harsh winters and/or to exploit seasonally available resources (Olivier, 1982; Holman *et al.*, 1988), then climatic changes may have also directly contributed to their extinction. If ecological changes disrupted migration routes, then extinction may have resulted from nutritional stress caused by overfeeding or limited access to resources (Martin and Klein, 1984; Holman *et al.*, 1988). Alternatively, animals may increase their range size when stressed. For example, modern white-tailed deer usually inhabit a home range less than 3.2 km across, but they increase their range size to over 14 km across when environmentally stressed (Marchington and Hirth, 1984). Thus, changes in an animal's movement patterns may correlate with environmental stresses. Reconstructing migration routes and their ecological significance has been difficult because traditional taphonomic methods yield little information about lifetime movement patterns. However, analysis of an animal's $^{87}Sr/^{86}Sr$ ratio may allow us to reconstruct an individual's movements.

An animal's $^{87}Sr/^{86}Sr$ ratio directly tracks the $^{87}Sr/^{86}Sr$ ratios of its environment. When environmental $^{87}Sr/^{86}Sr$ ratios vary regionally, the $^{87}Sr/^{86}Sr$ ratio of tooth enamel may be used to reconstruct an animal's lifetime movement patterns (Hoppe *et al.*, 1999). The $^{87}Sr/^{86}Sr$ ratio of a local environment is a combination of the $^{87}Sr/^{86}Sr$ ratio of material weathered from underlying bedrock and that deposited from atmospheric sources (Miller *et al.*, 1993; Chadwick *et al.*, 1999). Florida and southern Georgia are composed primarily of marine carbonates (Scott, 1992), which have relatively low $^{87}Sr/^{86}Sr$ ratios. Northern Georgia, in contrast, has bedrock composed of igneous and metamorphic rocks, which have relatively high $^{87}Sr/^{86}Sr$ ratios. Measurements of modern plants and small rodents, both of which reflect local $^{87}Sr/^{86}Sr$ ratios, reveal that environmental $^{87}Sr/^{86}Sr$ ratios in this region record patterns in underlying bedrock (Fig. 13.1) (Hoppe *et al.*, 1999). Florida environments display relatively low $^{87}Sr/^{86}Sr$ ratios of 0.7080 to 0.7095, while environments in the Appalachian Mountains, and in parts of central Georgia that are dominated by sediments from the Appalachians, have higher $^{87}Sr/^{86}Sr$ ratios of 0.7110 to 0.7143 (Hoppe *et al.*, 1999). Thus, animals that migrated outside of Florida toward the Appalachian Mountains should display higher $^{87}Sr/^{86}Sr$ ratios than individuals who did not migrate.

Additionally, comparison of microsample $^{87}Sr/^{86}Sr$ ratios and $\delta^{18}O$ values and/or $\delta^{13}O$ values may reveal whether an individual migrated on a consistent, seasonal basis or in a random, nomadic fashion. Since the $\delta^{18}O$ values of tooth enamel vary seasonally, seasonal migrations should produce $^{87}Sr/^{86}Sr$ ratios that correlate strongly with $\delta^{18}O$ values. Nomadic migrations, on the other hand, would produce no correlation between $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values. Seasonal migrations might also produce a correlation of $^{87}Sr/^{86}Sr$ ratios with $\delta^{13}C$ values, but such a correlation would only appear if an animal moved between ecosystems with different plants or different plant $\delta^{13}C$ values (Koch *et al.*, 1995).

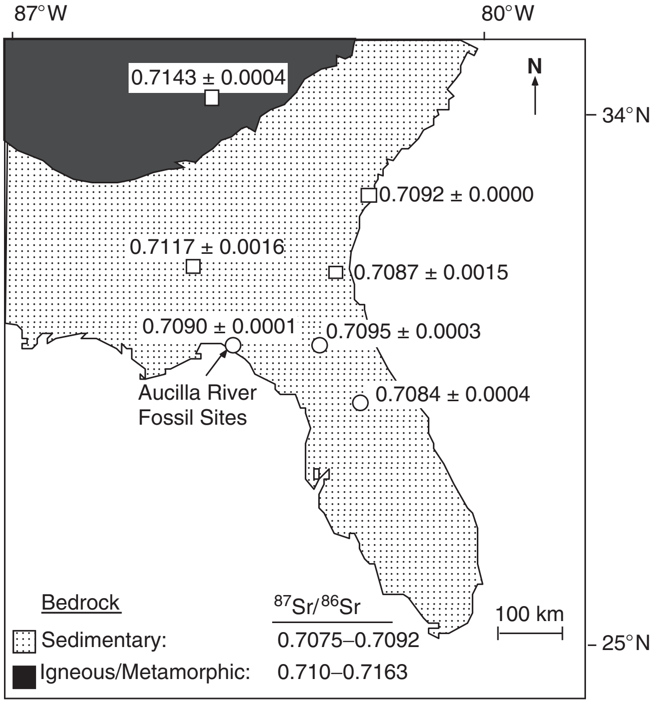


Figure 13.1 Distribution of environmental $^{87}Sr/^{86}Sr$ ratios across modern Florida and Georgia. Numbers represent the average ratios at each site ± one standard deviation. Modern plants (circles); modern rodents, *Sigmodon hispidus* (squares).

13.2 Materials and Methods

13.2.1 Localities

All specimens analyzed were recovered from four fossil quarries along the bottom of the Aucilla River. While all of these sites date between ~11,000 and ~40,000 radiocarbon years before present (RCYBP), the degree of chronological control varies from site to site. The Page-Ladson quarry yielded the largest number of fossil specimens with good chronological control (see Chapter 4, this volume). Page-Ladson specimens range in age from ~12,000 to ~15,000 RCYBP. Specimens recovered from the Latvis-Simpson quarry range in age from ~25,000 to ~32,000 RCYBP. Unfortunately, fossils from the Little River Rapids quarry and the Sloth Hole quarry were not recovered from well-stratified units. While some fossils were individually radiocarbon dated, and thus known to be late glacial in age (Table 13.1), the majority of these samples may range in age from ~11,000 to ~40,000 RCYBP. A final group of samples, consisting exclusively of Proboscidean teeth, were obtained from the

Ohmes Collection of the Florida Natural History Museum. This collection consists of a mixture of specimens retrieved from surface deposits near the Page-Ladson and Sloth Hole quarries and are believed to range in age from ~11,000 to ~40,000 RCYBP.

13.2.2 Sample Collection

We analyzed bulk tooth enamel from 69 specimens collected from the Aucilla River. We sampled bulk enamel from extinct species including mammoth (*Mammuthus columbi*), mastodon (*Mammut americanum*), tapir (*Tapirus veroensis*), horse (*Equus* sp.), and llama (*Palaeolama mirifica* and *Hemiauchenia macrocephala*), as well as from white-tailed deer (*Odocoileus virginianus*), which survive into modern times. These bulk samples reflect the average isotopic composition of each tooth (Koch *et al*., 1998). We also microsampled one mastodon and one mammoth molar to examine a time series of isotopic variations across approximately two years and one year of growth, respectively. Microsamples were milled from petrographic thin sections using a Lohmann Computerized Microsampler. Each mastodon microsample was collected from a groove (~0.15 mm deep, ~0.12 mm wide, and ~5.0 mm long) milled parallel to growth increments, although some of these samples had to be combined to obtain enough material for analysis of carbon and oxygen isotope ratios. Mammoth microsamples were also collected from grooves (~0.17 mm deep, ~0.06 mm wide, and ~5.0–15.0 mm long) milled parallel to growth increments.

13.2.3 Analytical Methods

Carbon and oxygen samples were prepared according to the methods described in Koch *et al*. (1998), then analyzed on a VG Optima or a Prism gas source mass spectrometer with an ISOCARB automated carbonate system. Dissolution of samples was achieved by reaction in a constantly stirred bath of 100% phosphoric acid at 90°C. Reaction time for each sample was greater than 5 min. Precision for analysis of calcite standards was ≤0.2% for $\delta^{13}C$ and $\delta^{18}O$. Replicate analysis of enamel samples ($n = 23$) differed by 0.12 ± 0.10% (mean ± 1σ) for carbon and 0.14 ± 0.12% for oxygen.

Strontium samples were prepared for analysis according to methods described in Hoppe *et al*. (1999) and measured on either a VG 354 or a VG 354-S thermal ionization mass spectrometer. All measurements are referenced to a value of $^{87}Sr/^{86}Sr$ = 0.71025 for the NBS 987 Sr standard and are precise to within ±0.00005.

Data were analyzed statistically with an F-test to confirm that there were no significant differences in the variance of values for each species. We then used one-way analysis of variance (ANOVA) to examine significant differences among mean values for each species. Finally, we used Scheffé's test to identify the sources of significant difference among mean values (Norman and Streiner, 1992).

13.3 Results

13.3.1 Carbon Isotopes

Because temporal changes in $\delta^{13}C$ values of the atmosphere could cause fluctuations between the $\delta^{13}C$ values of animals consuming the same diet, we focused primarily on comparison among specimens that were known to be of approximately the same age. The largest group of fossils were late glacial, ~12,000–15,000 RCYBP (Table 13.1). The second group of fossils was full glacial in age (~25,000–32,000 RCYBP). The final group of specimens, which consists almost entirely of proboscideans, ranges in age from ~11,000 to ~40,000 RCYBP.

Table 13.1 Isotopic ratios of bulk tooth enamel samples

Age	*Site*[1]	*Sample*	*Taxon*	$\delta^{13}C$[2]	$\delta^{18}O$[2]	$^{87}Sr/^{86}Sr$[3]
12–15K						
	PL	92513	*Tapirus*	*–12.0*	*27.2*	*0.7087*
	PL	92568	*Tapirus*	*–11.3*	*26.3*	*0.7087*
	LRR	180216	*Tapirus*	–13.5	29.3	
	LRR	200680	*Tapirus*	–11.4	29.7	
	PL	92522	*Odocoileus*	*–11.5*	*26.2*	*0.7097*
	PL	92563	*Odocoileus*	*–13.3*	*28.7*	*0.7086*
	PL	147359	*Odocoileus*	–15.9	30.6	*0.7092*
	PL	147362	*Odocoileus*	–14.1	28.7	*0.7092*
	PL	147364	*Odocoileus*	–13.6	29.9	*0.7094*
	PL	147365	*Odocoileus*	–14.6	29.1	*0.7087*
	PL	150249	*Odocoileus*	–13.0	28.0	*0.7087*
	PL	150470	*Odocoileus*	–13.8	28.6	*0.7108*
	PL	151916	*Odocoileus*	–14.7	28.4	*0.7087*
	PL	151917	*Odocoileus*	–14.2	32.1	*0.7091*
	PL	151941	*Odocoileus*	–10.9	31.7	*0.7093*
	PL	151942	*Odocoileus*	–13.8	27.8	*0.7089*
	PL	146914	*Hemiauchenia*	–12.8	32.5	
	PL	92512	*Palaeolama*	–12.4	32.5	
	PL	180214	*Palaeolama*	–14.9	32.0	
	PL	148670	*Equus*	–5.6	29.5	
	PL	14780	*Mammuthus*	0.5	31.1	*0.7089*
	LRR	200655	*Mammuthus*	0.5	33.5	*0.7095*
	PL	103505	*Mammut*	*–10.0*	*29.2*	*0.7099*
	PL	130570	*Mammut*	*–12.2*	*30.2*	*0.7101*
	PL	147400	*Mammut*	–10.7	30.1	
	PL	148668	*Mammut*	*–11.0*	*28.8*	*0.7114*
	PL	148669	*Mammut*	*–10.3*	*29.8*	*0.7101*
	PL	150775	*Mammut*	–11.9	30.2	*0.7101*
	PL	192224	*Mammut*	–9.8	30.7	*0.7097*
	PL	192226	*Mammut*	–10.3	31.4	0.7112
	SH	200681	*Mammut*	–11.6	29.1	
16K	3B	14779	*Mammuthus*	–0.2	30.6	0.7095
25–32K						
	LS	200673	*Equus*	–4.7	31.9	

Age	*Site*[1]	*Sample*	*Taxon*	$\delta^{13}C$[2]	$\delta^{18}O$[2]	$^{87}Sr/^{86}Sr$[3]
	LS	200674	*Equus*	–6.0	30.5	
	LS	200675	*Equus*	–4.4	32.34	
	LS	200668	*Tapirus*	–13.4	28.4	
	LS	200670	*Tapirus*	–13.5	28.3	
	LS	200651	*Odocoileus*	–14.5	27.6	
	LS	200652	*Odocoileus*	–13.3	27.9	
	LS	200653	*Odocoileus*	–14.5	31.9	
	LS	200654	*Odocoileus*	–15.1	29.4	
	LS	200657	*Odocoileus*	–15.6	28.5	
	LS	180220	*Mammut*	–10.7	29.8	
	LS	200666	*Mammut*	–11.2	30.6	
	LS	200667	*Mammut*	–11.2	30.4	
11–40K						
	SH	200678	*Palaeolama*	–13.4	30.7	
	OC	135730	*Mammuthus*	–0.5	32.4	
	OC	135731	*Mammuthus*	–2.4	30.6	
	OC	135732	*Mammuthus*	–1.2	31.1	
	OC	135733	*Mammuthus*	–3.8	30.4	
	OC	135734	*Mammuthus*	–2.5	31.4	
	OC	135737	*Mammuthus*	–0.6	31.1	
	OC	135738	*Mammuthus*	–0.3	33.6	
	SH	200662	*Mammuthus*	1.4	32.5	
	SH	200663	*Mammuthus*	–1.3	32.0	
	SH	47995a	*Mammuthus*	–4.9	29.4	
	SH	47995b	*Mammuthus*	–1.6	31.4	
	OC	135701	*Mammut*	–10.2	30.5	
	OC	135702	*Mammut*	–11.9	29.9	
	SH	200656	*Mammut*	–12.2	30.5	
	SH	200658	*Mammut*	–11.8	31.3	
	SH	200659	*Mammut*	–12.6	30.0	
	SH	200660	*Mammut*	–11.5	29.5	
	SH	200661	*Mammut*	–10.6	31.4	
	SH	200664	*Mammut*	–11.9	31.3	
	SH	200665	*Mammut*	–11.0	30.3	
	SH	200676	*Mammut*	–11.4	30.1	
	SH	200677	*Mammut*	–12.3	31.7	
	LRR	200679	*Mammut*	–10.5	30.7	

[1] Site names abbreviated as follows: PL = Page-Ladson, LRR = Little River Rapids, SH = Sloth Hole, LS = Latvis-Simpson, OC = Ohmes Collection.

[2] Numbers in italics previously published in Koch *et al*. (1998).

[3] Numbers in italics previously published in Hoppe *et al*. (1999).

We compared bulk $\delta^{13}C$ values of late glacial deer, an equid, mammoths, mastodons, tapir, and two species of llamas (Table 13.1, Fig. 13.2). However, due to the small number of llamas available, results from both species were combined for the purposes of statistical analyses. Late glacial mastodons, deer, tapir, and llamas all displayed highly negative $\delta^{13}C$ values characteristic of animals that feed primarily on C_3 vegetation. Deer had the lowest mean value, followed by llamas, then tapir, and finally mastodons. ANOVA analysis of these browsing taxa demonstrated that differences in the mean $\delta^{13}C$ values of species were significant ($F_{3,24} = 10.2$, $p < 0.001$), but pair-

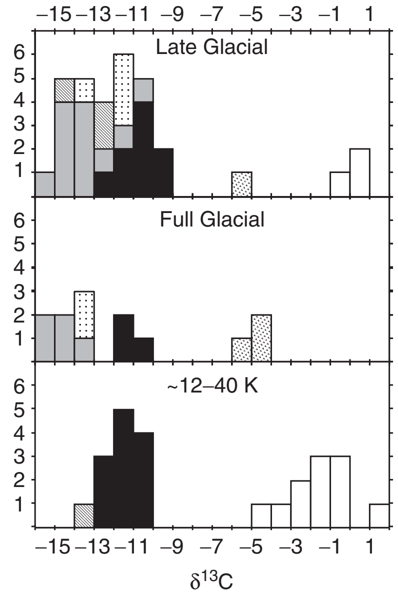


Figure 13.2 Histograms of bulk $\delta^{13}C$ values (PDB) of tooth enamel of species during each time slice: ■ Mastodons; □ mammoths; ▩ deer; ⬚ tapir; ▧ camelids; ▒ equids.

wise comparisons indicated that the only significant differences were between mastodons and deer and mastodons and llamas (Scheffé's test, $p < 0.05$). Pair-wise comparisons of the variance of $\delta^{13}C$ values for each species revealed no significant differences (F-test, $p > 0.05$). Both mammoths and the equid displayed $\delta^{13}C$ values that were significantly higher than the values of other animals ($F_{5,25} = 59.4$, $p = 0.0001$). Mammoths displayed the most positive $\delta^{13}C$ values, which were indicative of a diet consisting almost exclusively of C_4 grasses. The equid displayed a $\delta^{13}C$ value indicative of a mixed-diet consisting of both C_3 and C_4 vegetation.

Fewer individuals from full glacial times (~25,000–32,000 RCYBP) were available for study; however, similar patterns were observed for all taxa present (Table 13.1, Fig. 13.2). No significant differences in variance were found among species (F-test, $p < 0.05$). Once again deer had the most negative mean $\delta^{13}C$ values, followed by tapir, mastodons, and then equids. Differences among mean values for browsing taxa were significant ($F_{2,7} = 26.7$, $p < 0.001$). Mean values for mastodons were significantly different from values for both deer and tapir (Scheffé's test, $p < 0.05$), but mean values for deer and tapir were not significantly different from one another (Scheffé's test, $p > 0.05$). No mammoths were available from this time period, but the equids displayed $\delta^{13}C$ values that were significantly different from all other taxa ($F_{3,9} = 118.9$, $p = 0.0001$) and are intermediate between values expected for a pure C_3 browser and a C_4 grazer (Fig. 13.2).

The final group of specimens, which range from full glacial to late glacial in age, consisted of proboscideans and one llama (Table 13.1, Fig. 13.2). The llama and mastodons displayed negative $\delta^{13}C$ values indicative of animals that fed only on C_3 vegetation. The $\delta^{13}C$ value of the llama was more negative than any values displayed by mastodons. Mammoths displayed mean $\delta^{13}C$ values indicative of animals that fed primarily on C_4 vegetation mixed with the consumption of some C_3 vegetation (Fig. 13.2).

The patterns observed between the $\delta^{13}C$ values of each taxon appear to remain consistent with time. We tested for temporal changes by comparing the $\delta^{13}C$ values of deer, equids, mastodons, and tapir between full and late glacial times. None of these taxa displayed significant temporal differences in either mean values or variance ($p > 0.05$). While no mammoths or llama definitively full glacial in age were available for analysis, we compared mammoths and llama of indeterminate age with their late glacial counterparts. Differences in mean values were not significant ($p > 0.5$), but late glacial mammoths did have significantly lower variance than the mammoths of indeterminate age (F-test, $p < 0.05$). This may be an artifact of the small sample size ($n = 2$) of late glacial mammoths or a real difference among individual mammoths. Mastodons of indeterminate age were not significantly different from either their late glacial or full glacial counterparts ($F_{2,20} = 0.36$, $p > 0.5$; F-test, $p > 0.5$).

In addition to examining bulk samples, we also analyzed microsamples from one late glacial mastodon and one mammoth (~15,910 ± 160 RCYBP). The $\delta^{13}C$ values of microsamples displayed less variation than the range of values for bulk samples of the corresponding species (Table 13.1, Fig. 13.3). The mastodon microsamples were relatively negative, ranging from –9.8% to –11.3%, while mammoth microsamples were more positive, ranging from –0.4% to –1.6%. Variations between high and low $\delta^{13}C$ values were not obviously cyclic in either animal.

13.3.2 Oxygen Isotopes

Since an animal's $\delta^{18}O$ values change as environmental conditions vary, we again conducted interspecies comparisons only on individuals of approximately the same age. Samples were divided into time slices as discussed above. However, statistical analysis revealed few significant differences among species, perhaps due to the relatively high intraspecies variability (Fig. 13.4). For example, late glacial individuals display relatively high intraspecies variability (>2%) for all taxa except llamas (range = 0.5%). Only differences between the mean value of llamas and tapir were significant ($F_{5,25} = 5.1$, $p < 0.05$; Scheffé's test, $p < 0.05$), although the difference in the mean values of llama and deer was almost significant (Scheffé's test, $p = 0.05$). No llama specimens known to be full glacial in age were available to test whether this pattern was robust. However, mean $\delta^{18}O$ values for species with numerous individuals from both the full glacial and the late glacial display remarkably little difference. Deer, tapir, and mastodons displayed less than 0.5% difference in mean values, while the late glacial equid was ~1% lower than any of its full glacial counterparts. None of these differences was significant ($p < 0.05$).

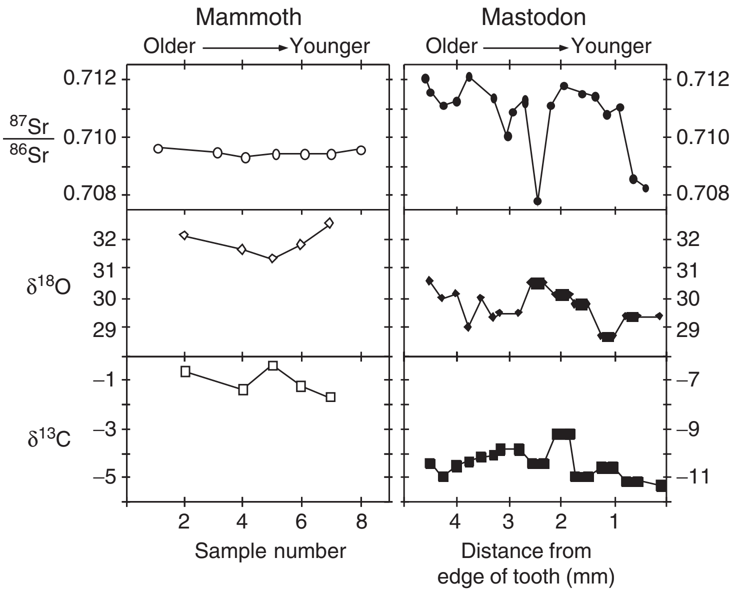


Figure 13.3 Analysis of ^{87}Sr/^{86}Sr ratios (circles), δ^{13}C values (squares), and δ^{18}O values (diamonds) of microsamples from mammoth sample 14779 (open symbols) and mastodon sample 148668 (closed symbols).

We also examined seasonal variations in environmental δ^{18}O values through analysis of the δ^{18}O values of mammoth and mastodon microsamples (Fig. 13.3). While values for mastodon microsamples were relatively homogenous (range = 1.8%), they nonetheless appeared to cycle twice in a systematic fashion from high to low δ^{18}O values. Mammoth microsamples appeared to cycle once from high to low values, although they have an even lower range of ~1.2%.

13.3.3 Strontium Isotopes

Due to the cost and time involved in measuring strontium isotope ratios, we concentrated primarily on samples from the late glacial, with the addition of one mammoth of known age (15,910 ± 160 RCYBP) (Table 13.1, Fig. 13.5). We examined not only proboscideans, which may have been migratory, but also deer and tapir, which presumably did not migrate. While the ^{87}Sr/^{86}Sr ratios of bulk samples revealed significant difference among the mean values of each species ($F_{3,18}$, $p < 0.01$), pair-wise comparisons revealed no significant differences among deer, tapir, and mammoths (Scheffé's test, $p > 0.05$). The ^{87}Sr/^{86}Sr ratios of these species were all low and were similar to the ^{87}Sr/^{86}Sr ratios of modern plants from the Aucilla River and other sites within Florida (Fig. 13.5). In contrast, bulk samples from mastodons displayed high

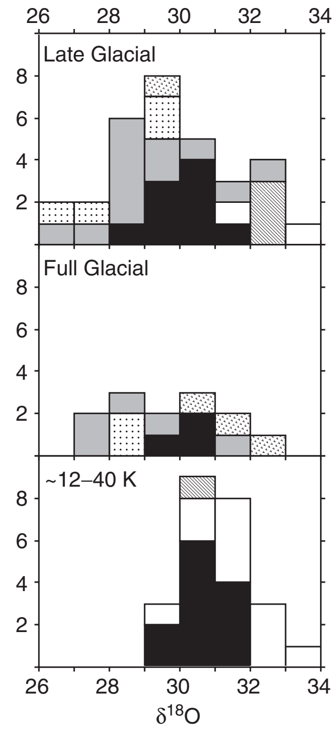


Figure 13.4 Histograms of bulk $\delta^{18}O$ values (SMOW) of tooth enamel of species during each time slice; ■ Mastodons; □ mammoths; ▩ deer; □ tapir; ▨ camelids; ⊡ equids.

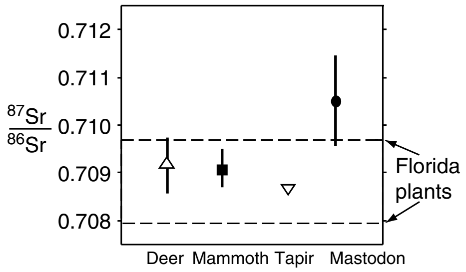


Figure 13.5 Average $^{87}Sr/^{86}Sr$ ratios of bulk samples from mastodons (circle), mammoths (square), deer (up-pointing triangle), and tapir (down-pointing triangle). Lines represent calculated ±1 standard deviation from average values for each species with over three individuals, or the range of sample values when only two individuals were available.

$^{87}Sr/^{86}Sr$ ratios that were significantly different from the mean values of resident species (Scheffé's test, $p < 0.05$) and were higher than the highest value observed for Florida plants. Mastodon microsamples displayed values (0.7078–0.7121) that exceeded the range of values observed in all bulk samples (Fig. 13.3). Microsample $^{87}Sr/^{86}Sr$ ratios varied systematically and repeatedly from high to low values. In contrast, mammoth microsamples displayed uniformly low $^{87}Sr/^{86}Sr$ ratios with a homogeneous distribution (0.7094–0.7096) and no obvious cycles.

13.4 Discussion

13.4.1 Paleodiets

Most of the Aucilla River mammals examined here appear to have been browsers; the highly negative $\delta^{13}C$ values of deer, llamas, tapir, and mastodon indicate that these animals consumed C_3 vegetation. Although a diet of C_3 grasses will also produce similarly negative $\delta^{13}C$ values, it seems unlikely that such grasses composed a significant part of these animals' diets. The positive $\delta^{13}C$ values displayed by mammoths demonstrate that C_4 grasses were abundant in this region, at least during late glacial times.

The accuracy of our dietary reconstruction can be easily confirmed for white-tailed deer. Modern observations show that white-tailed deer are indeed primarily browsers (Krausman and Ables, 1981). While corroborating evidence on the diets of extinct animals is less direct, it nonetheless also supports our interpretations. For example, observations of *Tapirus indicus*, which is closely related to the extinct *Tapirus veroensis*, have shown that modern tapir are primarily browsers (Williams and Petrides, 1980). While this analogy supports our reconstruction of the diets of *Tapirus veroensis*, it is best to compare individuals from several sites when attempting to reconstruct the dietary range of a species. Comparison of our results with previous measurements of tapir from Pleistocene sites across Florida (MacFadden and Cerling, 1996; Koch *et al.*, 1998) revealed that all individuals displayed similar, extremely negative values. It therefore seems likely that all Pleistocene tapir, like their modern relatives, were specialized browsers.

A more unusual source provides confirmation of the diets of mastodons. Deposits of mastodon digesta from Page-Ladson also suggest that mastodons consumed primarily browse (Webb *et al.*, 1992). Analysis of digesta may also reveal why the mean $\delta^{13}C$ values of mastodons were significantly more positive (by ~1–3%) than the values displayed by other browsing taxa. Such a difference could potentially result from several factors; mastodons may have preferentially foraged in different habitats, consumed vegetation from a higher level in the canopy, and/or their diet may have consisted of up to 20% C_4 plants (Koch *et al.*, 1998). However, digesta deposits suggest another explanation. They consisted primarily of C_3 vegetation, and evergreen trees were the most abundant component identified (Webb *et al.*, 1992). If mastodons preferentially consumed evergreen foliage, as has been suggested by others (e.g. King and

Saunders, 1984), then their $\delta^{13}C$ values would have been more positive than values of sympatric browsers that consumed deciduous vegetation. Analyses of microsamples provide additional insight into mastodon diets. Modern elephants have been observed to switch seasonally between grazing and browsing as the nutritional content of grasses changes (Sikes, 1971). If mastodons indeed supplemented a diet of browse with some C_4 grasses, then they would have likely done so on a seasonal basis. Such behavior would produce seasonal variations in the $\delta^{13}C$ values of a tooth. However, the $\delta^{13}C$ values of mastodon microsamples revealed little variation and no apparent cycles, suggesting that mastodon diets did not vary in a set seasonal pattern.

Reconstructing the diets of the two Aucilla River llama species, *Palaeolama* and *Hemiauchenia*, was less straightforward. Although $\delta^{13}C$ values suggested that all Aucilla River llamas consumed C_3 vegetation, observations have shown that their closest living relatives (animals in the genus *Lama*) are grazers or mixed-feeders (Nowak, 1991). However, analyses of premaxillary dimensions suggest that *Palaeolama* and *Hemiauchenia* were browsers or intermediate feeders (Dompierre and Churcher, 1996). Geochemical analyses of *Hemiauchenia* have been scarce. The isotopic signature of one individual from Florida yielded a positive $\delta^{13}C$ value indicative of a C_4 grazer in the previous study by MacFadden and Cerling (1996), in contrast to the highly negative value displayed by the individual analyzed in this study. A fuller range of samples was analyzed by Feranec and MacFadden (2000). The wider range of $\delta^{13}C$ values resulting from their study suggests that *Hemiauchenia* may have been a generalized feeder, but progressively through the Plio-Pleistocene switched from more browse to feeding more on grass.

Palaeolama has been more extensively studied. Not only were we able to analyze several individuals, but the taxon has also been examined from sites in Bolivia (MacFadden and Cerling, 1996) and Texas (Koch, 1998). All individuals of this taxon display highly negative $\delta^{13}C$ values, despite the regional abundance of C_4 grasses. This suggests that all these *Palaeolama* were indeed specialized browsers as also suggested by Webb and Stehli's (1995) functional analysis of the incisors and cheek teeth.

In contrast to the majority of animals recovered from the Aucilla River, mammoths and equids appear to have consumed a high proportion of C_4 foliage. Mammoths display the most positive $\delta^{13}C$ values; indeed, we can calculate that individuals from the late glacial consumed >90% C_4 vegetation (Koch *et al.*, 1998). Calculations of the amount of C_4 vegetation consumed by the other mammoths analyzed are less precise because their ages are not well known and thus corrections for the exact $\delta^{13}C$ value of atmospheric CO_2 cannot be precise (Koch *et al.*, 1998). Nonetheless, we estimate that the majority of mammoths consumed at least ~80% C_4 vegetation, although one individual appears to have consumed only ~54–58% C_4 vegetation. The observed variations may reflect increased consumption of either browse or C_3 grasses, which increase proportionally as climatic conditions become cooler or wetter (Teeri and Stowe, 1976). The lack of chronological control makes it difficult to distinguish between these two possibilities. However, analysis of mammoth microsamples confirms that dietary $\delta^{13}C$ values of an individual mammoth were relatively homogenous over the course of a year. Thus, the observed variations in the bulk $\delta^{13}C$ value of mammoths do not appear to reflect seasonal shift in diets to include more browse. Additionally, previous analyses of mammoths from across the southwest suggest that mammoths were primarily grazers, as their $\delta^{13}C$ values correlate with shifts in the percentage of C_3 versus C_4 grasses (Connin *et al.*, 1998). It therefore seems likely that the range of $\delta^{13}C$ values displayed by the Aucilla River mammoths reflects temporal changes in the local abundance of C_3 versus C_4 grasses.

Although equids also display $\delta^{13}C$ values that suggest consumption of C_4 grasses, they appear to have also consumed ~40–60% C_3 vegetation. While this vegetation may have been either C_3 browse or grass, the positive $\delta^{13}C$ values of mammoths suggest that C_4 grass composed ≥90% of the regional grass biomass during the late glacial. It therefore seems unlikely that diet of late glacial equids consisted of ≥40% C_3 grass. Additionally, previous analyses of equids have revealed a wide range of $\delta^{13}C$ values even when C_4 grass was regionally abundant (Connin *et al.*, 1998; Koch, 1998). This suggests that Pleistocene equids were mixed-feeders that consumed both grass and C_3 browse.

Overall the Aucilla River fauna appears to have contained animals that employed a variety of dietary strategies. Some species were specialists, primarily consuming either C_3 browse (i.e. deer, mastodons, tapir, and *Palaeolama*) or C_4 grass (i.e. mammoths). Other taxa may have been generalists (i.e. equids and *Hemiauchenia*). While some specialized feeders may have been nutritionally stressed by change in the local flora, it seems unlikely that all members of the Aucilla River fauna would experience dietary stress during the same floral reorganization. Additionally, the $\delta^{13}C$ values of browsers remain constant between the full and late glacial, suggesting that these taxa consumed the same diets during both time periods. It therefore seems unlikely that dietary stress played a significant role in the extinction of browsing species. However, additional work is needed to constrain the ages of the mammoths sampled in order to determine whether the same trend holds true for animals that consumed a large percentage of grass.

13.4.2 Oxygen Isotopes

The bulk $\delta^{18}O$ values of the Aucilla River fauna yielded few distinct patterns; the variation displayed within each species was generally greater than that displayed among species. Although the $\delta^{18}O$ values of animals often correlate with the values of local meteoric waters (Ayliffe *et al.*, 1992; Bryant and Froelich, 1995; Bryant *et al.*, 1996), other factors likely influenced the $\delta^{18}O$ values displayed by taxa from Aucilla River. For example, animals could display different $\delta^{18}O$ values depending on their body mass, their reliance on ingested plant water, and/or the type of plants in their diet (Förstel, 1978; Sternberg et al., 1984; Bryant and Froelich, 1995). Additionally, most individuals recovered were time-averaged over several thousand years, at least. Thus, the $\delta^{18}O$ values of the waters ingested by each individual may have varied with climatic fluctuations. Given these potential sources of variation, it is perhaps surprising that a significant difference in mean $\delta^{18}O$ values was found between llamas and tapir.

This result may have been an artifact of the small number of llamas ($n = 3$) and tapir ($n = 4$) analyzed. However, the fact that deer ($n = 12$) had a mean value that was almost significantly different from those of llamas suggests that llama may have been behaviorally or metabolically different from other taxa. Extinct llamas, like some of their modern relatives, may have been adapted to water-stressed conditions and thus satisfied their water requirements with a higher percentage of plant water, which could increase their δ^{18}O values relative to other taxa.

Due to such potential interspecies variations in δ^{18}O values, it is best to compare only intraspecies changes when reconstructing long-term (i.e. glacial to interglacial) changes in the δ^{18}O values of the local environment. Ideally, changes in the mean δ^{18}O value of precipitation would be recorded by corresponding offsets in the mean δ^{18}O value of several species. However, mean δ^{18}O values from full glacial and late glacial species do not display any significant differences or even a consistent direction of change. Yet other climatic proxies suggest that climate and the δ^{18}O values of precipitation in this region changed significantly between the full and late glacial. For example, pollen records suggest that Florida was much wetter during the late glacial than full glacial times (Watts and Hansen, 1994). Additionally, measurements of the Floridian aquifer show that groundwaters from the full glacial were ~2% enriched in δ^{18}O relative to Holocene groundwaters (Plummer, 1993). Thus, it seems that the mean δ^{18}O values of the Aucilla River taxa did not track long-term changes in the δ^{18}O values of regional waters. Long-term changes in the δ^{18}O values of precipitation may be overprinted by variation in the fractionation of δ^{18}O values among species and/or short-term changes in the δ^{18}O values of local waters.

Although bulk samples appeared not to reflect long-term climatic changes, microsamples may reflect seasonal changes in the δ^{18}O values of local waters. The δ^{18}O values of both the mastodon and mammoth show variations that appear to reflect annual cycles. However, the amplitudes of these signals are relatively low (~1.8% and ~1.2%, respectively) compared to expected seasonal variations in meteoric water (e.g. ~4.5% in modern Hatteras, NC). Since climate models and other proxy data suggest that seasonal temperature differences in the Northern Hemisphere were greater than modern at 12,000 BP (Kutzbach *et al.*, 1993), we would expect variations in the δ^{18}O values of local waters likewise to be greater. This suggests that seasonal variations are attenuated in mammoth and mastodon molars. This may have resulted from homogenization of local waters before ingestion and/or mixing of material from different seasons during microsampling. Attenuation of potential seasonal differences in the δ^{18}O values of body water may also be the result of a long lag time between initiation and finalization of enamel formation in proboscideans (Fisher and Fox, 1998).

Despite the fact that microsamples may not accurately record the absolute values of seasonal variation in local δ^{18}O values, the preservation of seasonal cycles in tooth enamel is still of potential interest in determining growth rates and defining season of deposition. The cycle of δ^{18}O observed in the mammoth suggests that these samples represent approximately one year of growth, while the repeated pattern displayed by mastodon microsamples samples suggests that these samples represent approximately two years of growth.

13.4.3 Migration Patterns

Most animals restrict their lifetime movements to a limited area, or home range, although they may also disperse in a permanent one-way move to a new home range. However, some animals move repeatedly throughout life. Movements that are repeated in the same pattern each year are defined as seasonal migrations, while movements that occur in a less regular fashion are defined as nomadic migrations. Bulk samples of strontium isotopes can be used to identify animals that moved outside of a local area, but may not distinguish between different migration patterns. Analysis of microsamples allows more precise reconstruction of the timing and extent of movement. We presented a more detailed discussion of the implications of $^{87}SR/^{86}SR$ ratios in animals from the Aucilla River in Hoppe *et al.* (1999). Here we present a summary of that work and incorporate the results of several additional measurements.

Predictions regarding the range size of the smaller taxa can be made based on direct observations of modern deer and tapir, both of which typically range over an area less than 10 km in diameter (Williams, 1979; Marchington and Hirth, 1984). We would thus expect Pleistocene deer and tapir to range only locally, and indeed the relatively low $^{87}Sr/^{86}Sr$ ratios measured for deer and tapir confirm that the majority of these individuals did not range outside of the Florida region.

More surprisingly, mammoths also display low $^{87}Sr/^{86}Sr$ ratios, suggesting that they stayed within the Florida region. Because the coastal plain environments have a relatively uniform distribution of $^{87}Sr/^{86}Sr$ ratios, mammoths may have moved large distances (250 or 500 km) without encountering high environmental $^{87}Sr/^{86}Sr$ ratios. However, microsamples from one mammoth display much less variability than is found within local Florida environments. It thus appears that this individual, at least, did not move large distances.

In contrast, the elevated $^{87}Sr/^{86}Sr$ ratios of mastodons suggest that they did migrate outside of Florida. They would have had to travel north ~250 km to reach environments with high $^{87}Sr/^{86}Sr$ in the Appalachian Mountains. However, if mastodons traveled along the flood plains of rivers that drained the mountains, then they may have reached environments with higher $^{87}Sr/^{86}Sr$ ratios at distances of only ~120 km from the Aucilla River. The high variability of $^{87}Sr/^{86}Sr$ ratios in microsamples from the Page-Ladson mastodon confirms the mobility of this individual. The low ratios in this tooth match the ratios of marine carbonates and the high ratios match those of Appalachian bedrocks, suggesting that this animal moved repeatedly between the coastal plain and the Appalachian Mountains.

Modern herbivores in mountainous regions often migrate seasonally from lower altitude winter ranges to higher altitude summer ranges, in response to changes in temperature and snow cover (Dingle, 1996). However, in mastodon microsamples, low $^{87}Sr/^{86}Sr$ ratios correlate with high $\delta^{18}O$ values, suggesting that this individual inhabited the low-lying coastal plains during at least one summer and northern regions during the winter season. Seasonally significant plant remains within mastodon digesta at Page-Ladson likewise suggest that mastodons inhabited this region of Florida during the summer and early fall seasons (Webb *et al.*, 1992 and Chapter 10 by Newsom and

Mihlbachler). Thus mastodons probably moved south in response to other factors besides cold temperature or deep snows. They may have instead moved in response to summer drought or other critical resource needs. Additionally, the variability of bulk ^{87}Sr/^{86}Sr ratios demonstrates that migration patterns differed between individual mastodons. This suggests that mastodons, like modern elephants (Eltringham, 1982), were not obligate seasonal migrants, but rather moved in a more nomadic fashion. However, as the Page-Ladson site represents at least several hundred years of deposition, the issue remains unresolved without further analysis of larger samples. It is quite possible that these mastodon populations migrated regularly on a seasonal basis. The observed variability in ^{87}Sr/^{86}Sr ratios among individuals may simply reflect the response of the local populations to century-scale climatic fluctuations.

We attributed the surprising differences in movement patterns between mammoths and mastodons to their fundamentally different dietary preferences (Hoppe *et al.*, 1999). During the late Pleistocene, southern Florida contained more open scrub and prairie habitat, whereas forests predominated in northern Florida and Georgia (Watts and Hansen, 1994). Thus, it is likely that the grazing mammoths preferentially foraged in the more open southern habitats, while the browsing mastodons foraged primarily in the forested habitats to the north.

13.5 Conclusions

This study uses several isotopic proxies to reconstruct the paleobiology of extinct species and test whether the taxa affected by the Pleistocene extinction shared common paleobiological attributes. Overall we found that extinct taxa appear to be more notable for their differences than their similarities. If climatically induced dietary stress contributed to the extinction of these taxa, then we would expect that extinct taxa would have more specialized diets than surviving taxa. Our results suggest that the reverse was true: extinct taxa include not only specialized browsers and grazers, but also generalized intermediate feeders. Additionally the δ^{13}C value of extinct taxa remained constant over time, suggesting that these animals did not dramatically change their dietary habits from full to late glacial times.

The δ^{18}O values of tooth enamel also displayed relatively little change between full and late glacial times. However, this is likely an artifact of the large variability displayed within each species. The fact that no consistent trend appears in the δ^{18}O values of each species suggests that samples from the Aucilla River fauna did not track local variation in meteoric water.

Another proposed stress is the potential climatic disruption of migration routes. Previously it has been difficult to evaluate the effects of such stresses due to the difficulty in reconstructing lifetime migrations from the fossil record. The results discussed in this study clearly show that ^{87}Sr/^{86}Sr ratios can be used to reconstruct lifetime migrations. However, once again we found that extinct animals, in this case mammoths and mastodons, did not share the same movement patterns. Mammoths appear to have ranged only locally in Florida, while mastodons appear to have migrated across distances of at least 120 km into granitic terrain. While mastodons may have been stressed by disruption of migration routes, it seems unlikely that mammoths were likewise affected. However, since we were only able to analyze the $^{87}Sr/^{86}Sr$ ratios of late glacial animals, it remains possible that these animals displayed movement patterns that had already been disrupted. Analysis of the $^{87}Sr/^{86}Sr$ ratios of animals from the full glacial should reveal whether the movement patterns of proboscideans changed with time, and whether this factor was associated with their extinction.

13.6 Acknowledgments

This research was supported by National Science Foundation grants EAR-9316371 and EAR-9725854. We thank S. David Webb for providing access to the Aucilla River specimens and for discussing Florida faunas. Valuable comments and technical assistance were provided by R. Carlson, M. Hogan, P. Holden, A. Hoppe, C. Janousek, and M. Mellott.

References

Ambrose, S. H. and Norr, L., 1993, Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate, in: *Prehistoric Human Bone: Archaeology at the Molecular Level* (J. B. Lambert and G. Grupe, eds.), pp: 1–37, Springer-Verlag, New York.

Ayliffe, L. K., Lister, A. M., and Chivas, A. R., 1992, The preservation of glacial–interglacial climatic signatures in the oxygen isotopes of elephant skeletal phosphate, *Palaeogeography, Palaeoclimatology, Palaeoecology* **99**:179–191.

Bocherens, H., Koch, P. L., Mariotti, A., Geraads, D., and Jaeger, J. J., 1996, Isotope biogeochemistry (^{13}C, ^{18}O) of mammalian enamel from African Pleistocene homonid sites: implications for the preservation of paleoclimatic signals, *Palios* **11**:306–318.

Brooks, J. R., Flanagan, L. B., Buchmann, N., and Ehleringer, J. R., 1997, Carbon isotope composition of boreal plants: functional grouping of life forms, *Oecologia* **110**:310–311.

Bryant, J. D. and Froelich, P. N., 1995, A model of oxygen isotope fractionation in body water of large mammals, *Geochimica et Cosmochimica Acta* **59**:4523–4537.

Bryant, J. D., Koch, P. L., Froelich, P. N., and Showers, W. J., 1996, Oxygen isotope partitioning between phosphate and carbonate in mammalian apatite, *Geochimica et Cosmochimica Acta* **24**:5145–5148.

Cerling, T. E., Harris, J. M., MacFadden, B. J., Leaksy, M. G., Quade, J., Elsenmann, V., and Ehleringer, J. R., 1997, Global vegetation change through the Miocene/Pliocene boundary, *Nature* **389**:153–158.

Chadwick, O. A., Derry, L. A., Vitousek, P. M., Huebert, B. J., and Hedin, L. O., 1999, Changing sources of nutrients during four million years of ecosystem development, *Nature* **397**:491–497.

Churcher, C. S., 1980, Did North American mammoths migrate? *Canadian Journal of Anthropology* **1**:103–105.

Connin, S. L., Betancourt, J., and Quade, J., 1998, Late Pleistocene C_4 plant dominance and summer rainfall in the southwestern United States from isotopic study of herbivore teeth, *Quaternary Research* **50**:179–193.

Dansgaard, W., 1964, Stable isotopes in precipitation, *Tellus* **16**:436–468.

DeNiro, M. J. and Epstein, S., 1979, Relationship between the oxygen isotope ratios of terrestrial plant cellulose, carbon dioxide, and water, *Science* **204**:51–53.

Dingle, H., 1996, *Migration: The Biology of Life on the Move*, Oxford University Press, New York.

Dompierre, H. and Churcher, C. S., 1996. Premaxillary shape as an indicator of the diet of seven extinct late Cenozoic New World camels, *Journal of Vertebrate Paleontology* **16**:141–148.

Ehleringer, J. R., 1989, Carbon isotopes ratios and physiological processes in arid land plants, in: *Stable Isotopes in Ecological Research* (P. W. Rundel, J. R. Ehleringer, and K. A. Nagy, eds.), pp. 41–54, Springer-Verlag, New York.

Eltringham, S. K., 1982, *Elephants*, Blandford Press, Poole.

Feranec, R. S. and B. J. MacFadden, 2000, Evolution of the grazing niche in Pleistocene mammals from Florida: evidence from stable isotopes, *Palaeogeography, Palaeoclimatology, Palaeoecology* **162**:155–169.

Fisher, D. C. and Fox, D. L., 1998, Oxygen isotopes in mammoth teeth: sample design, mineralization patterns, and enamel–dentin comparisons, *Journal of Vertebrate Paleontology* **18**:41A–42A.

Förstel, H., 1978, The enrichment of ^{18}O in leaf water under natural conditions, *Radiation and Environmental Biophysics* **15**:323–344.

Fricke, H. C. and O'Neil, J. R., 1996, Inter- and intra-tooth variation in the oxygen isotope composition of mammalian tooth enamel phosphate: implications for palaeoclimatological and palaeobiological research *Palaeogeography, Palaeoclimatology, Palaeoecology* **126**:91–99.

Graham, R. W. and Lundelius, E. L., 1984, Coevolutionary disequilibrium and Pleistocene extinctions, in: *Quaternary Extinctions: A Prehistoric Revolution* (P. S. Martin and R. G. Klein, eds.), pp. 223–249, University of Arizona Press, Tucson.

Guthrie, D. R., 1984, Mosaic, allelochemics and nutrients, in: *Quaternary Extinctions: A Prehistoric Revolution* (P. S. Martin and R. G. Klein, eds.), pp. 259–298, University of Arizona Press, Tucson.

Haynes, G., 1991, *Mammoths, Mastodonts, and Elephants: Biology, Behavior, and the Fossil Record*, Cambridge University Press, Cambridge.

Holman, J. A., Abraczinskas, L. M., and Westjohn, D. B., 1988, Pleistocene proboscideans and Michigan salt deposits, *National Geographic Research* **4**:4–5.

Hoppe, K. A., Koch, P. L., Carlson, R. W., and Webb, S. D., 1999, Tracking mammoths and mastodons: reconstruction of migratory behavior using strontium isotope ratios, *Geology* **27**:439–442.

King, J. E. and Saunders, J. J., 1984, Environmental insularity and the extinction of the American mastodont, in: *Quaternary Extinctions: A Prehistoric Revolution* (P. S. Martin and R. G. Klein, eds.), pp. 315–339, University of Arizona Press, Tucson.

Koch, P. L., 1998, Isotopic reconstruction of past continental environments, *Annual Review Earth and Planetary Science* **26**:573–613.

Koch, P. L., 1989, Paleobiology of Late Pleistocene Mastodonts and Mammoths from Southern Michigan and Western New York. University of Michigan. Ph.D. dissertation, p. 280.

Koch, P.L., Fischer, D.C., and Dettman, D., 1989, Oxygen isotope variation in the tusks of extinct Proboscideans: A measure of death and seasonality, *Geology* **17**:515–519.

Koch, P. L., Behrensmeyer, A. K., and Fogel, M. L., 1991, The isotopic ecology of plants and animals in Amboseli National Park, Kenya, *Annual Report of the Director of the Geophysical Laboratory, Carnegie Institution of Washington* 1989–1990:163–171.

Koch, P. L., Heisinger, J., Moss, C., Carlson, R. W., Fogel, M. L., Behrensmeyer, A. K., 1995, Isotopic tracking of change in diet and habitat use in African elephants. *Science* **267**:1340–1343.

Koch, P. L., Hoppe, K. A., and Webb, S. D., 1998, The isotope ecology of late Pleistocene mammals in North America part 1. Florida, *Chemical Geology* **152**:119–138.

Krausman, P. R. and Ables, E. D., 1981, *Ecology of the Carmen Mountains White-tailed Deer*, U.S. Department of the Interior, Washington, DC.

Kurtén, B. and Anderson, E., 1980, *Pleistocene Mammals of North America*, Columbia University Press, New York.

Kutzbach, J. E., Guetter, P. J., Behling, P. J., and Selin, R., 1993, Simulated climate change: results of the COHMAP climate-model experiments, in: *Global Climates since the Last Glacial Maximum* (H. E. Wright Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartlein, eds.), pp. 24–93, University of Minnesota Press, Minneapolis.

Lee-Thorp, J. A. and van der Merwe, N. J., 1987, Carbon isotope analysis of fossil bone apatite, *South African Journal of Science* **83**:71–74.

Lee-Thorp, J. A. and van der Merwe, N. J., 1991, Aspects of the chemistry of modern and fossil biological apatites, *Journal of Archaeological Sciences* **18**:343–354.

MacFadden, B. J. and Cerling, T. E., 1996, Mammalian herbivore communities, ancient feeding ecology, and carbon isotopes: a 10 million-year sequence from the Neogene of Florida, *Journal of Vertebrate Paleontology* **16**:103–115.

MacFadden, B. J., Solounias, N., and Cerling, T. E., 1999, Ancient diets, ecology, and extinction of 5-million-year-old horses from Florida, *Science* **283**:824–827.

Marchinton, R. L. and Hirth, D. H., 1984, Behavior, in: *White-tailed Deer: Ecology and Management* (L. K. Halls, ed.), pp. 129–168, Stackpole Books, Harrisburg.

Marino, B. D., McElray, M. B., Salawitch, R. J., and Spaulding, W. G., 1992, Glacial-to-interglacial variations in the carbon isotopic composition of atmospheric CO_2, *Nature* **357**:461–466.

Martin, P., 1984, Prehistoric overkill: the global model, in: *Quaternary Extinctions: A Prehistoric Revolution* (P. S. Martin and R. G. Klein, eds.), pp. 354–403, University of Arizona Press, Tucson.

Martin, P. S. and Klein, R. G. (eds.), 1984, *Quaternary Extinctions: A Prehistoric Revolution*, University of Arizona Press, Tucson.

Medina, E. and Minchin, P., 1980, Stratification of $\delta^{13}C$ values of leaves in Amazonian rain forests, *Oecologia* **45**:337–378.

Miller, E. K., Blum, J. D., and Friedland, A. J., 1993, Determination of soil exchangeable-cation loss and weathering rates using Sr isotopes, *Nature* **362**:438–441.

Miller, G. H., Magee, J. W., Johnson, B. J., Fogel, M. L., Spooner, N. A., McCulloch, M. T., and Ayliffe, L. K., 1999, Pleistocene extinction of *Genyornis newtoni*: human impact on Australian megafauna, *Science* **283**:205–283.

Norman, G. R. and Streiner, D. L., 1992, *Biostatistics the Bare Essentials*, Mosby, St. Louis.

Nowak, R. M., 1991, *Walker's Mammals of the World*, Volume 5, John Hopkins University Press, Baltimore.

O'Leary, M. H., 1981, Carbon isotope fractionation in plants, *Phytochemistry* **20**:553–567.

O'Leary, M. H., 1988, Carbon isotopes in photosynthesis, *BioScience* **38**:328–336.

Olivier, R. C. D., 1982, Ecology and behavior of living elephants: bases for assumptions concerning the extinct woolly mammoth, in: *Paleoecology of Beringia* (D. M. Hopkins, J. V. Mathews, C. E. Schweger, and S. B. Young, eds.), pp. 291–305, Academic Press, New York.

Owen-Smith, R. N., 1988, *Mega-herbivores*, Cambridge University Press, New York.

Plummer, L. N., 1993, Stable isotope enrichment in paleowaters of the southeast Atlantic coastal plain, United States, *Science* **262**:2016–2020.

Rozanski, K., Araguas-Araguas, L., and Gonfiantini, R., 1993, Isotopic patterns in modern global precipitation, in: *Climate Change in Continental Isotopic Records* (P. K. Swart, K. C. Lohmann, and S. Savin, eds.), pp. 1–35, American Geophysical Union, Washington, DC.

Saurer, M., Aellen, K., and Siegwolf, R., 1997, Correlating delta 13C and delta 18O in cellulose of trees, *Plant Cell and Environment* **20**:1543–1550.

Scott, T. M., 1992, A geological overview of Florida, State of Florida Department of Natural Resources Open File Report No. 50, p. 78.

Sharp, Z. D. and Cerling, T. E., 1998, Fossil isotope records of seasonal climate and ecology: straight from the horse's mouth, *Geology* **26**:219–222.

Sikes, S. K., 1971, *The Natural History of the African Elephant*, American Elsevier Publishing Co., Inc., New York.

Sternberg, L. O., DeNiro, M. J., and Johnson, H. B., 1984, Isotope ratios of cellulose from plants having different photosynthetic pathways, *Plant Physiology* **74**:557–561.

Stuart-Williams, H. L. Q., Schwarcz, H. P., White, C. D., and Spence, M. W., 1996, The isotopic composition and diagenesis of bone from Teotihuacan and Oaxaca, Mexico, *Palaeogeography, Palaeoclimatology, Palaeoecology* **126**:1–14.

Teeri, J. A. and Stowe, L. G., 1976, Climatic patterns in the distribution of C-4 grasses in North America, *Oecologia* **23**:1–12.

van der Merwe, N. J. and Medina, E., 1991, The canopy effect, carbon isotope ratios and foodwebs in Amazonia, *Journal of Archeological Science* **18**:249–259.

Vogel, J. C., 1978, Recycling of carbon in a forest environment, *Oecologia Plantarum* **13**:89–94.

Watts, W. A. and Hansen, B. C. S., 1994, Pre-Holocene and Holocene pollen records of vegetation history from the Florida peninsula and their climate implications, *Palaeogeography, Palaeoclimatology, Palaeoecology* **109**:167–176.

Watts, W. A., Hansen, B. C. S., and Grimm, E. C., 1992, Camel Lake: A 40,000-yr record of vegetational and forest history from northwest Florida, *Ecology* **73**:1056–1066.

Webb, S. D and F. G. Stehli., 1995, Selenodont Artiodactyls (Camelidae and Cervidae) from the Leisey Shell Pits, Hillsborough County, Florida. *Bulletin of the Florida Museum of Natural History* 37:621–643.

Webb, S. D., Dunbar, J., and Newsom, L., 1992, Mastodon digesta from north Florida, *Current Research in the Pleistocene* **9**:114–116.

Williams, K. D., 1979, Radio-tracking tapirs in the primary rain forest of west Malaysia, *The Malayan Nature Journal* **32**:253–258.

Williams, K. D. and Petrides, G. A., 1980, Browse use, feeding behavior, and management of the Malayan tapir, *Journal of Wildlife Management* **44**:489–494.

Chapter 14

Paleoindian Archaeology

JAMES S. DUNBAR
Senior Archaeologist, Public Lands Archaeology, Florida Bureau of Archaeological Research
Mailing Address: R. A. Gray Bldg, 500 South Bronough Street, Tallahassee, FL 32399-0250, USA.
Street address: B. Calvin Jones Center for Archaeology, 1001 DeSoto Park Drive, Tallahassee, FL 32301, USA.
E-Mail: jsdunbar@dos.state.fl.us, Phone: (850) 245-6307, Fax: (850) 245-6463

14.1 Introduction

Despite the discovery of Paleoindian sites east of the Mississippi River, the stratigraphic and temporal establishment of the Early Paleoindian Clovis and Middle Paleoindian Folsom sequence west of the Mississippi River has been a standard by which other Paleoindian sites in the Americas have been judged. This is particularly true of Clovis sites in the Desert Southwest because they are viewed as evidence of the founding human populations, at least regionally, and because western archaeologists were first to establish a regional chronostratigraphy and geoclimatic model of the Southwestern US (Bryan and Albritton, 1943; Bryan, 1950; Antevs, 1954, 1962a,b;

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 403–435

Haynes, 1971, 1982, 1984, 1990, 1991, 1993; Haynes *et al*., 1999). Following Kirk Bryan and Ernst Antevs, C. Vance Haynes has dedicated much of his professional career fine-tuning the geoclimatic evidence gathered from Paleoindian sites in the Southwest. These researchers were the first to develop a regionally based chronology that placed stratigraphy and environmental data in time. The resulting chronostratigraphy and geoclimatic data have played a vital role in the interpretation of the Southwestern Paleoindian cultural development. In short, it is the strength of the Southwestern approach that has been lacking elsewhere in the Americas.

However, it would be inappropriate to adopt the regionalized data from the Southwest in order to impose it in a different geographic region; for example the Southeast US. The patterns of climate, habitat, and human occupation should be evaluated on their own merits keeping in mind the likelihood of distinct regional differences. It is from this perspective that the Paleoindian components at the Page-Ladson site are discussed.

14.2 History of Paleoindian Site Investigations

Some of the earliest archaeological investigations in Florida resulted in the discovery of Paleoindian artifacts (Wyman, 1875); though the possibility of their antiquity or potential association with Pleistocene megafauna was not recognized. Early in the 20th century human remains and artifacts were found in association with Pleistocene megafauna at Vero (Sellards, 1916) and Melbourne (Gidley, 1929 , 1930), Florida south of Cape Canaveral. However, the so-called "Vero and Melbourne man" discoveries were controversial (see for example Sellards *et al*., 1917; Stewart, 1946) and left unanswered the question: Do Pleistocene archaeological remains occur in North America? It remains uncertain if the Vero and Melbourne finds are Pleistocene sites. Perhaps one day another site in the "Melbourne bone bed" (Sellards, 1947) will provide the answer.

Clarence J. Simpson, an employee of the Florida Geological Survey and veteran who participated in the 1930 underwater recovery of a mastodon skeleton at Wakulla Springs, discovered carved Proboscidean ivory shafts, lanceolate projectile points, and stone tools with mastodon remains at the Simpson's Flats site (8Co174) in the Ichetucknee River. The site was located about one mile south of the Ichetucknee headspring in the central river channel (Simpson, 1941). His notable discoveries were published in *American Antiquity* in an article entitled "Beveled artifacts in Florida of the same type as artifacts found near Clovis, New Mexico" (Jenks and Simpson, 1941). After WWII, Simpson reported several more sites in Florida that had produced "Folsom-like" lanceolate points (Haynes, 1991). The ivory shafts recovered from the Ichetucknee River were sufficiently similar to the Clovis shafts from Blackwater Draw near Clovis, New Mexico, yet the stone projectile points were not Clovis. Simpson (1948) used the term Folsom-like to characterize all lanceolate points from Florida that were reminiscent of Folsom or Clovis.

Clarence Simpson began working with Columbia University PhD student William E. Edwards in a search for Paleoindian remains in stratified position. Simpson's efforts to demonstrate that Paleoindian lanceolate points predated other diagnostic point types in Florida (Dolan and Allen, 1961) were disrupted by his untimely death in 1952. Simpson's protégé, William Edwards, recovered both lanceolate and notched points below much younger archaeological components at the Lake Helen Blazes site (8BR27) in Brevard County (Edwards, 1952) yet his find received only minimal recognition. John Goggin was another archaeologist in the hunt for stratified Paleoindian sites and had corresponded with Clarence Simpson. John Goggin conducted test excavations near the mouth of the Santa Fe River where it meets the Suwannee River based on Simpson's guidance (Goggin, 1950). Though Goggin fell short of demonstrating the stratigraphic position of lanceolate points he formalized the type name Suwannee to include the lanceolate points having a resemblance to established Paleoindian types both fluted (Clovis and Folsom) and unfluted Plainview. The three of the four specimens he depicted are not fluted and the fourth is indeterminately fluted. All are slightly waisted (Goggin, 1950) and typical of the waisted Suwannee point form (Dunbar and Hemmings, 2004).

Wilfred T. Neill made the first widely accepted discovery of a stratified Paleoindian site in Florida at Silver Springs in Marion County (8Mr92). Neill recognized the lanceolate, fluted, and overshot flaked points as being Clovis-like, however, conceded to John Goggin by calling them Suwannee points (Neill, 1958). In the lowest level of the site Neill recovered one classic Clovis and two preforms. He also recovered a classic Clovis as well as a waisted Clovis from nearby displaced context (Neill, 1958:43, Plate 3a–d and g). The Silver Springs site placed Florida on the Paleoindian map for archaeologists (see for example Willey, 1966:31; Jennings, 1968:84).

A number of archaeologists, for instance Goggin (1950), identified artifact types based on serrations developed using archaeological and stratigraphic evidence. Ripley Bullen was the first to develop a comprehensive projectile point typology for Florida by synthesizing the work of others as well as his own. He identified three basic Paleoindian types that have, for the most part, withstood subsequent developments. These lanceolate point types are Clovis, Suwannee, and Simpson (Bullen, 1968a; Bullen, 1975).

Two hypotheses were developed to explain why so many diagnostic Paleoindian artifacts (both fluted and unfluted lanceolate points) were being recovered from underwater settings in Florida. The first was the Oasis hypothesis of Wilfred T. Neill. He proposed water levels in Florida were very much below present during the Pleistocene relegating surface water to oasis-like settings; such oases attracted large game animals and Paleoindian hunters (Neill, 1964). Neill developed this idea after he left the Florida Museum of Natural History and assumed managerial responsibilities at the Silver Springs tourist attraction. Neill was intrigued by the discoveries of SCUBA divers who were finding numerous fossil and artifacts in the spring cavern as well as surface channel of Silver Springs, Silver River.

SCUBA diving in Silver Springs had become commonplace because the TV Series *Sea Hunt*, starring Lloyd Bridges, was being filmed in the clear water near the spring-head. One of the series stunt doubles and the diving instructor who taught Lloyd Bridges how to SCUBA dive, Benjamin "Ben" Waller, developed an alternative hypothesis. Ben Waller developed the "River Crossing" hypothesis (Waller, 1969, 1970), which proposed that Paleoindian hunters ambushed large Pleistocene animals while the animals were attempting to cross from one side of the river to the other. He felt the water effectively impeded the animals making them easy targets. The Oasis and River Crossing hypotheses are seemingly opposite from one another in that one assumes water levels were low and rivers such as Silver River were dry, while the other proposed the rivers were flowing and Paleoindian hunting was staged at shallow-water river fords such as those frequently encountered by Ben Waller in the Santa Fe River.

Randy Daniels and Mike Wisenbaker investigated the Harney Flats site (8Hi407) located in the right-of-way of I-75 east of Tampa Florida. This multicomponent site included the remains of a Paleoindian base camp (Daniel and Wisenbaker, 1987). The diagnostic points from the site were identified as Suwannee and Simpson types, no Clovis points were found. The identification of some points as Simpson types, while falling within the definition of Ripley Bullen's typology were problematic because they also fall within the range that also includes the Suwannee type (Bullen, 1968a:48–49). The problem lies with an overlap in the slightly waisted form of Suwannee with the generally more recurvate Simpson type. The overlap is seen when considering Bullen's original definitions for the types and comparing his original type case specimens (Bullen, 1968b) stored at the Florida Museum of Natural History in Gainesville, Florida. As a result all of the points from the Harney Flats site are considered to fall within the range of the Suwannee type, which includes both an excurvate- to parallel-sided form as well as a waisted or recurvate form (Dunbar and Hemmings, 2004).

The intent here is not to detail the typological differences between types; rather it is to point out that Bullen did not distinguish the full range of lanceolate point variability that either distinguishes the unique attributes of chronologically different types or identifies the morphological ranges that occur within a culture's set of contemporaneous forms.

Returning to the Harney Flats site, two major components were identified in nearly the same stratigraphic position representing Middle Paleoindian Suwannee and Early Archaic Bolen stone tool assemblages. Daniels and Wisenbaker concluded, "there was not enough geological deposition between discrete occupations to stratigraphically separate materials" (Daniels and Wisenbaker, 1978:38). Excavation at the Wakulla Lodge site revealed a multiple component site similar to the Harney Flats site in that a Paleoindian component was determined to be in contact with a subsequent Bolen component (Jones and Tesar, 2000, 2004) even though the Paleoindian component was older than that at Harney Flats. Both the Wakulla Springs Lodge and Harney Flats situation indicate there was minimal deposition of eolian sediment in Florida from the Paleoindian to the first part of the Early Archaic. Only after Bolen times are archaeological components separated in hilly eolian sands as they are at Harney Flats and Wakulla Lodge.

The Wakulla Springs Lodge site (8Wa239) is another important Paleoindian site because it yielded a Simpson point tool assemblage different in many respects from the Suwannee tool assemblage found at Harney Flats (Jones and Tesar, 2004). Prior to the property becoming a state park, a Simpson point was recovered and put on display in the lobby of the Wakulla Lodge. It appears to be a white, patinated specimen suggesting it was a land find. Where it was recovered remains uncertain. This point is distinctively different compared to the waisted Suwannee type and, judging from the photograph, it is either basely thinned or fluted. It also displayed three-quarter shot, percussion flaking on both lateral margins that over lap in the middle of the blade. It is an extremely recurvate point with a narrow, pronounced hafting waist that is more than two times smaller than the blade width (Jones and Tesar, 2004:9).

The Paleoindian component Wakulla Lodge yielded a large (18.6 cm) "bifacial core that is shaped like a middle stage Simpson ... preform" (Jones and Tesar, 2004:15–16). Part of the stone tool assemblage included lanceolate points that were manufactured on thin flakes extracted from bifacial cores similar to the Simpson preform. Points and tools manufactured from these large bifacial thinning flakes averaged about 5–7 cm in length and were percussion-struck from the biface. The lanceolate projectile point recovered in context from the Wakulla Lodge site was described as Clovis-like even though it was manufactured on a thin flake and had a flute-like feature that actually represented an unaltered flat-side of the flake preform. Clovis reduction strategy reduced thick bifacial blanks by percussion flaking that included basal fluting and overshot flaking. The Wakulla specimen was manufactured from a thin flake and was not overshot flaked or fluted (Jones and Tesar, 2004:88–92). The point, however, is recurvate- to parallel-sided and in that aspect is somewhat Clovis-like (Fig 14.6B).

Sloth Hole, an underwater site located in the Aucilla River (8Je121), like the Silver Springs site, has a Clovis component that yielded both classic Clovis (the excurvate- to parallel-sided) and waisted Clovis (the slightly waisted or recurvate) types. Numerous carved ivory shafts have also been recovered from Sloth Hole (Hemmings, 1999). Excavation at Sloth Hole revealed that Clovis-age artifacts rested above undiagnostic chert debitage. A radiocarbon sample taken from the oldest debitage producing level at Sloth Hole yielded a date of 12,300 ± 50 ^{14}C BP (Beta, 95341)(Hemmings, 1999:14–16).

The Ryan-Harley site in the Wacissa River, a tributary of the Aucilla River, was the first Suwannee campsite investigated with bone preservation. Salvage excavations were conducted in a channel section that was actively eroding. The effort resulted in the recovery of three waisted Suwannee points, an ivory shaft fragment, and giant armadillo, and sloth bones recovered from displaced context. Materials recovered *in situ* from test excavations included a parallel-sided Suwannee preform, many Clovis-like tools, and horse, tapir, and other faunal remains. Bone specimens of extant as well as extinct species were too mineralized and lacked collagen content; therefore the Suwannee component could not be radiocarbon dated (Dunbar *et al.*, in press).

Another Suwannee campsite, the Norden site (8Gi40), has been preliminarily investigated and is very similar to the Ryan-Harley site (Smith *et al.*, 1997). The Norden site is located in the Santa Fe River basin. It also yielded a Clovis-like stone tool kit along with waisted and parallel-sided Suwannee points. Similar to the Ryan-Harley site, faunal bone is mineralized and the site has not been dated. Faunal specimens from a test unit included horse or *Bison*-sized ungulate remains as well as extant Holocene species (Vojnovski and Dunbar, in press).

14.3 The Diagnostic Artifacts

14.3.1 Early and Middle Paleoindian Stone Tools

Clovis, Simpson, and Suwannee sites have been investigated in Florida, however, sites with multiple components and diagnostic artifacts have not been found. Furthermore, the Clovis component of the Sloth Hole site is the only radiometrically dated Paleoindian site in Florida with diagnostic artifacts. While other Paleoindian components have been radiometrically dated at the Sloth Hole and Page-Ladson site, no diagnostic artifacts were recovered. Therefore there is no direct stratigraphic or chronological evidence for the position of Simpson or Suwannee in relation to Clovis or in relation to one another. The absence of established radiometric chronology was the reason for lumping the distribution of Clovis, Simpson, and Suwannee points together (Dunbar *et al.*, 1989; Dunbar, 1991). Consideration of Clovis, Simpson, and Suwannee as a group led Bonnichsen to state that "Dunbar, at least, recognizes that all of the styles of Florida fluted points could be contemporaneous" (Bonnichsen and Turnmire, 1991:316); an interpretation that was entirely unintended.

Most archaeologists including this author place Suwannee points as the post-Clovis, Middle Paleoindian type. Suwannee points are typically found in the coastal plain of Florida, Georgia, and South Carolina (Goodyear *et al.*, 1990; Anderson, 1996). By far the greatest concentration of Suwannee points occurs in north-central Florida west of the St. Johns River and northward from Tampa Bay along the Gulf coast to the Choctawhatchee River (Dunbar, 1991; Goodyear, 1999).

The Simpson type is the least common type, followed by Clovis and Suwannee. However, the variation in Florida Paleoindian point forms is not entirely encompassed by these types (Dunbar and Hemmings, 2004). A good example is the lanceolate point form recovered from the Wakulla Springs Lodge site. It is a type manufactured from a thin flake and employed a manufacturing strategy that greatly differs from the Clovis, Simpson, and Suwannee strategy of reducing thick blanks bifacially. Another example is the Redstone type (Cambron *et al.*, 1990:108–109; Tesar and Whitfield, 2002), which is not common in Florida, but occasionally occurs as an isolated specimen (see for example Bullen, 1969). (Bullen originally identified this isolated find as a Clovis point, it is not, the specimen is classic Redstone.) The late Paleoindian Dalton type (Goodyear, 1982), ubiquitous elsewhere in the Southeast US, is also uncommon in Florida.

Other point forms, some waisted and others parallel to excurvate, also do not appear to fit within established type templates of Bullen (1975). The range of variation or temporal difference in any of these suggested forms has yet to be worked out and depends on the discovery of sites capable of yielding answers.

A recent effort to revise the Simpson point type by identifying unique attributes is showing great promise (Dunbar and Hemmings, 2004). The revised criteria serve to eliminate the overlap that Bullen left unresolved with waisted Suwannee points (Bullen, 1968a,b). Distinctive morphological traits of the Simpson type include a wide, thin mid-blade cross-section (thickness to width ratios of 12:1 to 21:1); a recurvate, waisted hafting area that forms a narrow-neck, which differs compared to the Suwannee type; and large, ¾ struck (from the blade lateral sides) percussion flaking used to thin the blade cross-section. It is a flaking technique reminiscent of yet different from Clovis overshot flaking. Based on morphological attributes as well as structural aspects of the hafting area, Simpson points appear to be most consistent with knife rather than projectile point utilization. Evidence from the only documented Simpson age site in Florida, the Wakulla Springs Lodge site, indicates that the projectile point type associated with Simpson knives were non-waisted, basally ground lanceolate points made from thin flakes. Thus middle stage Simpson preforms were not only tools in themselves, they provided flakes for tool and point production and could be further reduced to manufacture Simpson points (Jones and Tesar, 2004).

The Clovis and Suwannee tool kits are similar in many respects. Waisted Clovis points tend to be fluted and display overshot flaking. Waisted Suwannee points are most frequently unfluted and do not display overshot flaking. Nevertheless, a small population of Suwannee points display occasional multiple fluting on one or both sides as well as overshot flaking. The distal tips of Clovis points tend to be broad with rounded tips viewed dorsal-ventrally but in lateral view are thinned toward razor-sharpness. The tips on waisted Suwannee points differ and come to an acute tip viewed dorsal-ventrally and lack the razor-sharp edge in lateral view. Waisted Clovis and Suwannee points have similar blade width to hafting waist dimensions. The similarities and differences between the waisted forms of Clovis and Suwannee as well as similarities in other parts of their stone tool kits are considered evidence that Clovis is the likely ancestor of Suwannee (Dunbar and Hemmings, 2004).

With that said, Dennis Stanford correctly pointed out that both Suwannee and Simpson point sites remain undated and hypothesized "that when dated, they may be slightly older than Clovis" (Stanford, 1991:9). The Horn Rock Shelter 2 (41Bq46) in central Texas near Waco has yielded a waisted Suwannee or Suwannee-like point at and below Folsom levels (Redder, 1985:40–42 and Fig. 2g) in Middle to Early Paleoindian context. I accept the more conservative view that Suwannee points are post-Clovis, however this view also poses a problem. If Suwannee points are post-Clovis, but are associated with horse, tapir, and other megafauna species believed extinct by post-Clovis times, how could Suwannee point-making people hunt megafauna? The short answer appears to be that the most reliably dated Clovis sites with associated megafauna remains are located west of the Mississippi River in a different environmental region. The region west of the Mississippi River experienced a Clovis drought (Haynes, 1984, 1991, 1993; Haynes *et al.*, 1999) but the Southeastern US did not (see Chapter 5). Therefore environmental stresses on megafauna populations were absent during Clovis and Suwannee times in the Southeast. An episode of environmental stress does take place in the Southeast after ~10,500 ^{14}C BP followed by a more dramatic *Bolen drought* ~10,000 ^{14}C BP to ~9,500 ^{14}C BP (Dunbar, 2002:167–169). Since the stratigraphic integrity of the Ryan-Harley site is not in question (Balsillie *et al.*, submitted for publication), the only other alternative would be that Stanford was correct and Suwannee points are either contemporary with or pre-Clovis in age.

14.3.2 Late Paleoindian Stone Tools

Ripley Bullen recognized Dalton, Tallahassee, Beaver Lake, and Santa Fe lanceolate point types as Late Paleoindian, Dalton, or Dalton-like variants that occur in Florida (Bullen, 1975:44–47). He also recognized Greenbriar, Union Side Notched, Hardaway Side Notched, and Gilchrist as having Dalton and/or Hardaway affinity and, therefore, Late Paleoindian (Bullen, 1975:49–50 and 53–54). After Bullen set up the Florida point typology, the need to revise certain parts of that typology has been recognized. His classification of Late Paleoindian Florida types is in need of the most extensive revisions.

For instance most of Bullen's Late Paleoindian lanceolate types now appear to either represent post-Paleoindian types or to include an isolate Paleoindian form or two not common in Florida. Many of the Florida type-case specimens for the Tallahassee type originated from much later ceramic period mound sites. The Santa Fe type is now recognized as dating from the Late Archaic and associated with fiber-temper pottery sites (Mikell, 1997). The Florida Beaver Lake type named after a northern Alabama type (Cambron *et al*., 1990:10) is sufficiently different and is also believed to represent a much younger type. As is true today, Bullen recognized that Dalton points were uncommon in Florida.

Bullen also placed three notched point types (Union, Greenbriar, and Hardaway Side Notched) and one pseudo-notched type (Gilchrist) in the Late Paleoindian. Different specimens in the Florida type-case collection of Hardaway Side Notched actually resemble both Hardaway–Dalton and the Hardaway Side Notched types of the Carolinas (Daniel, 1998:51–52). Gilchrist subtype 4 also resembles the Carolina Hardaway–Dalton type. However, recent investigations of Hardaway sites in the Carolinas have shown that both types of Hardaway points are restricted geographically primarily to the piedmont and rarely occur south of the fall line of South Carolina (Goodyear *et al*., 1990; Daniel, 1998). Therefore the type name Hardaway for a Florida type is misleading. It is not the intent here to propose alternative type names, rather it is to simply point out that there are no true Hardaway points from Florida although there is a point type resembling the Hardaway type in some respects. More important are the Florida notched or pseudo-notched types (Union, Greenbriar, and Hardaway-like) that may represent Late Paleoindian types. Because these types have not been recovered from datable context their temporal placement remains uncertain.

14.3.3 Paleoindian Bone and Ivory Tools

Shafts manufactured from thick-walled megafauna long bone or tusk-ivory are another artifact type associated with Paleoindian sites. They have been recovered in abundance at the Sloth Hole Clovis site in the Aucilla River. One of the Sloth Hole ivory shafts has been radiocarbon dated ~11,050 ^{14}C BP, which is clearly Clovis age (Hemmings, 2004) and is similar to bone and ivory shafts recovered from Clovis sites elsewhere in North America (Sellards, 1952:31–33; Lahren and Bonnichsen, 1974;

Gramly, 1993). Similar osseous shafts are also common in Old World Upper Paleolithic sites (Knecht, 1991). The hafting end of an ivory shaft was recovered from the Ryan-Harley Suwannee point site in displaced context. This suggests Paleoindian osseous shafts were manufactured and used during Suwannee times (Dunbar *et al.*, in press).

Bone pins or points manufactured from the bones of smaller mammals, for instance white-tailed deer, are frequently associated with post-Paleoindian, Archaic and younger archaeological sites (Milanich, 1994). Bone pins of this type are smaller in diameter than bone shafts manufactured on thick-walled megafauna bone and tusk-ivory. The diameter limit of bone pins is due to the bone-wall thickness of medium-sized game animals such as the white-tailed deer. The co-occurrence of bone pins and Pleistocene megafauna remains in Florida Rivers led to speculation that the smaller bone pins also date to Paleoindian times (Waller, 1983). Archaeological tests at the Dunnigan's Old Mill site (8Gi24) located on the banks of the Santa Fe River uncovered a bone pin with a faunal assemblage that included Pleistocene megafauna. It was found in four pieces, three were recovered contacting one another on old bone breaks and a fourth, proximal end fragment, displayed a green-bone fracture and was found about a meter away. All four pieces fit together to form a complete bone pin. The break between the proximal and distal pieces is a longitudinal fracture caused by head-on impact indicating probable use as a projectile point. It is a one-end pointed and other-end blunted variety and reminiscent of other bone pins that are much younger. However, It was distinctive because it displayed little post-splinter-groove technique grinding (finishing) except for the distal tip, which had been honed to a point. As a result the bone pin was more or less rectangular in cross-section because its lateral margins had not been ground (Vojnovski and Dunbar, in press). Typically, bone pins from younger, Holocene context have been honed into a rounded or oval cross-section along their lateral margins (Willis, 1988).

There is a plethora of other bone and ivory tools of Paleoindian age that will not be detailed here but have been documented elsewhere (Dunbar and Webb, 1996; Webb and Hemmings, 2001; Hemmings *et al.*, 2004), particularly in a major contribution by Hemmings (2004).

14.4 Cultural–Temporal Position of the Early, Middle, and Late Paleoindian

The Early Paleoindian timeframe is recognized here as being somewhat open ended at its beginning with the most solid early dates from Florida representing an average of seven radiocarbon dates of 12,425 ± 32 ^{14}C BP for Unit 3. Two other Southeastern sites, Cactus Hill in Virginia (McAvoy and McAvoy, 1997) and the Topper site in South Carolina (Goodyear, 2000, 2001, 2003), have yielded dates older than Page-Ladson. All three are pre-Clovis in age. The oldest component at the Cactus Hill site contained a pre-Clovis point type manufactured on thin flakes as well as conical blade cores and prismatic blades (Fig. 14.6A). The pre-Clovis stone tool from Cactus Hill has been informally referred to as Clovis-lite (Marshall, 2001a,b) and more technically as part of the Miller complex first identified at the Meadowcroft Shelter (Adovasio *et al*., 1999:428), an infamous pre-Clovis site located in Pennsylvania. The oldest component of the Topper site differs from Cactus Hill and is dominated by small micro tools (Goodyear, 2000). The stone tool assemblage is sufficiently different so that if both the Miller assemblage at Cactus Hill and the micro-tool assemblage at the Topper site are conclusively determined to be pre-Clovis, it appears there was not one but two different pre-Clovis cultures in the Southeast. Before returning to the discussion of temporal boundaries, it is also important to note that the Topper site is not the only Paleoindian micro-tool site in the Southeast; the oldest, undated component of the Avery Island site in Louisiana has a micro-tool component below an Early Archaic San Patrice component (Gagliano, 1967). The end of the Early Paleoindian timeframe coincides with the transcontinental Clovis tool-making tradition evolving to more regionalized Middle Paleoindian traditions ~11,000 ^{14}C BP (Anderson *et al*., 1996; Goodyear, 1999).

The Middle Paleoindian appears to span the time from ~11,000 ^{14}C BP to ~10,500 ^{14}C BP and the Late Paleoindian from ~10,500 ^{14}C BP to ~10,000 ^{14}C BP (Anderson *et al*., 1996; Goodyear, 1999).

14.5 The Paleoindian Archaeology of the Page-Ladson Site

14.5.1 Paleoindian Site Components

Before discussing the Paleoindian components of the Page-Ladson site I offer a few things for consideration.

First is the nature of artifact losses and discards. The keystone stratigraphic sequence and its archaeological components are located in a sinkhole within the channel of the Aucilla River. The artifacts found in undisturbed stratigraphic position accumulated as the result of human activity in and near the sinkhole. During periods of lower water table human activity took place near the center of the sinkhole, a factor that favored artifacts losses in that area. Conversely, during times of higher water table the shoreline expanded away from the center of the sinkhole, a factor that did not favor artifact losses in the central sinkhole. This explains the occurrence of multiple artifacts in components deposited during low water episodes and isolated artifacts in components deposited during high water episodes in the central sinkhole.

Second, Unit 4 represents fluvial silts deposited during a prolonged episode of high water table. Three lithic artifacts recovered from this unit represent three different components. Fluvial conditions during the deposition of Unit 4 were such that downstream transport of items such as debitage flakes and bones, articulated and disarticulated freshwater bivalves, and animal coprolites did not take place. The organic content of Unit 4 did not sink until sufficiently waterlogged and once settled to the bottom, fragile items such as leaves, seeds, etc. remained undisturbed. Unit 4 appears to be an uninterrupted column of deposition with no obvious erosion breaks caused by flowing water even though flowing brought flotsam to this *cul-de-sac* where it eventually settled. The natural land bridge once located just south of the sinkhole did not collapse until the middle Holocene. The isolated artifacts in Unit 4 are the result of human activity that took place on the sinkhole margins during an episode of extended high water conditions when it was less likely they would be deposited in the central sinkhole.

Third, the preservation of bone, even in the oldest levels of the site, was extraordinary in the Page-Ladson sinkhole. Collagen was well preserved which provided the opportunity for radiocarbon dating. Carnivore bites and chew-marks, large animal trampling scratches, human produced cut-marks, impact crushing, and pathologies that altered bone specimens were all well preserved. Shallow submerged sites such as the Ryan-Harley Suwannee point site in the Wacissa River have bone preservation but the bone is mineralized and lacks the collagen content necessary for radiocarbon dating. In addition, biotical material such as seeds and wood did not survive; a factor most likely caused by the Ryan-Harley site's higher elevation and the interval of late Younger Dryas and Preboreal water table decline. It remains to be determined if Early and Middle Paleoindian age charcoal survived at sites such as the Ryan-Harley site, although it seems the chances are more probable.

Therefore, it is not only the very deep stratigraphic column that makes the Page-Ladson site unique, it is the preservation, and the circumstances under which the materials entered the sinkhole as it filled that make this site critically important. The keystone sequence at the Page-Ladson site has provided the means for detailed interpretation of environmental reconstruction and the timing of events as well as the occurrence of human activity at the site.

14.5.2 Evidence of Human Activity, Chronology, and Component Integrity

The sinkhole at the Page-Ladson site acted as a basin of deposition throughout most of the late glacial recession. During that time at least five Paleoindian components were deposited in the central sinkhole. The age of each archaeological component is listed in Table 14.1. A selection of lanceolate points from the Page-Ladson site is shown in Fig. 14.1.

The oldest component includes debitage and human altered bone and occurs in Unit 3 along with a rich array of Pleistocene faunal remains. This component is designated Early Paleoindian I. Figure 14.2 presents a plan view of Unit 3 surface as exposed in Test F. A second archaeological component, albeit meager, is designated Early Paleoindian II and represents an isolated debitage flake deposited in Unit 4L. A third, Clovis-age component is represented by another isolated debitage flake in the middle part of Unit 4U. The fourth component consists of at least one debitage flake from a Middle Paleoindian context that may represent Suwannee, since a number of Suwannee points were reported as surface recoveries from displaced context.

Table 14.1 Chronology of in situ *archaeological components at the Page-Ladson site*

Component	*Artifact count*	*Stratigraphic Unit and number of statistically related dates averaged*	*Maximum–minimum range of ^{14}C dates in the sample*	*Average of statistically related ^{14}C dates*	*Two sigma calendar year range (cal BP)*	*Relative area under probability distribution*
Early Paleoindian-I	11[1]	Unit 3 ($n = 7$)	12,570 ± 100 12,370 ± 90	12,425 ± 32	15,405 14,146	1.00
Early Paleoindian-II	1	Unit 4L ($n = 3$)	12,310 ± 50 12,260 ± 60	12,289 ± 30	15,408 13,865	1.00
Early Paleoindian Clovis-age	1	Unit 4U middle three sets of $n = 2$ related dates	11,790 ± 50 11,240 ± 90	11,732 ± 105 11,270 ± 100	14,980 13,013	1.00
Middle Paleoindian	1[2]	Unit 4U top, ($n = 2$)[3]	10,970 ± 100 10,600 ± 70	10,721 ± 57	12,983 12,407	1.00
Late Paleoindian	21	Unit 5 (2, samples from top of Unit 5)	10,360 ± 115 10,016 ± 124	10,200 ± 84	12,359 11,342	1.00

[1] Includes nine lithic artifacts and altered mastodon bones including a cut-marked tusk, alveolus section broken from skull and longitudinal fractured thoracic spine with impact crush-mark on distal end.

[2] One and possibly a second specimen although the second specimen was recovered on the contact of Units U4 and U5

[3] These dates are not statistically related nevertheless they were averaged. The samples were derived from the uppermost part of Unit 4, one from Test C to the south and the other from Test F to the north. The surface of Unit 4 was obliquely truncated by erosion prior to the deposition of Unit 5 (Dunbar, 2002) accounting for the difference in age.

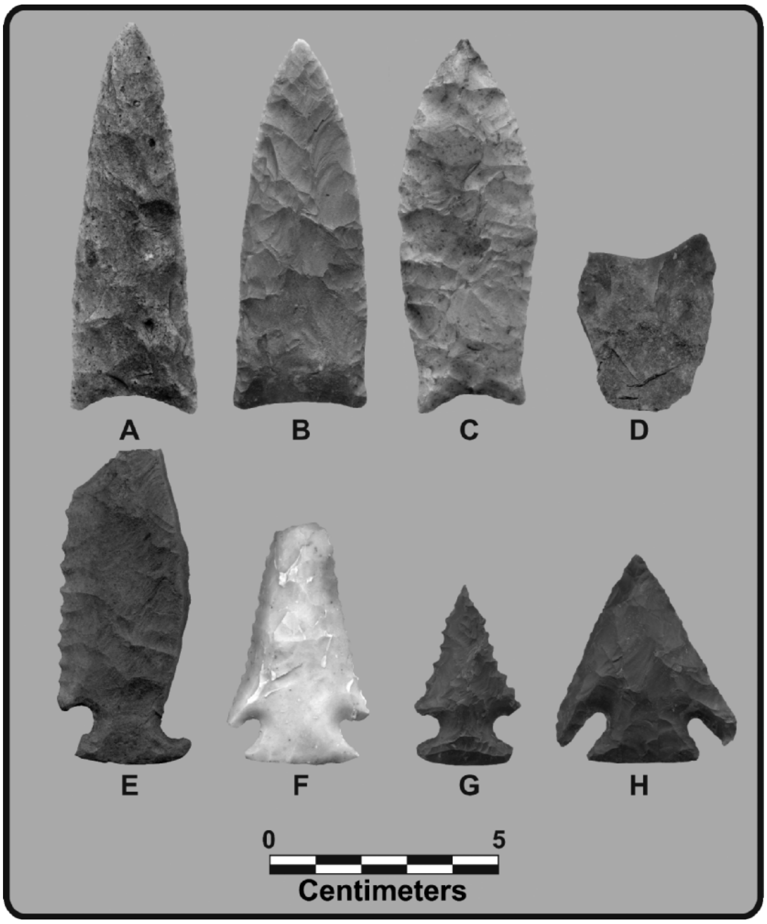


Figure 14.1 Selected Lanceolate Points from Page-Ladson site. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

Above the Middle Paleoindian component, Unit 5 contained a fifth Late Paleoindian component.

There were no diagnostic artifacts recovered from any of the Paleoindian components at the Page-Ladson site. Therefore this fails to meet the archaeological criteria for confirmation as a true Clovis or Suwannee site due to the lack of formalized, diagnostic artifacts, particularly projectile points indicative of a time index (Dincauze, 1984). However, all archaeological criteria are fulfilled at the Page-Ladson site; perhaps the most important of which is stratigraphic site integrity. In other chapters the depositional agents, environments, and chronology of deposition have been discussed in detail. Most radiocarbon assays taken from the same stratigraphic unit or level within the unit were determined to be statistically related

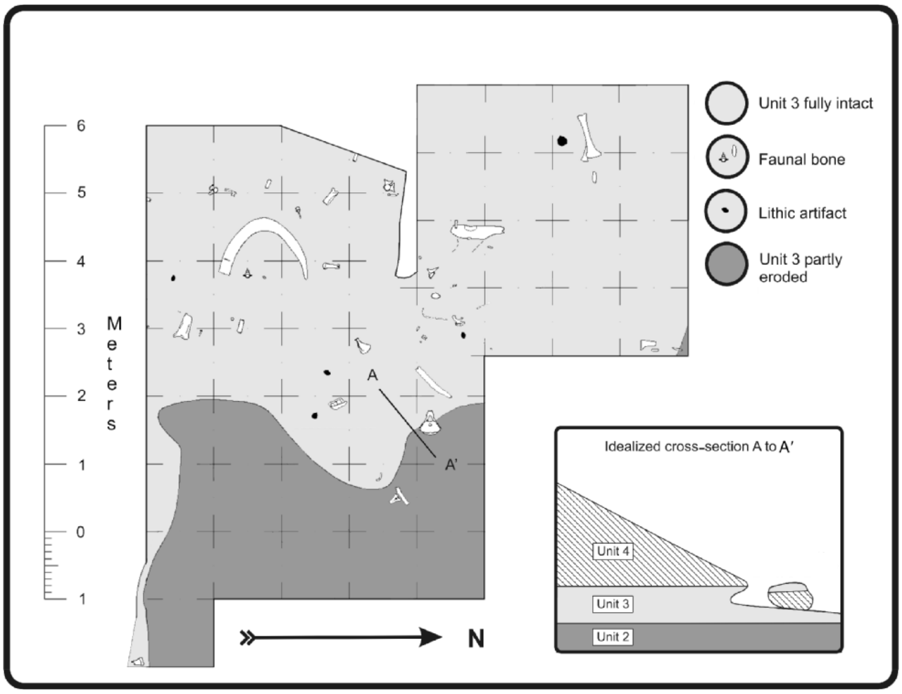


Figure 14.2 Plan view of Unit 3 in Test F.

and could be averaged. The radiocarbon samples collected during controlled excavation of the site provided no anomalously young evaluations mixed among any older assemblages. The artifacts, bones, botanical material, coprolites and other materials collected within a unit or level within the unit, are in unequivocal association with time.

Even though no diagnostic artifacts were recovered *in situ* from the Page-Ladson Paleoindian components, the artifacts recovered are not crude or simple and they are not geo-facts, they are artifacts. For example, one of the debitage flakes recovered from Unit 3 is a ground platform, bifacial reduction flake struck from a large stone tool. In addition, the debitage flakes recovered from Unit 3 represent at least three different textures of coastal plains chert indicating there were at least three different tools being re-sharpened. One of the debitage flakes from Unit 3 displays use as a non-diagnostic, expedient tool. Finally, tectonic forces do not affect Florida and there is no naturally occurring source of chert outcropping around the sinkhole rim. In other words, the null hypothesis that the lithic artifacts were natural geo-facts can be positively rejected.

The Early Paleoindian-I and Late Paleoindian components have produced multiple artifacts that were deposited during episodes of low water table conditions. The components held within Unit 4 represent isolated losses or discards during high water table conditions.

14.5.3 Artifacts from *In Situ* Context

Table 14.2 lists the artifacts recovered by level in Paleoindian context at the Page-Ladson site.

14.5.3.1 Early Paleoindian I

The assemblage of artifacts from Unit 3 included a utilized flake, debitage, a cut-marked *Mammut americanum* tusk, and crushed and green fractured thoracic spine (Table 14.2). The lithic artifacts are depicted in Fig. 14.3. A broken section *Mammut americanum* alveolus was recovered very near the tusk. Its close proximity seems significant because the cut-marks on the tusk are located above the alveolus line on a part of the tusk that was originally inside the animal's skull (Chapter 12). Many other *Mammut americanum* bones were recovered along with numerous other species of large-, medium-, and small-sized animals (Figs. 14.4 and 14.5, animals).

Early Paleoindian-I component, held in Unit 3, is the most solidly dated, stratigraphically sound Paleoindian component east of the Mississippi River that has yielded pre-Clovis evidence of human presence. Unit 3 also represents one of the most toughly investigated and abundantly dated Older Dryas phase sites in the world. The preservation of bone and botanical specimens is generally superb in Unit 3 and provides the type of information needed to enhance the inter-regional correlation being called for by the INTIMATE project group, a multi-national effort to improve the chronological precision and understanding of the late Pleistocene event stratigraphy (Lowe *et al.*, 2001; Lowe, 2002). For example, analysis of strontium isotopes from annual growth rings of the tusk showed the mastodon had migrated between the granitic region of north Georgia to the limestone region of Florida and had thrived in both settings prior to the animal's death in the Page-Ladson sinkhole (Hoppe *et al.*, 1999). Among the preserved remains in the Early Paleoindian-I component is the partial gut-track digesta of *Mammut americanum* composed of twigs and branches (Webb *et al.*, 1992; Newsom *et al.*, 1993). Analysis of carbon isotopes from the annual growth rings of the tusk corroborated the digesta analysis and showed that the animal was indeed a browser (Koch, 1998; Koch *et al.*, 1998) of trees, shrubs, and herbs (Webb *et al.*, 1992).

14.5.3.2 Early Paleoindian II, Clovis Age, and Middle Paleoindian

Isolated debitage flakes were recovered from Unit 4L, 4U middle, and Unit 4U upper indicating human activity, although perhaps sporadic, did take place near the sinkhole. The artifact from Unit 4L represents another pre-Clovis occurrence, however negligible. The other isolated flakes from Unit 4U middle and 4U upper probably represent Early Paleoindian Clovis and Middle Paleoindian, Suwannee components.

14.5.3.3 Late Paleoindian

A total of 21 artifacts were recovered in Unit 5 within a 12 m^2 area in Test C. Most of the specimens are debitage flakes, but also include a few tools, among them, a non-diagnostic biface perform. Notably absent from Unit 5 were adzes and other formalized wood working tools related to the younger, Early Archaic Bolen component that lies on and above the Unit 5 surface.

Table 14.2 Artifacts recovered in situ *from archaeological components Test C–F area*

Type of artifact	*Late Paleo*[1]*: Unit 5*	*Middle Paleo*[1]*: Unit 4 upper*	*Early Paleo*[1] *Clovis-age: Unit 4U middle*	*Unit 4U lower*	*Unit 4L–4U contact*	*Early Paleo*[1]*: II Unit 4L*	*Unit 3–4 transition*	*Early Paleo*[1]*: I Unit 3*	*Unit 2*	*Unit 1U*	*Type totals*
Biface, preform	2	0	0	0	0	0	0	0	0	0	2
Uniface, formalized tools	2	0	0	0	0	0	0	0	0	0	2
Uniface, utilized	1	0	0	0	0	0	0	1	0	0	2
Debitage, all	15	1	1	0	0	1	0	7	0	0	25
Production, cores	1	0	0	0	0	0	0	0	0	0	1
Production possible, hammerstone	0	0	0	0	0	0	0	1	0	0	1
Bone, tusk cut by lithic	0	0	0	0	0	0	0	1	0	0	1
Bone, crushed thoracic spine	0	0	0	0	0	0	0	1	0	0	1
Artifacts per unit totals	21	1	1	0	0	1	0	11	0	0	35

[1] Paleo Paleoindian.

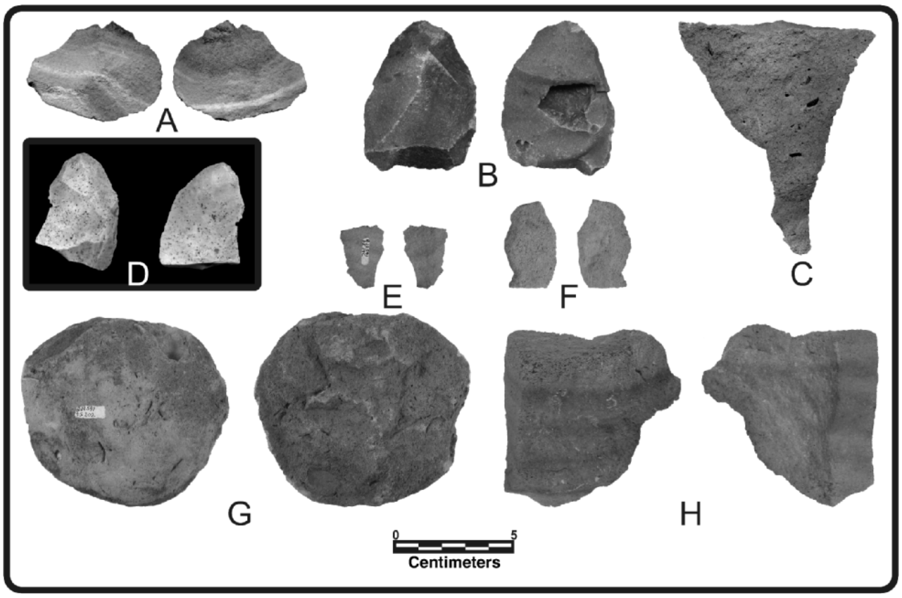


Figure 14.3 Lithic artifacts from Unit 3, the Early Paleoindian-I component of the Page-Ladson site. Photo by Aucilla River Prehistory Project.

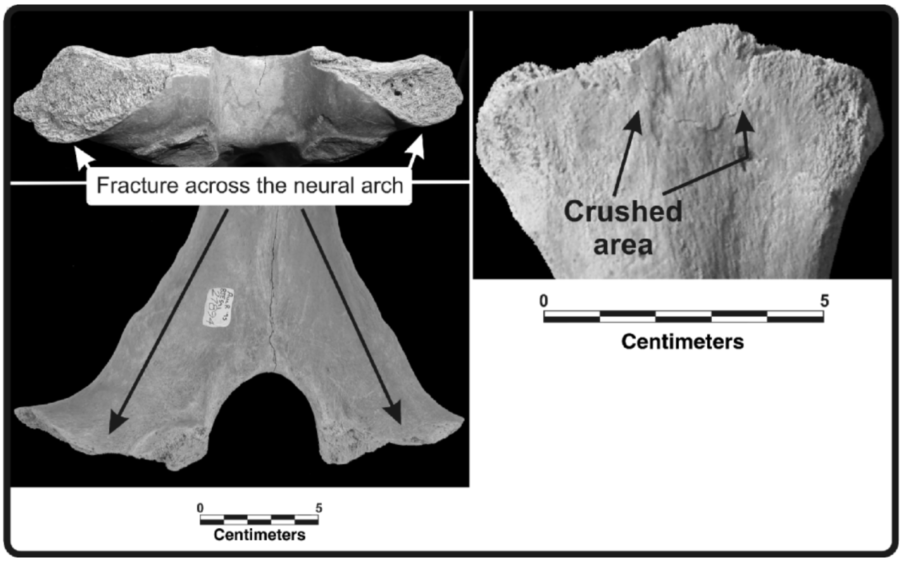


Figure 14.4 Mastodon thoracic spine with green fracture across the neural and impact-mark on the dorsal side of the distal spine. Photo by Aucilla River Prehistory Project.

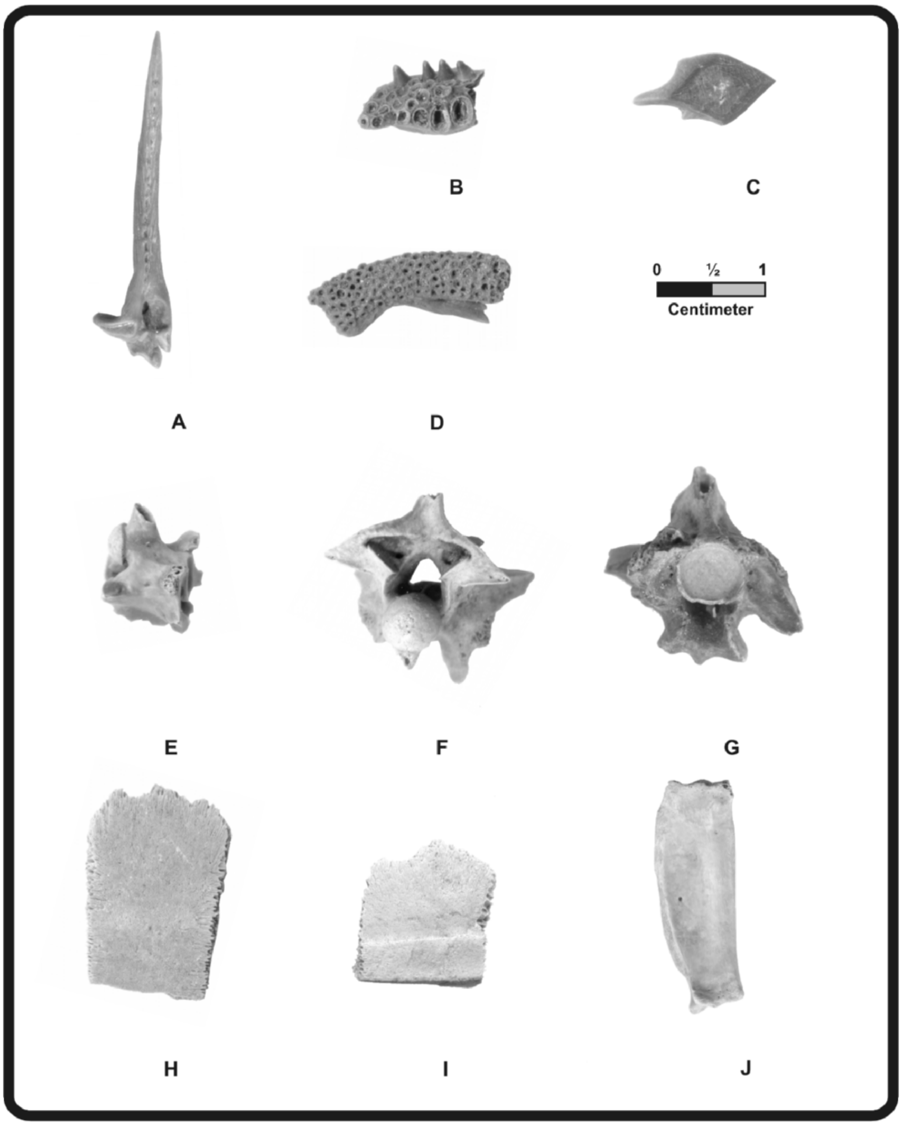


Figure 14.5 Example of small bone assemblage from Unit 3 at the Page-Ladson site: A – *Ictaluridae* (pectoral spine), B and D – *Osteichthyes* (unidentified cranial), C – *Lepisosteus* spp. (scale), E, F, and G – *Serpentes* (vertebra), H and I – *Kinosternidae* (carapace and marginal), J – *Aves* (phalanx). Photo by Aucilla River Prehistory Project.

14.5.4 Artifacts from Displaced Context

The artifact assemblage recovered from displaced context at the Page-Ladson site included a number of Paleoindian points.

Among the points recovered from displaced context are two forms that are excurvate- to parallel-sided, lanceolate-shaped points with margins that have been basally ground for hafting, however, they are not fluted. Both are not Clovis or any other defined type, yet they are Clovis-like. They are Plainview-like but are not Plainviews, a regional Southwestern type. One form was manufactured by substantial reduction of a once thicker, biface preform (Fig. 14.1A, B). The other form was manufactured differently from a thin flake that was moderately retouched by percussion flaking and then marginally finished by pressure flaking (Fig. 14.6C, D).

The unfluted points made from bifacial thinning flakes at times displays part of the original thinning flake surface at the base, therefore has the appearance of being fluted (Fig. 14.6E). It has been referred to as Page-Ladson type (Dunbar and Hemmings, 2004) and the specimens from the Page-Ladson site are correspondingly similar to the specimens recovered from the Wakulla Springs Lodge site, Simpson-age Paleoindian component (Fig. 14.6B) (Jones and Tesar, 2004).

The Page-Ladson type appears to be a candidate for the Early PaleoindianI assemblage of artifacts recovered from context at the Page-Ladson site. It is also worth noting that one of the specimens from the Page-Ladson site appears to be manufactured

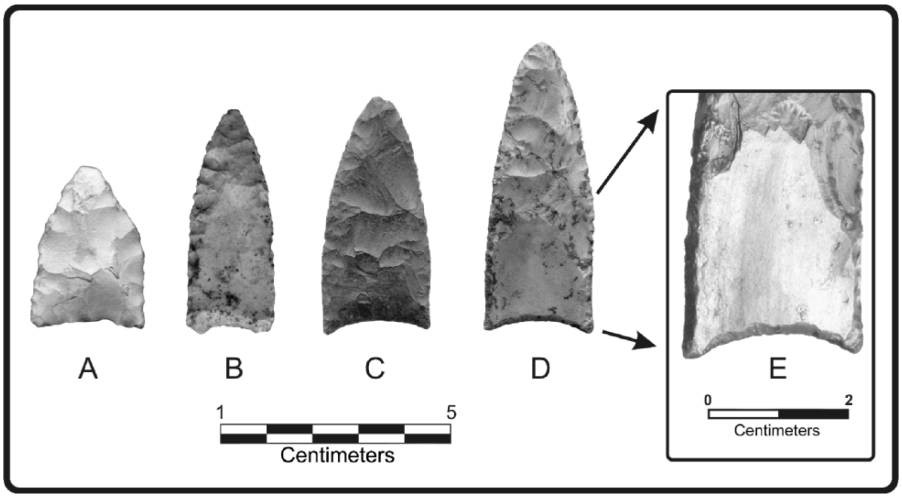


Figure 14.6 Page-Ladson and Page-Ladson like points manufactured on thin flakes. (A) Miller Plain type from the ~15,000 radiocarbon-year level of the Cactus Hill site, Virginia, (B) Page-Ladson type from the Wakulla Springs Lodge site, (C, D, and close-up of D depicting flake scar is E) Page-Ladson type from the Page-Ladson site. Photo by Aucilla River Prehistory Project.

from Flint River jasperoid, a Georgia chert type (Fig. 14.6D). Florida Paleoindian sites are notorious for having tool kits made from local as opposed to imported chert sources (Daniel and Wisenbaker, 1987). The jasperoid specimen represents an occurrence more typical of Clovis band mobility elsewhere in the US where stone tools were made from lithic sources, used, and then discarded far away from their source of origin (Stanford, 1991:2). Therefore, the jasperoid point from the Page-Ladson site appears to be the first formalized tool from a Florida Paleoindian context that was imported from outside Florida. Coincidental or not, the acquisition of Flint River chert for point manufacture means that it was obtained along the same migration path as the *Mammut americanum* that eventually met its demise at the Page-Ladson site (Hoppe *et al.*, 1999) ~12,400 ^{14}C BP.

The other, unnamed type of lanceolate point from Page-Ladson was manufactured in a very different manner. It was bifacially reduced from large and much thicker preform blank. The lithic material selected for point manufacture was also of a different quality. One of the three specimens was manufactured from high quality microcrystalline chert, the second from a fine-grained chert of lesser quality, and the third from a medium-grained, vuggy chert of inferior quality. All of the specimens have slightly concave to almost flat bases. The variation in the chert quality, absence of a noticeable basal concavity, as well as the lack of any distinctive edge attributes suggest this type was derived from a different cultural tradition or was one among other contemporary types used by a culture for different functions or hunting modes. It is different from the established Paleoindian types in Florida (Bullen, 1975) and Alabama (Cambron *et al.*, 1990). Attributes that indicate this point is a Paleoindian type include occasional overshot flaking, lanceolate shape, and lateral and basal grinding of the hafting area. None of the specimens are fluted and the two intact specimens have acute tips. It is an unfluted, recurvate- to parallel-sided point type that may or may not be related to the type manufactured on thin flakes (Fig. 14.1).

A third type of projectile point recovered from displaced context is the recurvate or waisted Suwannee point (Fig. 14.1). Waisted Suwannee points are most frequently laterally thinned, are not fluted, and have acute distal tips. However, a small percentage of waisted Suwannee points do have multiple flute scars that effectively thin the base and/or overshot flake scars that serve to laterally thin the blade cross-section. At two other Florida sites, the Ryan-Harley site (8JE1004) and Norden site (8GI40), waisted Suwannee points are associated with extinct Pleistocene faunal remains. Suwannee points are relatively placed in time as Middle Paleoindian.

Yet a fourth type of artifact recovered from the Page-Ladson site is made from Proboscidean ivory tusks (Fig. 14.7). They are carved ivory points or foreshafts. These artifacts were manufactured from long splinters of mastodon or mammoth tusks. They were shaped into tubular rods, sharpened on one end and obliquely truncated and basally roughened on the other to facilitate hafting. At least one ivory shaft from the Sloth Hole site in the lower Aucilla River has been radiocarbon dated to 11,050 ^{14}C BP, Clovis age (Hemmings, 2004). The hafting end of another specimen was recovered from the Ryan-Harley Suwannee point site; therefore it is possible that ivory shafts were also manufactured by Suwannee point-making people. The age of the

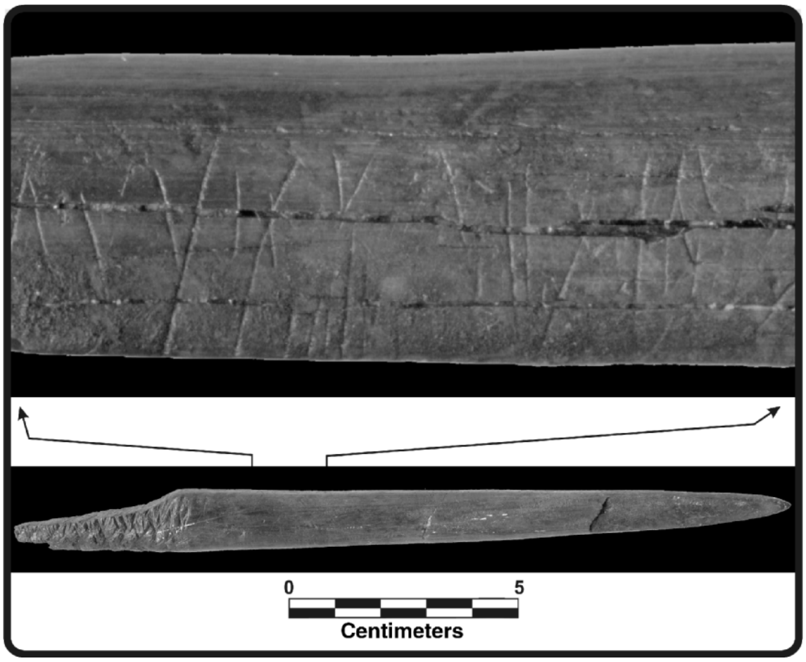


Figure 14.7 Ivory shaft. Photo by Aucilla River Prehistory Project.

Page-Ladson ivory shafts is assumed to be Clovis or Suwannee (~11,500 ^{14}C BP to 10,500 ^{14}C BP).

Course-grained or large-grained chert accounts for about 4% (*n* = 106) of the total debitage count recovered from displaced context in the Page-Ladson sinkhole. A few tools of large-grained chert were also recovered. The occurrence of this small, but persistent sample of artifacts of large-grained chert is worthy of note because two of the artifacts from the Early Paleoindian-I component are also made from large-grained chert. Paleoindian use of microcrystalline chert in the Southeastern US has been well documented (Goodyear, 1983). The use of large-grained, presumably poorer quality chert has not been documented or at least mentioned as a material utilized by Paleoindians. One of the Early Paleoindian artifacts from Unit 3 that displays utilization is made from large-grained chert. As previously mentioned one of the points from displaced context at the Page-Ladson site is also made from inferior quality chert. Our investigations of the site led to the recovery of a large-grained scraper, abraders, and hammerstones. Therefore, it also appears possible that certain classes of Paleoindian stone tools were purposely made from large-grained chert. Perhaps durability coupled with intended use played an important role in the selection of lithic resources for stone tool manufacture. Projectile points may have been best suited for microcrystalline chert manufacture, whereas abraders and hammerstones, as well as certain classes of scrapers, and expedient tools were well suited for large-grain chert manufacture.

14.6 Discussion

One view of the Southeastern cultural–temporal transition from Paleoindian to Early Archaic is placed at ~10,500 ^{14}C with the development of lanceolate Dalton and other contemporary tool traditions. The premise for this assignment is based on the concept of adaptive continuity and the assumption that megafauna had become extinct prior to the Younger Dryas onset ~11,000 ^{14}C BP (Meltzer and Smith, 1986; Meltzer, 1988), but this is a distinctly Southwestern view (Haynes, 1991).

The date of Pleistocene extinction has been extensively investigated and accurately evaluated in the Southwestern US (Haynes, 1984; Meltzer *et al.*, 1986; Haynes, 1991; Haynes, 1993; Haynes *et al.*, 1999). However, the Southwestern chronology should not be imposed on the Southeastern US. Clearly the chronostratigraphy and geoclimatic data for the Southeastern US differs greatly from that of the Southwestern US (see Chapter 5). The timing of extinction (or more correctly extirpation) of a species from one region does not mean it disappeared in other regions, particularly at the same time. Species extinction is often time-transgressive. Thus the estimated end of the Rancholabrean mammal age, now placed at ~9,500 ^{14}C BP, came with the extinction of the last large-bodied Pleistocene mammals in North America (Bell *et al.*, 2003:286 and 295). And the Southeastern data now suggest that extinction was regionally complete by the latter part of the Younger Dryas, prior to ~10,000 ^{14}C BP (Dunbar *et al.*, in press; Vojnovski and Dunbar, in press).

Returning to the concept of adaptive continuity from Paleoindian to Early Archaic life ways, adaptive continuity assumes a more gradual, less eventful cultural transition during the shifts of late Pleistocene and early Holocene climate and the resulting biotic rearrangements (Daniel, 1998). Adaptive continuity is opposed to the notion that cultural readaptation was brought about by Pleistocene megafauna extinction. It also opposes the notion of extinction caused by the over hunting of blitzkrieging Paleoindians over the North American landscape. This hypothesis of adaptive continuity was enunciated by Meltzer and Smith, and again by Grayson and Meltizer (Meltzer and Smith, 1986; Grayson and Meltzer, 2003) as a general foraging alternative to Paul Martin's Pleistocene overkill hypothesis (Martin, 1967).

Both Martin's and Meltzer's views have come into serious question based on the recent findings by Kathryn Hoppe related to mammoth migration patterns in the Southeastern and Southwestern US (Hoppe *et al.*, 1999; Hoppe, 2004). Based on the isotope analysis of bones from numerous sites, Hoppe determined that mammoth were not long-distance migratory animals. At the Blackwater Draw, Clovis site in New Mexico two different mammoth groups occupied two different but overlapping ranges of about 250 km or less. In addition, the multiple occurrences of mammoth remains in Southwestern Clovis sites do not represent mass kills of one event; rather they represent multiple Clovis procurements of individual mammoths during different events (Hoppe, 2004:141–142). Hoppe's finding supports the notion of an extended, continuing, and purposeful Clovis procurement strategy. It does not support the concepts of rapid overkill (Martin, 1967) or general foraging that primarily excluded the procurement of megafauna (Meltzer and Smith, 1986; Meltzer, 1988).

However, the most important implication of her findings relates to hunting strategy. If mammoths did not undertake long-range migrations similar to African elephants, then the notion of Paleoindians following migrating herds is also not true. Therefore a revised strategy might be that Paleoindians, most likely Clovis people in North America, began migrating to new territory as the mammoth populations within the range they had been exploiting were depleted. This takes time, something that the blitzkrieg hypothesis does not allow and the hypothesis of adaptive continuity ignores as a rational possibility.

Viewed from another perspective both the blitzkrieg and general foraging hypotheses are polarized and represent either/or extremes. An alternative hypothesis proposed here suggests that Pleistocene megafauna, particularly herding animals such as horse, bison, Proboscideans, etc., were an integral part of the Paleoindian diet, however megafauna extinction was not the result of blitzkrieg over hunting. Megafauna extinction did result in the need for cultural change. This hypothesis suggests *disrupted continuity* during the transition from Paleoindian to Early Archaic.

Meltzer's general foraging hypothesis has become bound by selectively including and excluding evidence (Hemmings *et al*., 2004). Meltzer's most recent machination states:

> The matter returns, as it must, to the empirical record, and there the facts are clear: very few kill sites have been found – and then only mammoth and mastodon – this in spite of decades of intensive searching, and a rich paleontological record of many of these animals (we do not lack for fossils of this age). ... Since specialized big-game hunting was not a significant component in Clovis subsistence, we still face the question of why (or how) Clovis groups moved so far, so fast (Meltzer, 2004:552).

That begs the question, what should be included as evidence of Paleoindian subsistence; butchered marked bones, handcrafted bone tools, Pleistocene megafauna kill sites, or just what part of this evidence? For example, can bone tools made from megafauna species other than Proboscideans be counted as evidence? Certainly culturally modified Pleistocene megafaunal remains have been found in the Southeastern US, although not necessarily at kill sites and not necessarily in stratified contexts (Jenks and Simpson, 1941; Simpson, 1948; Bullen *et al*., 1970; Webb *et al*., 1984; Dunbar *et al*., 1989; Dunbar *et al*., 1991; Dunbar and Webb, 1996; Webb and Hemmings, 2001; Hemmings, 2004, Hemmings *et al*., 2004; Dunbar *et al*., in press; Vojnovski and Dunbar, in press). Exacerbating the problem is the survivability of Pleistocene bone east of the Mississippi River. Bone preservation is non-existent in the vast majority of Paleoindian sites. Hemmings (2004) best counters Meltzer's exclusions of the documented evidence of Paleoindian and megafauna interactions for Clovis sites nationwide. Accordingly Hemmings has shown that Clovis people virtually exploited all known species of now extinct North American megafauna and he has done so in a conservative way.

As a result I would modify Meltzer's statement of the "facts" by saying there have been very few Paleoindian campsites with bone preservation (as opposed to kill sites) identified. Campsites are the most likely places to hold information about Paleoindian subsistence. At campsites a wide range of tools made from stone, bone, shell, or wood were manufactured, maintained, and lost in archaeological context. It is also where the greatest variety of food remains is likely to have accumulated and therefore provide direct evidence of Paleoindian dietary patterns.

The paleontological record in the Southeastern US has yielded unexpected evidence about the variety and population of Neogene Period grazing animals. This is an important consideration if we are to think about the limitations and opportunities that climate and biotic diversity offered Paleoindian groups in the Southeast. *Mammuthus* first appear in the Florida paleontological record at the beginning of the Irvingtonian (land mammal age ~1.8 Ma cal years BP)(Bell *et al*., 2003). Prior to that, during the Blancan (land mammal age), Camelidae species (camel and llama family) were primarily browsers. Stable isotope evidence has been used to trace an evolutionary change in the grazing niche with the introduction of the *Mammuthus*.

> Across the Blancan/Irvingtonian boundary, *Hemiauchenia* [a camelid species] changes from a strict C_3 browser to a mixed feeder. This significant change is opposite that which we might expect with the dispersal of large C_4 grazers like *Mammuthus* [mammoth] into Florida because competition for grass would supposedly force other animals to consume more browse. For this reason, it is possible that this change may not be due to competition from the immigrant *Mammuthus*, but could be due to a change in the flora, possibly moving toward a more open, savanna-like habitat. It is also possible that the change in flora might be due to the effects and behavior of *Mammuthus* to maintain open habitats, as seen by *Loxodonta* [elephant] in African ecosystems today (Feranec and MacFadden, 2000:166).

Therefore, if the introduction of *Mammuthus* effectively increased grazing space in a way that favored an increase of grazing species, should not the extinction of *Mammuthus* serve to reduce open habitat and grazing possibilities? Another Pleistocene Proboscidean, *Mammut* may also have played a role. It, like *Mammuthus,* was also capable of impacting the flora. Although a browser, *Mammut* had the body size needed to do things such as uproot or otherwise damage trees. A logical assumption might be that the eastern woodlands encroached on grazing habitats after the extinction of *Mammuthus* and *Mammut*: a factor that may have placed *Equus, Bison*, and the Camelidae in a precarious position. The point being, the extinction of two underpinning species of Proboscideans resulted in a cascade effect and led to the extinction of other browsers. In Florida medium-sized herd-animals such as *Equus* and Camelidae became extinct and *Bison* was extirpated to territory west of the Mississippi River. A result of the Late Pleistocene extinction in the Southeastern US was the replacement of herd-animal congregations by the more solitary, woodland browser: the white-tailed deer, *Odocoileus virginianus*.

To further explore the idea that *Bison antiquus* became extinct and was not replaced by *Bison bison* in the Southeast US requires consideration of the post-Paleoindian prehistoric record as well as the colonial historic record. There are two accounts of possible *Bison bison* remains in post-Pleistocene prehistoric context in Florida, and both are equivocal. For example the occurrence of a *Bison* or *Bos* thoracic vertebra from an Ft Walton-age component at the Waddells Mill Pond site (8Ja65) is equivocal not only because the bone element was not diagnostic of *Bison*, but also because the faunal bone assemblage included *Sus scrofa* (pig) a European introduced species. This and other artifacts suggested the site or one of its components is colonial (Percy, 1974). An unidentified Weeden Island midden on the Chassahowitzka River in Citrus County, Florida was reported to have included a *Bison* bone from the shell midden. However, there are no records of the investigation, the site was not recorded, and the specimen, reported by Wilfred T. Neill, was lost or not collected (Robertson, 1974). Actually there is no evidence for the occurrence of Holocene *Bison* in the Southeast until historic colonial times, after which it fluoresces until the early 19th century (Rostlund, 1960; Rucker, 1992).

At the end of the Pleistocene the eastern woodlands encroached upon the former patchwork environs that had existed earlier as open wooded habitats, parklands, and savannas (Webb *et al*., 2004:524). Within these so-called pristine forests Native Americans eventually developed agriculture and the technology necessary to reestablish open fields for crop production, which once again allowed open wooded habitats, parklands, and savannas to be established (Denevan, 1992:371–372). Yet there is no evidence of *Bison* in the Southeastern US during the prehistoric part of the Holocene (Rostlund, 1960; Rucker, 1992). *Bison* migrations began during historic, colonial times after the effects of European disease had taken their toll and Native American populations had been decimated. By 1650 Native American populations had been reduced by 90%, but the European occupation of the land remained substantially low until about 1750 (Denevan, 1992:379). It was the absence of substantial human population that allowed *Bison* to migrate into the Southeast US because the croplands were mostly fallow abandoned fields which provided good graze (Rostlund, 1960:401–403). The *Bison* population is estimated to have peaked in the Southeast around 1700 and then declined (Rostlund :403). The last account of *Bison bison* in Florida was in 1821 and the southern extreme of their migrations was in the Manatee River area near Tampa, Florida (Rucker, 1992:120). Thus, similar to the end of the Pleistocene in the Southeast US, the species, *Bison bison* once again was extirpated west as the eastern woodlands encroached and human populations returned to tend agricultural fields.

The absence of Holocene *Bison* in the Southeast has a number of important archaeological implications. Among the most obvious is the abrupt termination of big game hunting by the Preboreal onset ~10,000 ^{14}C BP. This is unlike the scenario of continued *Bison* hunting subsequent to the extinction of other megafauna west of the Mississippi River during Folsom times (Haynes, 1991; Haynes *et al*., 1999).

A recent study of the transition from Paleoindian to Archaic life ways at the Wilson-Leonard site in Central Texas provides evidence of the transition that took place on the periphery of *Bison* hunting territory. At ~10,000 ^{14}C BP, the abandonment of lanceolate Plainview points in favor of expanding stem Wilson points (a notched to notched-like point) is believed to be related to a decline in large-sized animal hunting to a broad spectrum pattern more reliant on hunting medium- to small-sized animals. The Wilson-Leonard site is located in the Southern Plains where *Bison* populations waxed and waned during the Holocene in concert with climate change. The shift in dietary patterns at the site is believed to be due to *Bison* availability (Bousman *et al*., 2002).

Another consideration of the Southeastern evidence indicates Florida in particular supported different types of Pleistocene habitats which supported a unique combination of northern, western, tropical, and endemic species (Webb and Wilkins, 1984; Graham *et al*., 1996; Ellis *et al*., 1998; Bell *et al*., 2003; Webb *et al*., 2004). The compilation of FAUNMAP represented analyses of 2945 late Pleistocene fossil localities in the US. The results of analyzing the database showed there was faunal heterogeneity during the late Pleistocene that was replaced by Holocene homogenous populations. Florida stands out because it was distinct from other faunal clusters during the Pleistocene; however, after the late Holocene, Florida clusters with the rest of the Southeastern US (Graham *et al*., 1996:1603). It is within this context that assemblages of heterogeneous faunas existed in "true paleocommunities reflecting environments that no longer exist" and, during the terminal Pleistocene, began "to pull apart in very complex patterns" (Webb *et al*., 2004:524).

14.7 Conclusions

The intertwined data of megafaunal extinction and cultural change in the Southeast US do not support the notion of adaptive continuity for the Paleoindian to Early Archaic transition. The data suggest instead rapid and significant disruption in both faunal and floral assemblages. In order to survive human cultures developed radical new adaptations to Nature's new demands. The transition from Paleoindian to Early Archaic had a distinctly different outcome in the Southeast as compared to the traditional view in the Southwest US. In Florida it appears likely that cultural adaptation from Paleoindian to Archaic life ways took place toward the end of Suwannee Point times and had been completed by Bolen Point times. This, of course, remains to be demonstrated at more sites. Continued research at the Norden and Ryan-Harley and other Suwannee age sites will ultimately resolve this issue.

The Florida Paleoindian Period includes not only the continent-wide Clovis culture (Hemmings, 2004), but also includes the seemingly regionalized Suwannee and Simpson cultures. Evidence from the Page-Ladson site suggests the Page-Ladson lanceolate is yet another point-making tradition that is Clovis-like in terms of the outline shape of parallel-sided to excurvate-sided points, however, that is where the similarity ends. In terms of their morphological features of manufacture, a sub-form of the Page-Ladson lanceolate is similar to the smaller, "Clovis-like" points recovered from the Wakulla Lodge site with a Simpson stone tool assemblage (Jones and Tesar, 2004). If the Page-Ladson lanceolate type proves to be the missing diagnostic type associated with the Early Paleoindian-I component, it does not stand alone as an isolated occurrence because it also shares similar traits with the Miller Plain type found in pre-Clovis context elsewhere in the eastern US (McAvoy and McAvoy, 1997).

Simpson and Suwannee points as detailed above, are mostly a Florida phenomena that extend into the Coastal Plain of surrounding states. The distribution of Simpson and Suwannee points appears to mirror the distinctive paleofaunal communities that once occupied Pleistocene Florida (Graham *et al*., 1996; Ellis *et al*., 1998; Bell *et al*., 2003; Webb *et al*., 2004). There is only one well-documented Simpson site in Florida and it poses more questions than answers. Chief among these questions is where does the Simpson tool assemblage fit in time. It is clearly Paleoindian, more scarce than Clovis, and includes small projectile points that most closely resemble the Miller Plain in manufacture. There is much to be worked out about the Paleoindian chronology in the extreme Southeastern US.

Research at the Page-Ladson site resulted in the first detailed chronostratigraphic and geoclimatic reconstruction in the Southern US. This research provides the framework for understanding the region's Paleoindian cultural history to be more fully discussed in Chapter 20 of this volume. The record begins with credible evidence of Paleoindian activity during the Older Dryas about 12,425 ± 32 ^{14}C BP (n = 7) and extends upward into the Early Archaic.

The INTIMATE project group recently suggested:

> The INTIMATE Event Stratigraphy scheme has been proposed as a *standard* against which to compare regional stratigraphic schemes, and as a basis for establishing the synchroneity (or asynchroneity) of comparable events or sequences of events throughout the North Atlantic region. ... One question that emerges is whether it would be better in the future to channel resources towards the generation of high-resolution radiocarbon data sets from carefully selected, key regional sequences, rather than dilute them by supporting a rather large number of more limited investigations (Lowe *et al*., 2001:1178–1180).

The Page-Ladson site is a key regional sequence, which has shed light on the regional event stratigraphy. This event stratigraphy brackets different episodes of human activity in the context of successive Pleistocene environments using the approach in development by the INTIMATE project group. Adopting its approach, which promises to be a productive direction for the future of Paleoindian research in the Southeastern US, has already benefited the Aucilla River Research Project.

References

Adovasio, J. M., D. Pedler, J. Donahue, and R. Stuckenrath. 1999. No Vestige of a Beginning Nor Prospect for an End: Two Decades of Debate on Meadowcroft Rockshelter. *Ice Age Peoples of North America: Environments*, *Origins, and Adaptations*, editors R. Bonnichsen, and K. L. Turnmire, pp. 416–431. Center for the Study of the First Americans, Corvallis, OR.

Anderson, D. G. 1996. Models of Paleoindian and Early Archaic Settlement in the Lower Southeast. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 29–57. University of Alabama Press, Tuscaloosa, AL.

Anderson, D. G., L. O'Steen, and K. E. Sassaman. 1996. Environmental and Chronological Considerations. *The Paleoindian and Early Archaic Southeast*, editors D. G Anderson, and K. E. Sassaman, pp. 3–15. University of Alabama Press, Tuscaloosa, AL.

Antevs, E. 1954. Climate of New Mexico During the Last Glacio-Pluvial. *Journal of Geology*, 62 (2):182–191.

Antevs, E. 1962a. Late Quaternary Climates in Arizona. *American Antiquity*, 28 (2):193–198.

Antevs, E. 1962b. Transatlantic Climatic Agreement Versus C (Super 14) Dates. *Journal of Geology*, 70 (2):194–205.

Balsille, J. H., Means, G. H., Dunbar, J. S. 2006. The Ryan/Harley Site: Sedimentology of an Inundated Paleoindian Site in North Florida. *Geoarchaeology: An International Journal*, 21 (4): 363–391.

Bell, C. J., E. L. Lundelius, A. D. Barnosky, R. R. Graham, E. H. Lindsay, D. R. Ruez, H. A. Semken, S. D. Webb, and R. J. Zakrezwski. 2003. The Blancan, Irvingtonian, and Rancholabrean Mammal Ages. *Late Cretaceous and Cenozoic Mammals of North America: Biostratigraphy and Geochronology*, editor M. O. Woodburne, pp. 232–314. Columbia University Press, New York.

Bonnichsen, R., and K. L. Turnmire. 1991. *Clovis Origins and Adaptations*. Center for the Study of the First Americans, Oregon State University, Corvallis, OR.

Bousman, C. B., M. B. Collins, P. Goldberg, T. Stafford, J. Guy, W. B. Baker, D. G. Steele, M. Kay, A. Kerr, G. Fredlund, P. Dering, V. Holiday, D. Wilson, W. Gose, S. Dial, P. Takac, R. Balinsky, M. Mason, and J. F. Powell. 2002. The Paleoindian–Archaic Transition in North America: New Evidence from Texas. *Antiquity*, 76:980–990.

Bryan, K. 1950. The Geology and Fossil Vertebrates of Ventana Cave. *The Stratigraphy and Archaeology of Ventana Cave*, editor E. W. Haury, pp. 75–126. University of Arizona Press, Tucson, AZ.

Bryan, K., and C. C. Albritton. 1943. Soil Phenomena As Evidence of Climate Changes. *American Journal of Science*, 241:469–490.

Bullen, R. P. 1968a. *A Guide to the Identification of Florida Projectile Points*. 1, Florida State Museum, Gainesville, FL.

Bullen, R. P. 1968b. *The Collection of Florida Point Types*. Florida Archaeology Collections, Florida Museum of Natural History, Gainesville, FL.

Bullen, R. P. 1969. A Clovis Fluted Point from the Santa Fe River, Florida. *Florida Anthropologist*, 22 (1–4):36–37.

Bullen, R. P. 1975. *A Guide to the Identification of Florida Projectile Points*. revised edition, Kendall Books, Gainesville, FL.

Bullen, R. P., S. D. Webb, and B. I. Waller. 1970. A Worked Mammoth Bone from Florida. *American Antiquity*, 35 (2).

Cambron, J. W., D. C. Hulse, and D. L. DeJarnette. 1990. *Handbook of Alabama Archaeology: Part I, Point Types*. Archaeological Research Association of Alabama, Moundville, AL.

Daniel, I. R. 1998. *Hardaway Revisited*. University of Alabama Press, Tuscaloosa, AL.

Daniel, I. R., and M. Wisenbaker. 1987. *Harney Flats: A Florida Paleo-Indian Site*. Baywood Publishing Co., Farmingdale, NY.

Denevan, W. M. 1992. The Pristine Myth: The Landscape of the Americas in 1492. *Annals of the Association of American Geographers*, 82 (3):369–385.

Dincauze, D. F. 1984. An Archaeological Evaluation of the Case for Pre-Clovis Occupations. *Advances in World Archaeology*, 3:275–323.

Dolan, E. M., and G. T. Allen. 1961. *An Investigation of the Darby and Hornsby Springs Sites, Alachua County, Florida, Special Publication No. 7*. Florida Geological Survey, Tallahassee, FL.

Dunbar, J. S. 1991. Resource Orientation of Clovis and Suwannee Age Paleoindian Sites in Florida. *Clovis Origins and Adaptations*, editors R. Bonnichsen, and K. Turnmire, pp. 185–213. Center for the Study of the First Americans, Corvallis, OR.

Dunbar, J. S.2002. *Chronostratigraphy and Paleoclimate of Late Pleistocene Florida and the Implications of Changing Paleoindian Land Use*, Masters of Sciences Thesis, Florida State University, Tallahassee, FL.

Dunbar, J. S., and C. A. Hemmings. 2004. Florida Paleoindian Points and Knives. *New Perspectives on the First Americans*, editors B. T. Lepper, and R. Bonnichsen, pp. 65–72. Center for the Study of the First Americans, Texas A&M University Press, College Station, TX.

Dunbar, J. S., and S. D. Webb. 1996. Bone and Ivory Tools from Submerged Paleoindian Sites in Florida. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 331–353. University of Alabama Press, Tuscaloosa, AL.

Dunbar, J. S., S. D. Webb, and D. Cring. 1989. Culturally and Naturally Modified Bones from a Paleoindian Site in the Aucilla River, North Florida. *Bone Modification*, editors R. Bonnichsen, and M. Sorg, pp. 473–497. Center for the Study of the First Americans, Orno, Main.

Dunbar, J. S., S. D. Webb, and M. Faught. 1991. Inundated Prehistoric Sites in Apalachee Bay, Florida, and the Search for the Clovis Shoreline. *Paleoshorelines and Prehistory: An Investigation of Method*, editors L. L. Johnson, and M. Stright, pp. 117–146. CRC Press, Inc., Boca Raton, FL.

Dunbar, J. S., Hemmings, C. A., Vojnovski, P. K., Webb, S. D., and Stanton, W., 2006. The Ryan/Harley Site 8Je1004: A Suwannee Point Site in The Wacissa River, North Florida: *Paleoamerican Prehistory: Colonization Models, Biological Populations, and Human Adaptations*, College Station, TX, Center for the Study of the First Americans, Texas A&M University.

Dunbar, J. S. and Vojnovski, P. K. In press. Early Floridians and Late Mega-mammals: Some Technological and Dietary Evidence From Four North Florida Paleoindian Sites. *Foragers of the Terminal Pleistocene*, editors Renee B. Walkee, and Boyce N. Driskell. University of Nebraska Press, Lincoln, Nebraska.

Edwards, W. E. 1952. *The Lake Helen Blazes Site of Central Florida*, PhD dissertation, Columbia University, New York.

Ellis, C., A. C. Goodyear, D. F. Morse, and K. B. Tankersley. 1998. Archaeology of the Pleistocene–Holocene Transition in Eastern North America. *Quaternary International*, 49–50:151–166.

Feranec, R. S., and B. J. MacFadden. 2000. Evolution of the Grazing Niche in Pleistocene Mammals from Florida: Evidence from Stable Isotopes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 162:155–169.

Gagliano, S. M. 1967. *Occupation Sequence at Avery Island*. Louisiana State University Press, Baton Rouge, LA.

Gidley, J. W. 1929. Ancient Man in Florida: Further Investigations. *Bulletin of the Geological Society of America*, 40:491–502.

Gidley, J. W. 1930. Investigations of Early Man in Florida. *Explorations and Field Work of the Smithsonian Institution in 1929*, 3060:37–38.

Goggin, J. M. 1950. An Early Lithic Complex from Central Florida. *American Antiquity*, 16:46–49.

Goodyear, A. C. 1982. The Chronological Position of the Dalton Horizon in the Southeast United States. *American Antiquity*, 47 (2):382–395.

Goodyear, A. C. 1983. A Hypothesis for the Use of Crytocrystalline Raw Materials Among Paleoindian Groups of North America. *Eastern Paleoindian Lithic Resource Use*, editors C. J. Ellis, and J. C. Lothrop, pp. 1–9. Westview Press, Boulder, San Francisco and London.

Goodyear, A. C. 1999. The Early Holocene Occupation of the Southeastern United States: A Geoarchaeological Summary. *Ice Age Peoples of North America: Environments, Origins,* *and Adaptations*, editors R. Bonnichsen, and K. L. Turnmire, pp. 432–481. Oregon State University Press, Corvallis, OR.

Goodyear, A. C. 2000. Topper Site: Results of the 2000. Allendale Paleoindian Expedition. *Legacy*, 5 (2):18–25.

Goodyear, A. C. 2001. Allendale 2001 Season Successfully Completed. *Legacy*, 6 (1):15 & 28.

Goodyear, A. C. 2003. The Allendale Paleoindian Expedition. At web page *http://allendale-expedition.net/*, date accessed 2004.

Goodyear, A. C., J. L. Michie, and T. Charles. 1990. The Earliest South Carolinians. *Occasional Papers No. 2 of the Archaeology Society of South Carolina*, 34 pages, Columbia, SC.

Graham, R. W., E. L. Lundelius, M. A. Graham, R. S. Schroeder, R. S. Toomey, E. Anderson, A. D. Barnosky, J. A. Burns, C. S. Churcher, D. K. Grayson, R. D. Guthrie, C. R. Harington, G. T. Jefferson, L. D. Martin, H. G. McDonald, R. E. Morlan, H. A. Semken, S. D. Webb, L. Werdelin, and M. C. Wilson. 1996. Spatial Response of Mammals to Late Quaternary Environmental Fluctuations. *Science*, 272:1601–1606.

Gramly, R. M. 1993. *The Richey Clovis Cache: Earliest Americans Along the Columbia River*. 1st ed, Persimmon Press, Buffalo, NY

Grayson, D. K., and D. J. Meltzer. 2003. A Requiem for the North American Overkill. *Journal of Archaeological Science*, 30:585–593.

Haynes, C. V. 1971. Time, Environment, and Early Man. *Arctic Anthropology*, 8 (2):3–14.

Haynes, C. V. 1982. Were Clovis Progenitors in Beringia. *Paleoecology of Beringia*, editors D. Hopkins, J. Matthews, C. Schweger, and S. Young. Academic Press, New York.

Haynes, C. V. 1984. Stratigraphy and Late Pleistocene Extinction in the United States. *Quaternary Extinctions: A Prehistoric Revolution*, editors P. M. Martin, and R. G. Klein, pp. 345–353. University of Arizona Press, Tucson, AZ.

Haynes, C. V. 1990. The Antevs–Bryan Years and the Legacy for Paleoindian Geochronology: [Monograph] Establishment of a Geologic Framework for Paleoanthropology. *Special Paper – Geological Society of America*, 242:55–68.

Haynes, C. V. 1991. Geoarchaeological and Paleohydrological Evidence for a Clovis-age Drought in North America and its Bearing on Extinction. *Quaternary Research*, 35:438–450.

Haynes, C. V. 1993. Clovis–Folsom Geochronology and Climate Change. *From Kostenki to Clovis: Upper Paleolithic–Paleo-indian Adaptations*, editors O. Soffer, and N. D. Praslov, pp. 219–236. Plenum Press, New York, NY.

Haynes, C. V., D. J. Stanford, M. Jordy, J. Dickenson, J. L. Montgomery, P. H. Shelley, I. Rovner, and G. A. Agogino. 1999. A Clovis Well at the Type Site 11,500 B.C.: the Oldest Prehistoric Well in America. *Geoarchaeology*, 14 (5):455–470.

Hemmings, C. A. 1999. *The Paleoindian and Early Archaic Tools of Sloth Hole (8Je121): An Inundated Site in the Lower Aucilla River, Jefferson County, Florida*. Masters Thesis, Department of Anthropology, University of Florida, Gainesville, FL.

Hemmings, C. A. 2004. *The Organic Clovis: A Single Continent-wide Cultural Adaptation*. University of Florida, Department of Anthropology, University of Florida, Gainesville, FL.

Hemmings, C. A., J. S. Dunbar, and S. D. Webb. 2004. Florida's Early-Paleoindian Bone and Ivory Tools. *New Perspectives on the First Americans*, editors B. A. Bradley, and R. Bonnichsen, pp. 87–92. Center for the Study of the First Americans, Texas A&M University Press, College Station, TX.

Hoppe, K. A. 2004. Late Pleistocene Mammoth Herd Structure, Migration Patterns, and Clovis Hunting Strategies Inferred from Isotopic Analyses of Multiple Death Assemblages. *Paleobiology*, 30 (1):129–145.

Hoppe, K. A., P. L. Koch, R. W. Carlson, and S. D. Webb. 1999. Tracking Mammoths and Mastodons: Reconstruction of Migratory Behavior Using Strontium Isotope Ratios. *Geology*, 27 (5):439–442.

Jenks, A. E., and H. H. Simpson. 1941. Beveled Artifacts in Florida of the Same Type as Artifacts Found Near Clovis, New Mexico. *American Antiquity*, 6:314–319.

Jennings, J. D. 1968. *Prehistory of North America*. McGraw-Hill Book Company, New York, NY.

Jones, B. C., and L. D. Tesar. 2000. The Wakulla Springs Lodge Site (8WA329): a Preliminary Report on a Stratified Paleoindian Through Archaic Site, Wakulla County, Florida. *Florida Anthropologist*, 53 (2–3):98–115.

Jones, B. C., and L. D. Tesar. 2004. *Wakulla Springs Lodge Site (8Wa329) in Edward Ball Wakulla Springs State Park Wakulla County, Florida*. Florida Bureau of Archaeological Research, Tallahassee, FL.

Knecht, H. 1991. *Technological Innovations and Design During the Early Upper Paleolithic: A Study of Organic Projectile Technologies, Volume II*, PhD dissertation, New York University, New York, NY.

Koch, P. L. 1998. Isotopic Reconstruction of Past Continental Environments. *Annual Review of Earth Planetary Science*, 26 (1):573–613.

Koch, P. L., K. A. Hoppe, and S. D. Webb. 1998. The Isotopic Ecology of Late Pleistocene Mammals in North America Part 1. Florida. *Chemical Geology*, 152 (1–2):119–138.

Lahren, L., and R. Bonnichsen. 1974. Bone Foreshafts from a Clovis Burial in Southwest Montana. *Science*, 186 (4157):147–150.

Lowe, J. J. 2002. *INTIMATE Event Stratigraphy Radiocarbon Correlation for the Older Dryas Onset*, e-mail from Lowe at the Center for Quaternary Research, University of London, Egham, Surrey, UK to James S. Dunbar, Florida State University and Florida Bureau of Archaeological Research.

Lowe, J. J., W. Z. Hoek, and the INTIMATE Group 2001. Inter-regional Correlation of Palaeoclimate Records for the Last Glacial–Interglacial Transition: A Protocol for Improved Precision Recommended by the INTIMATE Project Group. *Quaternary Science Reviews*, 20:1175–1187.

Marshall, E. 2001a. Clovis First. *Science*, 291 (5509):1732.

Marshall, E. 2001b. Pre-Clovis Sites Fight for Acceptance. *Science*, 291 (5509):1730–1732.

Martin, P. S. 1967. Prehistoric Overkill. *Pleistocene Extinctions: the Search for a Cause*, editors P. S. Martin, and H. E. Wright. 75–120, Yale University Press, New Haven, CN.

McAvoy, J. M., and L. D. McAvoy. 1997. Archaeological Investigations of the Site 44SX202, Cactus Hill, Sussex County, Virginia, *Research Report Series N0. 8*. Virginia Department of Historical Resources, Richmond, VA.

Meltzer, D. J. 1988. Late Pleistocene Human Adaptations in Eastern North America. *Journal of World Prehistory*, 2 (1):1–51.

Meltzer, D. J. 2004. Peopling of North America. *The Quaternary Period in the United States*, editors A. R. Gillespie, S. C. Porter, and B. F. Atwater. Elsevier, Amsterdam.

Meltzer, D. J., and B. D. Smith 1986. Paleoindian and Early Archaic Subsistence Strategies in Eastern North America. *Foraging, Collecting, and Harvesting: Archaic Period Subsistence and Settlement in the Eastern Woodlands*. Center for Archaeological Investigations Occasional Paper No. 6:3–31.

Meltzer, D. J., D. D. Fowler, J. A. Sabloff, and Society for American Archaeology. 1986. *American Archaeology, Past and Future:A Celebration of the Society for American Archaeology, 1935–1985*. Published for the Society for American Archaeology by the Smithsonian Institution Press, Washington.

Mikell, G. A. 1997. A Case of Direct Association Between Fiber-tempered Pottery, Late Archaic Stemmed Points, and Santa Fe Points at the Reddick Bluff Site, Walton County. *Florida Anthropologist*, 50 (2):83–94.

Milanich, J. T. 1994. *Archaeology of Precolombian Florida*. University Press of Florida, Gainesville, FL.

Neill, W. T. 1958. A Stratified Early Site at Silver Springs, Florida. *Florida Anthropologist*, 11:38–48.

Neill, W. T. 1964. The Association of Suwannee Points and Extinct Animals in Florida. *Florida Anthropologist*, 17:17–32.

Newsom, L. A., S. D. Webb, and J. S. Dunbar. 1993. History and Geographic Distribution of *Cucurbita pepo* Gourds in Florida. *Journal of Ethnobiology*, 13:75–97.

Percy, G. 1974. A Review of Evidence for Prehistoric Indian Use of Animals in Northwest Florida. *Bureau of Historic Sites and Properties Bulletin* No. 4:65–93.

Redder, A. J. 1985. Horn Shelter Number 2: The South End. *Central Texas Archaeologist*, 10:37–65.

Robertson, J. S. 1974. Fossil Bison of Florida. *Pleistocene Mammals of Florida*, editor S. D. Webb. The University Presses of Florida, Gainesville, FL.

Rostlund, E. 1960. The Geographic Range of the Historic Bison in the Southeast. *Annals of the Association of American Geographers*, 50 (4):395–407.

Rucker, B. R. 1992. Where the Buffalo Roamed: American Bison on the Gulf Coast During the Age of Exploration. *Gulf Coast Historical Review*, 8 (1):114–126.

Sellards, E. H. 1916. Human Remains and Associated Fossils from the Pleistocene of Florida. *Eighth Annual Report of the Florida State Geological Survey*, 8:123–160 plus plates.

Sellards, E. H. 1947. Early Man in America: Index to Localities and Selected Bibliography. *Bulletin of the Geological Society of America*, 58 (10):955–978.

Sellards, E. H. 1952. *Early Man in America*. University of Texas Press, Austin, Texas.

Sellards, E. H., R. T. Chamberlin, T. W. Vaughan, A. Hrlicka, O. P. Hay, and C. C. MacCrudy. 1917. *Symposium on the Age and Relations of the Fossil Human Remains at Vero, Florida*, Volume 25, no. 1, 62 pp. *Journal of Geology*.

Simpson, J. C. 1941. *Yuma Type Points from Florida*. Misc. Document Files, 4 page letter on file at Florida Museum of Natural History, Gainesville, FL.

Simpson, J. C. 1948. Folsom-like Points from Florida. *Florida Anthropologist*, 1 (1):11–15.

Smith, R. C., J. S. Dunbar, and M. F. Faught. 1997. An Underwater Archaeological Survey in the Santa Fe River, Florida. BAR 36, Florida Bureau of Archaeological Research Tallahassee, FL.

Stanford, D. 1991. Clovis Origins and Adaptations: An Introductory Perspective. *Clovis: Origins and Adoptions*, editors R. Bonnichsen, and K. L. Turnmire, pp. 1–14. Center for the Study of the First Americans, Corvallis, OR.

Stewart, T. D. 1946. Reexamination of the Fossil Human Skeletal Remains from Melbourne, Florida with Further Data on the Vero Skull. *Smithsonian Miscellaneous Collections*, 106 (10):1–28.

Tesar, L., and J. Whitfield. 2002. A Reduction Deduction: A Clovis-like Fluted Base from the Chipola River. *Florida Anthropologist*, 55 (2):89–104.

Vojnovski, P. K., and J. S. Dunbar. In press. Early Floridians and Late Mega-Mammals: Some Technological and Dietary Evidence from Four North Florida Paleoindian Sites. *Foragers of the Terminal Pleistocene*, editors R. B. Walker, and B. N. Driskell. University of Nebraska Press, Lincoln, NE.

Waller, B. I. 1969. Paleo-indian and Other Artifacts from a Florida Stream Bed. *Florida Anthropologist*, 22 (1–4):37–39.

Waller, B. I. 1970. Some Occurrences of Paleo-indian Projectile Points in Florida Waters. *Florida Anthropologist*, 23 (4):129–134.

Waller, B. I. 1983. Florida Anthropologist Interview with Ben Waller. *Florida Anthropologist*, 36:31–39.

Webb, S. D., and C. A. Hemmings. 2001. Ivory and Bone Tools from Late Pleistocene Deposits in the Aucilla and Wacissa River, North-Central Florida. *Enduring Records: the Environmental and Cultural Heritage of Wetlands*, editors B. A. Purdy, pp. 1–8. Oxford Books, Oxford, England.

Webb, S. D., and K. T. Wilkins. 1984. Historical Biogeography of Florida Pleistocene Mammals. *Contributions in Quaternary Vertebrate Paleontology: A Volume in Memorial to John E. Guilday, Special Publication No. 8*, editors H. H. Genoways, and M. R. Dawson, pp. 370–383. Carnegie Museum of Natural History, Pittsburgh, PA.

Webb, S. D., J. T. Milanich, R. Alexon, and J. S. Dunbar. 1984. A *Bison antiquus* Kill Site, Wacissa River, Jefferson County, Florida. *American Antiquity*, 49:384–392.

Webb, S. D., J. S. Dunbar, and L. Newsom. 1992. Mastodon Digesta from North Florida. *Current Research in the Pleistocene*, 9:114–116.

Webb, S. D., R. W. Graham, A. D. Barnosky, J. B. Bell, R. Franz, E. A. Hadly, E. L. Lundelius, H. G. McDonald, R. A. Martin, H. A. Semken, and D. W. Steadman. 2004. Vertebrate Paleontology. *The Quaternary Period in the United States*, editors A. R. Gillespie, S. C. Porter, and B. F. Atwater, pp. 519–538. Elsevier, Amsterdam.

Willey, G. R. 1966. *An Introduction to American Archaeology: Volume 1*, *North and Middle America*. Prentice-Hall, Inc., Englewood Cliff, NJ.

Willis, C. 1988. Controlled Surface Collection of the Little River Rapids Site (8Je603): A Stratigraphically Deflated Site in the Aucilla River, North Florida. *Florida Anthropologist*, 41 (3):453–470.

Wyman, J. 1875. *Fresh-water Shell Mounds of the St. Johns River, Florida*. Peabody Academy of Sciences, Salem, MA.

SECTION D: EARLY HOLOCENE EVIDENCE

> "Until we understand human behaviors ... from the perspective of both natural and social sciences, our ability to understand and manage a world in which *H. sapiens* is the dominant species will be critically compromised."
>
> **James H. Brown and Mark V. Lomolino**.

The richest assemblage of cultural and natural material recovered by the Aucilla River Prehistory Project comes from a dark stratum high on the north bank of the Page-Ladson site complex. The ARPP team devoted many seasons to extending excavations on this surface. During the 1990s the work moved eastward from Test C into Tests F and G. During the first year we had missed a subtle stratigraphic distinction between specimens scattered on the surface of the dark stratum and those entombed within a lighter-colored unit rich in biogenic silica thinly deposited above it. But, thereafter, we clearly separated Unit 5 below, affectionately known as "the Bolen Surface", from Unit 6L.

The five chapters in this section focus closely on changes that led to the Bolen occupation at Page-Ladson and its aftermath. Critical analyses include chemical and physical studies of the subaerial surface (which never formed a proper soil), faunistic and floristic studies, and beautiful details of the siliceous microorganisms that lived in the quiet waters that subsequently covered that surface.

An excellent set of carbon dates from the Bolen Surface clearly place it just after 10,000 ^{14}C BP. At this same time, right at the beginning of the Holocene, there are major changes in global climates. These changes occur at the end of the Younger Dryas and the beginning of the Preboreal. During the same interval the Gulf of Mexico felt the strong impact of glacial meltwater released into the Mississippi River by Meltwater Pulse 1B. The strong regional drought and lowered local water table induced Bolen people to occupy the apron of the Page-Ladson sinkhole. They retreated when rainfall and water tables rose again. It is interesting to note that when ARPP had excavated equivalent aged sediments in Test B from a more eastern part of the site complex, the Bolen cultural component was less clearly represented, evidently because it lay about 3 m deeper in the sinkhole than the rich beds along the north bank.

The wealth of natural and cultural material that accumulated on the Bolen Surface are truly remarkable. The lithic specimens include side-notched and corner-notched points in many stages of manufacture and reworking. The Dalton-like adzes and novel wood wedges are clearly associated with the many pieces of chopped and otherwise modified wood. Two hearths were recognized on this surface, and others were probably disturbed by subsequent gentle erosion. The unusually high charcoal inputs recorded in Chapter 6 are very probably related to the use of fire in hearths and in land clearing. A very large cypress log was partly modified. Toward the east end, it gave the appearance of being a dugout canoe, but its purpose remains unknown. Dimple stones of chert present an interesting challenge to interpret. The partial cranium of an antlered deer, possibly used as a ceremonial drinking cup, is one of the most intriguing pieces. In the overlying sediments of Unit 6L artifacts are slightly removed from the probable locus of occupation. On the other hand, two architectural stakes, driven vertically through Unit 6L into Unit 5 presumably anchored a platform (or dock) above the rising water in post-Bolen time.

Chapter 15

Terrestrial Soil or Submerged Sediment: The Early Archaic at Page-Ladson

SYLVIA SCUDDER
Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.

15.1 Introduction

The Page-Ladson site (8JE591) is one of a cluster of related sites being examined by a team of researchers for the Aucilla River Prehistory Project. Located beneath the

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 439–459

waters of the Aucilla River just below its confluence with the Wacissa River in Jefferson County, Florida, the site is composed of mineral and organic strata of Pleistocene and Holocene age. The site's ecological record documents climatic cycles of wet/warm and dry/cool periods, based on pollen and plant remains. A dynamic history of sedimentation is documented in the strata: a basal red peat (>12,570 yr BP) is overlain by various tan to gray silts and silt loams mixed with vegetation, sand and peat lenses, bone, chert chips, and shells. [Note: The use of soil textural terms such as "silt loam" is employed throughout this study to denote textural class (percentage of sand, silt, and clay), and does not imply that the underwater strata are soils.] Near the top of the excavated column in Test Pits C and F is a dark brown silty clay loam, dated to approximately 10,000 yr BP and laden with organic matter, wood fragments, and shell (Stratum 2A, Chapter 3 by Kendrick). Paleoindian artifacts were found scattered on the upper surface of this stratum which was labeled the "Bolen layer" to reflect the dominance of that artifact type.

15.2 Objectives of this Study

The discovery of Bolen-period artifacts on Stratum 2A, the dark brown Bolen layer, raised the question that the level might have been at one time the surface of a terrestrial soil that served as a living area for Paleoindians. Clusters of charcoal and mollusc shells and a wooden stake dated to 8905 BP protruding vertically through the surface added to the speculation that this might have been a subaerial horizon (see Chapter 18 by Carter and Dunbar).

This study characterizes Stratum 2A and adjacent strata and compares them with known local soils. The objective of this characterization is to categorize the Bolen layer as either part of a soil or as a sediment using the accepted concept of a soil as a differentially weathered body of parent material (Birkeland, 1984; Buol *et al*., 1989). Interpretations are based on data from standard soil analytical techniques such as particle-size distribution, chemical element extractions, X-ray diffraction identification of clays, and organic carbon determinations. These data are coupled with analyses of the biological components of the strata: molluscs, bone fragments, phytoliths, and other biogenic silica forms such as sponge spicules and diatoms (see McCarty and Schwandes, this volume, for a detailed discussion of biogenic silica extraction and analysis from Stratum 2A samples).

15.3 Soils in the Aucilla River Region

The Aucilla River, which forms the boundary between Jefferson and Taylor Counties, arises in Georgia and flows through the Northern Highlands physiographic province of Florida, across the Cody Scarp, and onto the coastal lowlands to discharge into the Gulf of Mexico (White, 1970; Allen, 1989). The Aucilla River cuts through the Hawthorn Group in its northern reaches and the Suwannee Formation to the south (Scott, 1998). The Hawthorn Group is overlain by the Miccosukee Formation (Yon, 1966:Plate 1) in large areas of the northern half of the county. The upper Miocene Miccosukee is extremely heterogeneous, being an aggregate of "... lenticular clayey sands and clay beds ... moderately sorted to poorly sorted, coarse to fine-grained, varicolored clayey, quartz sand and montmorillonitic, kaolinitic, varicolored, sandy clays (with) frequently cross-bedded sands ..." (Allen, 1989:96). Allen interprets these sediments as representing a deltaic environment. Pleistocene quartz sands with montmorillonitic clay lenses and Holocene sands overlie all of the sedimentary formations in the southern half of the county below the Cody Scarp.

These sedimentary formations, in combination with the Pleistocene and Holocene sands and clays mentioned above, provide much of the parent material from which the local soils are formed. Most soils in stable terrestrial environments form in a vertical weathering sequence from the surface downward. Factors such as precipitation, vegetation, slope, aspect, and biological organisms act on the parent rock and/or unconsolidated sediments through time, slowly forming true soils with differentiated horizons (Jenny, 1941). This is the case for some soils in the vicinity of the Page-Ladson site. At Page-Ladson, however, there is also evidence of alluvial influences on soil formation: fine-grained sediments deposited by periodic over-bank flooding of the river and, conversely, truncated soils cut away and terraced by flood events. These additions to and subtractions from the local body of soils result in a more complex pedogenic history than that of more stable upland areas. Buried soils, truncated (eroded) or cummulic (thickened) soils, heterogeneous layers of mineral, and organic parent materials, all are found within a small area.

The karst topography through which the Aucilla River flows is an extremely active landscape, as evidenced by sinkholes in the bottom of the river as well as in upland areas, by abandoned river channels, and by the river itself, disappearing below the land surface and then re-surfacing or rising again miles downstream. These active geological processes also contribute to the complexity of the soils on a regional level.

In the immediate vicinity of the Page-Ladson site, Allen (1989) records Tooles, Nutall, and small areas of Chaires soil series. Tooles and Nutall soils are members of groups within the Alfisol order, which includes soils that form on limestone parent material (Soil Survey Staff, 1975). The Chaires soil is a Spodosol – the order characterized by a subsurface horizon of accumulation of organic carbon and aluminum, a spodic horizon. Although the soil survey maps delineate only these three series in the vicinity of the site, soil survey map units have a minimum area of three acres. Since soils are part of a dynamic system that varies continuously across the landscape, it is more realistic to think of the Page-Ladson area as being dominated by the three mapped soil types, but with many named and un-named soils also represented.

The stratigraphic column recorded in the underwater excavation units of the site is described in detail elsewhere in this volume (Chapter 3 by Kendrick). Stratum 2A is one of the uppermost levels, the upper boundary of which is within 4 m of the modern river's surface. It is overlain by a gray silt loam with inclusions of abundant freshwater shells, plant fragments, charcoal, freshwater sponge spicules, and fish bone. It is underlain by a massive pale brown loam with thin peat lenses, freshwater shells, fish and other vertebrate bone, copepods, sponge spicules, and coral fragments.

15.4 Pedogenesis: Principles and Applications

The objective of this study is to characterize and define the Bolen layer in the context of site stratigraphy. In order to select criteria that can be used to compare Stratum 2A to local soils that have evolved under subaerial conditions, the distinctions between soils and sediments must be clearly understood.

15.4.1 Sediments versus Soils

Sediments can be single grains or aggregates. They can be composed of primary minerals, physical or chemical weathering products of primary minerals, recombined secondary minerals such as clays, organic residues, or any combination of these materials. They can accumulate in massive, homogeneous strata or as thin stringers or lamellae, in well-sorted assemblages such as dune sand or the poorly sorted results of an avalanche. In the realm of soil science, sediments are considered as a type of parent material or precursor of soils. They may contain the same elements and constituents as a particular soil and they may be layered, but they may not be weathered into subparallel altered horizons and still be considered sediments.

Joffe (1949) defines soil as "... a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics ...". The classical factors of soil formation (climate, vegetation, organisms, topography, and time) act on undifferentiated parent material, whether unconsolidated or lithified, to form the evolving mosaic of soils found on the landscape. The soils themselves may be very simple, e.g. a thin accumulation of decaying organic matter over sand, or they might be quite complex. The overlay of soil horizons on heterogeneous parent materials such as those found in formerly glaciated regions or old river valleys can be a challenge to interpret (Birkeland, 1984).

Soil horizons are defined in terms of what has either accumulated in or been removed from the original parent material during the weathering process. Most surface horizons accumulate organic carbon from the decay of vegetation. As a soil matures, a characteristic leached zone (E horizon) begins to develop between the surface (A) horizon and the unweathered parent material below. The fine particles, minerals, organic matter, and secondary compounds removed from the surface horizon and leached through the E horizon begin to collect in subsurface zones of accumulation (B horizons).

The physically deposited or chemically precipitated compounds in soil B horizons are different in form and composition than their precursors. It is these differences that allow inferences to be made about the stage of development of a soil. Calcium carbonates and clays are two examples of such ‘before-and-after’ changes. Two of the most common carbonate parent materials of soils are limestone and shell. Their original forms are self-evident. As these materials weather, soluble calcium is released into the soil solution and moves downward through the soil column. When it reaches a zone of saturation, it precipitates on the undersides of the mineral grains it has flowed over, forming pendants (Soil Survey Staff, 1975; Courty *et al.*, 1989). The characteristic shape of these pendants easily differentiates this form of calcium carbonate from the original parent form.

Secondary soil clays also assume characteristic forms. Sources of soil clay may be residual – such as the clay lenses of the Miccosukee Formation or the gray matrix of the Hawthorn Group. They may also form from dissolution and recombination of primary minerals in a silica- and aluminum-enriched soil environment (Rich and Obenshain, 1955; Rich, 1968; Birkeland, 1984). As these variously derived clays are leached downward, they coat the insides of soil pores and the surfaces of soil aggregates, forming oriented clay films, or cutans, which are characteristic of pedogenic translocation processes. Like the carbonates, the secondary pedogenic forms of clay are very different than their precursors.

15.4.2 Hydric Soils and Histosols

A hydric soil is one “... that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation” (Carlisle, 1990). The water table may remain below the soil surface and still achieve hydric conditions. A hydric soil may or may not have a surface layer of decomposed organic material; this depends on the source and volume of organic input and land management practices such as burning and draining. The morphology of hydric soils may vary considerably, but the requisite anaerobic conditions produce characteristic morphological features such as gleyed (yellow, gray, or black) colors due to iron depletion (leaching) and natural retention of organic carbon.

A histosol is a type of hydric soil which is defined by having at least 12% organic carbon in the upper horizon (Buol *et al.*, 1989). Horizons (tiers) are defined by the degree of decomposition of the constituent organic matter. Characteristically, the lower tiers are more degraded than the upper tiers and present a “peat-over-muck” sequence.

15.4.3 Inundation

Although the definition of hydric soils includes statements about seasonal saturation or inundation, the permanent drowning of a terrestrial soil (by a river, lake, marine edge) after its formation is a different phenomenon. According to Kuehl and Denson (1993), the submergence of a soil does not significantly change its character as long as it remains intact and undamaged by fluvial processes. In an archaeological survey of the Oklawaha River, Kuehl found that terrestrial soils on segments of the banks had essentially the same morphological and chemical characteristics as adjacent drowned soils.

15.4.4 Anthropogenic Soils

The question of possible human influence on Stratum 2A adds another level of complexity to the analysis. Human impact on soils can be either enriching or degrading, depending on the trajectory of land use practices, the intensity and duration of settlement in one location, landscape manipulation, original soil type, and many other factors (Scudder *et al*., 1996). Recent studies of anthropogenic soils have focused on the most durable evidence of human use, including particle-size changes, accumulation of phosphorus, calcium, magnesium, and some trace minerals, and soil morphological changes (Conway, 1983; Konrad *et al*., 1983; Sandor, 1992; Foss *et al*., 1993). Comparison of characterization data for anthropogenic soils and native (non-human-influenced) local soils forms the basis of these studies. Post-depositional changes must also be taken into consideration since pedogenesis is an on-going process and soils are not static bodies (Holliday, 1992).

15.5 Materials and Methods

15.5.1 Sampling

Test units were excavated into the west bank of the Aucilla River, beginning a few meters below the water's surface and extending toward the central channel in stair-step fashion, approaching but not including a deep sinkhole in the river bottom. One-liter samples for this study were extracted at 15 cm intervals from the north face of Test G (sample numbers "P-L 1–8"), samples from the center of each stratigraphic layer were taken from the west faces of Tests G and H (samples "P-L 9–14" and "P-L 15–22", respectively). Four intact block samples bracketing and including Stratum 2A were also taken from the north face of Test G.

Samples were transported to the Environmental Archaeology lab at the Florida Museum of Natural History, Gainesville. There they were cataloged and subsampled for distribution to various analytical labs. Remaining bulk samples are stored wet for future use.

15.5.2 Terrestrial Survey and Soil Descriptions

Soils on the west bank and floodplain of the Aucilla River in the vicinity of the site were examined using a manual Dutch auger. Plugs were removed in 20 cm sections, placed in sequence on a plastic drop-cloth, and described using selected standard soil description criteria: horizon thickness and arrangement, color and mottling, and thickness of horizon boundaries (Soil Survey Staff, 1981). Estimates of texture (percent of sand, silt, and clay) and structure within each horizon, and presence/abundance of roots, pebbles, and artifacts were also recorded. Samples from the terrestrial survey were not saved.

15.5.3 Physical and Chemical Analyses

Particle-size distribution was determined using the pipette method of Day (1965). Fifty-gram subsamples from each of the 22 samples taken from Units G and H were tested. Microphotographs were taken through a Zeiss SV8 stereomicroscope using an MC 100 35 mm camera with tungsten film.

15.5.3.1 Chemical Analyses

Total phosphorus content was determined by alkaline oxidation (Dick and Tabatabai, 1977). Total nitrogen content was determined using the University of Iowa's LECO carbon analyzer. Total carbon was quantified by LECO and by loss-on-ignition at 550°C (organic fraction) and 1000°C (inorganic fraction) for 1 h each (Dean, 1974). Organic carbon content was determined by both Walkley-Black dichromate digestion and loss-on-ignition. Organically bound aluminum and iron were extracted by sodium pyrophosphate, inorganically bound aluminum and iron by hydrochloric acid.

15.5.3.2 Mineralogical Analysis

Clays were identified by X-ray diffraction. Clay fractions were first isolated by dispersion and centrifugation, then plated onto ceramic tiles. Paired tiles were saturated with either potassium chloride or magnesium chloride and glycerol, then X-rayed at room temperature (~25°C) using copper k-α radiation.

15.5.3.3 Biological Analyses

Identification of invertebrates in the sediments was accomplished by sorting wet 100 ml subsamples under a dissecting microscope. Preliminary groupings of bivalves, gastropods, foraminifera, bone, and insects were further identified using the comparative collections at the Florida Museum of Natural History and the expertise of collections staff. Descriptions of other sediment inclusions such as fossil invertebrates, plant parts, and corals were recorded. Changes in color and texture of the sediment matrix, presence of lamellae, coatings on sand grains, and roundness of grains were also noted.

Extraction and quantification of biosilicates such as phytoliths, sponge spicules, and diatoms were undertaken by McCarty and Schwandes (Chapter 17, this volume). A summary of their results is discussed below.

15.6 Results

15.6.1 Physical Characteristics

15.6.1.1 Survey

The survey of river-bank and floodplain soils adjacent to the underwater excavations delineated small, heterogeneous areas of varying soil types. Soils closest to the river-bank (e.g. ST# 1) are clayey, possibly truncated by flooding, with only about 10 cm of mixed organic matter and sand topsoil. Soils on a small sand and limestone ridge 10 m west of the bank (ST# 2) are thin, comprised of about 10 cm of fine sand over clay. Approximately 15 to 20 m south of the sand ridge, a small, flat area of fine silty sand over clay exhibited a leached E horizon (ST# 3 and 4). Faint dark brown lamellae were present above the E horizon at that locality.

15.6.1.2 Particle-size Distribution Analysis

The particle-size distribution analysis classified most of the underwater sediments as silt loam (Table 15.1). This soil texture category includes soils with 50% or more silt and 27% or more clay. The so-called "clay" sediments above and below Stratum 2A actually contained 37.6–77.8% silt and only 4.6–24.3% clay. Two of the three Stratum 2A samples were classified as clay loams, containing 30.4 and 37% clay and less silt than the sub- and super-adjacent samples. The third Stratum 2A sample fell into the silt loam category. One upper sample (P-L# 14) contained significantly more sand than any other – 80% – and qualified as a loamy sand. Of the sand fractions, fine and very fine sands were most abundant.

15.6.1.3 X-ray Diffraction of Clays

The X-ray diffraction of clays identified smectites (a group of "shrink-swell" clays) as the most abundant type in all samples (Table 15.2). Minor peaks that appeared to signal the presence of kaolinite collapsed with potassium saturation, thereby identifying them as second-order smectite peaks.

15.6.2 Biological Components

15.6.2.1 Identifications of Faunal Remains

The identifications of faunal remains from selected samples are summarized in Table 15.3. The most abundant animals in the samples were the freshwater rams-horn snails (family Planorbidae). These decreased in number with increasing depth: the three samples from the stratum directly overlying 2A contained 14–648 individuals while

Table 15.1 Particle-size distribution analysis, Page-Ladson sediments

	Wt. (%)									
P-L#	*VC*[1]	*C*	*M*	*F*	*VF*	*TS*	*Si*	*Cl*	*Si + Cl*	*Texture class*[2]
8	0.0	0.8	2.0	7.2	18.0	28.0	59.5	12.5	72.0	Silt loam
7	0.0	0.4	1.2	5.2	16.0	22.8	59.8	17.4	77.2	Silt loam
6	0.4	1.2	2.0	6.4	14.0	24.0	56.2	19.8	76.0	Silt loam
5	0.4	1.2	2.8	10.4	13.6	28.4	71.6	0.0	71.6	Silt loam
4[3]	0.0	0.4	1.6	6.8	7.2	16.0	47.0	37.0	84.0	Silty clay loam
3	0.4	0.4	1.6	8.0	14.8	25.2	51.6	23.2	74.8	Silt loam
2	0.4	1.2	4.8	15.6	15.2	37.2	46.8	16.0	62.8	Loam
1	0.4	1.2	4.8	15.6	16.0	38.0	45.0	17.0	62.0	Loam
14	0.0	0.0	5.2	64.8	10.0	80.0	12.0	8.0	20.0	Loamy sand
13	0.4	0.8	2.0	8.8	17.2	29.2	55.4	15.4	70.8	Silt loam
12	0.0	0.0	0.8	6.0	15.2	22.0	62.5	15.5	78.0	Silt loam
11	0.2	0.8	1.8	7.8	14.8	25.4	52.0	22.5	74.5	Silt loam
10[3]	3.6	1.6	4.4	13.2	9.2	32.0	37.6	30.4	68.0	Clay loam
9	0.0	0.0	0.8	4.4	12.4	17.6	77.8	4.6	82.4	Silt loam
22	0.0	0.4	0.8	7.2	17.2	25.6	60.2	14.2	74.4	Silt loam
21	0.4	0.4	1.6	10.0	19.6	32.0	60.6	7.4	68.0	Silt loam
20	0.0	0.4	1.2	6.8	14.8	23.2	66.9	9.9	76.8	Silt loam
19	0.8	1.6	2.8	11.6	14.8	31.6	44.1	24.3	68.4	Loam
18[3]	0.0	0.4	2.8	9.2	3.2	15.2	63.0	21.8	84.8	Silt loam
17	0.0	0.4	2.4	8.8	12.0	23.6	57.0	19.4	76.4	Silt loam
16	0.0	0.0	0.4	4.4	10.0	14.8	64.4	20.8	85.2	Silt loam
15	0.0	0.8	4.4	13.2	11.2	29.6	52.8	17.6	70.4	Silt loam

[1] Particle-size classes: VC = very coarse (sand), C = coarse, M = medium, F = fine, VF = very fine, Si = silt, Cl = clay.

[2] Texture class = % sand, silt, and clay in <2 mm fraction.

[3] "Bolen" layer samples.

the deepest set of three samples contained only 1–13 individuals. Freshwater snails of the families Hydrobiidae and Physidae were also common in the upper levels and decreased in numbers with depth. Small articulated bivalves of an unidentified genus were present in two of the three Stratum 2A samples (6 and 33 individuals) and in smaller numbers in the sub- and super-adjacent strata. Small numbers of pea-clams of the genus *Pisidium* (family Sphaeriidae) were found in four scattered samples. Virtually all of the other vertebrate and invertebrate fragments identified were from aquatic creatures (e.g. freshwater catfish, limpets, sponges). Three fragments of land snails (1 Polygyra, 1 Gastrocopta, 1 unidentified) were taken from the uppermost level.

McCarty and Schwandes (Chapter 17) found freshwater sponge spicules, diatoms, and phytoliths from ten species of plants including *Sabal palmetto*, *Celtis* sp., *Serenoa repens*, *Ambrosia*, and several grasses and sedges. Many of the grass phytoliths (up to 60% in one of the Bolen level samples) were of the bulliform cell type, indicating that the plant was growing under excessively wet conditions.

Table 15.2 Clay identifications, Page-Ladson sediments

P-L#	*Mg/gly: R.T.*[1] *d-spacing (Å)*	*Identification*	*KCL: R.T.*[2] *d-spacing (Å)*	*I.D.*
6	20, (10)[3], 7.14, 3.57	Smectite (mica), kaolinite, 2nd kaol.	14.8	Smectite
5	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.		
4[4]	20, 10, 7.14, 3.57, 2.37	Smectite, mica, kaol, 2nd kaol, 3rd kaol.	15.8	Smectite
3	20, 7.14, 3.57	Smectite, kaolinite, 2nd kaolinite	14	Smectite
1	20, (10), 7.14, 3.57	Smectite (mica), kaolinite, 2nd kaol.		
12	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.		
11	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.		
10[4]	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.		
9	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.		
22	20, (10), 7.14, 3.57	Smectite (mica), kaolinite, 2nd kaol.		
20	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.	15.8	Smectite
18[4]	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.	15.8	Smectite
17	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.	15.8	Smectite
15	20, 10, 7.14, 3.57	Smectite, mica, kaolinite, 2nd kaol.		

[1] Mg/gly: R.T. = magnesium- and glycerol-saturated tile X-rayed at room temperature.
[2] KCL: R.T. = potassium-chloride-saturated tile, room temperature. This saturation was used to further identify smectites
[3] (*n*) = parentheses indicate minimal peaks.
[4] "Bolen" layer samples.

15.6.3 Chemical Analyses

Contents of total and organic carbon, total phosphorus (P) and nitrogen (N), and two different fractions of iron (Fe) and aluminum (Al) are summarized in Table 15.4. Total carbon (TC) content in the samples ranged from 7.5% to 14.7%, as measured by LECO carbon analyzer. A second assay of TC by loss-on-ignition, the method used to determine organic carbon content, yielded slightly lower results. Organic carbon (OC) content of the samples ranged from 3.9% to 10.9%. Stratum 2A samples contained approximately twice the OC as other samples.

Total phosphorus contents of the Stratum 2A samples and two of the upper level samples were significantly lower than the intervening levels (e.g. 461 mg/kg in 2A sample # 10 vs. 1520 mg/kg above and below). Conversely, contents of pyrophosphate-extracted iron and aluminum (those forms of Fe and Al bound to organic molecules) and hydrochloric acid-extracted aluminum (inorganically bound forms) were higher in Stratum 2A samples than any other. Hydrochloric acid-extracted iron was more abundant in Stratum 2A than in adjacent strata but most abundant in the two uppermost strata.

15.7 Discussion

The objective of this study is to categorize Stratum 2A – the Bolen layer – as either a terrestrial soil or an unweathered sediment. Implicit in the first possibility is the assumption that if 2A was at one time a subaerial soil, it served as an aboriginal

Table 15.3 Faunal identifications, Page-Ladson sediments

P-L#	*Planorbids #*	Planorbella scalarus	Physella spp.	*Hydrobiids*	Pisidium spp.	*Bivalves*	*Freshwater limpets*	*Land snails*	*Plant parts*	*Bone*	*Other*
8	40	0	34	4	2	–	0	1	Abundant	0	Common broken shell frags
6	648	3	59	250	0	2	2	0	Few	Fish	
4 “Bolen”	38	0	0	4	0	33	0	0	Common	Fish	“Peaty lumps”
3	14	0	1	0	0	1	0	0	Few	Fish	
1 (50 ml)	13	0	5	0	0	0	0	0	Common	0	
12	8	0	4	7	0	0	0	Polyg[1], Gast[2]	0	0	Beetle mandible
11	180	1	35	220	1	1	2	0	Few	0	3 calcareous algae
10 “Bolen”	0	0	0	0	0	0	0	0	Few	0	Few sponge spicules
9	1	0	0	0	0	0	0	0	0	1 fish scale	1 Dictyoconus = foram
22	8	3	4	13	0	0	0	0	Few	1 fish scale	Smooth silt or clay balls
20	14	0	5	15	0	0	0	0	Few	Fish basiocc	1 Dictyoconus
18 “Bolen”	8	0	0	1	0	6	0	0	Few	1 Ictal pect sp.	Soft white streaks
17	7	0	3	1	5	–	0	0	Few	0	
15	12	0	2	4	2	–	0	0	Few	Lepomis: otolith	cf. reptile tail vert., Copepods, 12 Dictyoconus, 1 coral frag.

[1] Polygyra.

[2] Gastrocopta.

Notes: Volume of samples = 100 ml unless otherwise stated Planorbids: freshwater, prefer low-moving but oxygenated waters *P. scalarus*: rams-horn, fresh water (FW). *Physella*: FW. Hydrobiidae: FW. *Pisidium*: peaclams, FW. Bivalves: various small freshwater genera.

Table 15.4 Contents of carbon, nitrogen, phosphorus, iron and aluminum, Page-Ladson sediments

P-L#	*Total C[1](%)*	*Total C[2] (%)*	*Organic C[1] (%)*	*Total N[2] (%)*	*Total P*	*Fe-pyro[3] (mg/kg)*	*Fe-HCl[4]*	*Al-pyro*	*Al-HCl*
8	11.6	14.01	5.2	0.27	969	1000	6600	150	1650
7	–	13.24	–	0.23	1015	1000	4200	200	1500
6	12.4	12.90	3.9	0.26	1480	900	2550	350	1950
5	–	12.75	–	0.31	1450	2150	2550	3450	2850
4	10.8	11.63	8.9	0.41	951	5150	5550	7400	3450
“Bolen”									
3	11.9	13.45	5.9	0.31	1820	500	4200	150	2550
2	–	12.08	–	0.24	1780	400	2700	100	3000
1	11	12.16	5	0.24	1860	350	1800	100	2250
14	–	7.50	–	0.27	230	1200	2550	650	1200
13	12.4	14.02	5.2	0.28	1200	1100	6600	100	1500
12	11.8	13.08	3.7	0.24	1060	700	4050	150	1650
11	12.2	12.86	4.6	0.27	1520	1050	3750	1300	3000
10	11.6	14.51	10.8	0.53	461	5550	4200	7800	3450
“Bolen”									
9	11.8	13.47	5.9	0.31	1520	400	2700	200	2250
22	12.6	13.22	4.2	0.29	1340	1600	11850	50	2400
21	–	13.31	–	0.28	1150	6150	18000	100	1800
20	11.7	13.34	4.3	0.25	1060	950	4800	350	1500
19	–	12.57	–	0.31	1710	2050	3900	3900	2850
18	12.4	14.74	10.9	0.56	554	9600	9900	7650	2550
“Bolen”									
17	11.7	13.31	6.1	0.32	1892	450	3900	100	2400
16	–	13.57	–	0.28	1520	450	3600	150	2550
15	11.2	12.26	5.4	0.23	1570	400	2400	100	2400

[1] Loss-on-ignition method.
[2] LECO carbon analyzer.
[3] Sodium pyrophosphate extraction.
[4] Hydrochloric acid extraction.

living area and the artifacts found on its surface are *in situ* remnants of human occupation. The second possibility – that it is an unweathered, submerged sediment – renders the habitation hypothesis untenable and calls for an alternative explanation for the presence of the artifacts.

The first line of inquiry into the nature of Stratum 2A is simple inspection. A series of microphotographs reveals extreme heterogeneity within the body of the layer, e.g. streaks and blobs of fine white sand, soft calcium nodules, and large, clear quartz grains surrounded by black silt (Fig. 15.1); intact shells embedded in this poorly sorted fabric (Fig. 15.2); bits of wood and plant fiber; fish bone; clusters of small bronze balls tentatively identified as aquatic insect droppings (Fig. 15.3). There is no evidence of horizonation, i.e. gradual sorting of particle-size classes, regular color change, or differentiation of organic matter into tiers or levels of decomposition. The absence of oriented clay films on larger sand grains and most natural planes signals a lack of translocation of fine particles such as that which would occur through a terrestrial soil, though in a few limited areas a dark plane or film (possibly manganese) was evident.

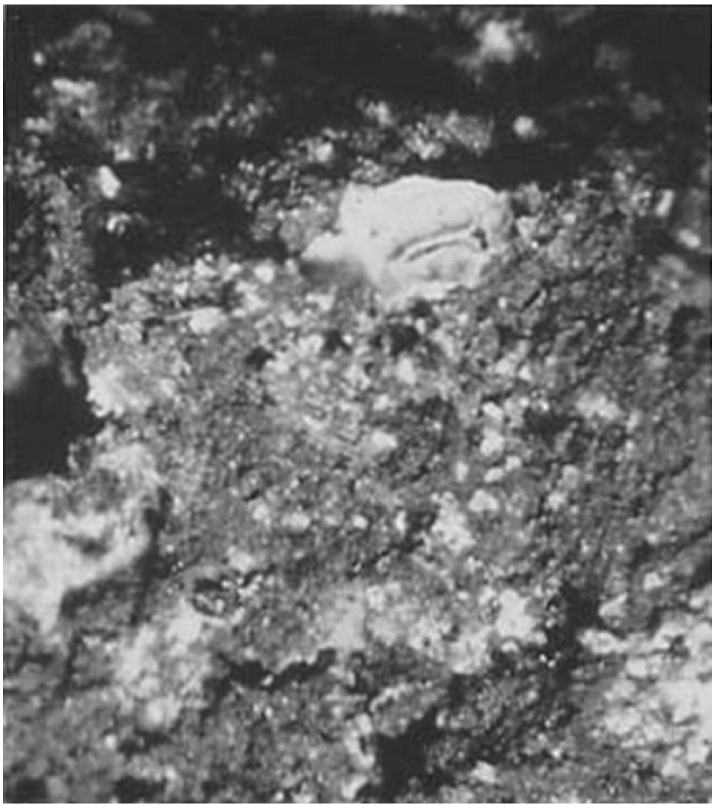


Figure 15.1 Page-Ladson Stratum 2A heterogeneity. Photo by Aucilla River Prehistory Project.

The lack of evidence of soil-forming processes is borne out by the other analyses. High levels of iron in Stratum 2A compared with local terrestrial soils (Table 15.5) indicate that the stratum has not been leached or drained. As Carlisle explains in the Hydric Soils of Florida Handbook (1990:42), iron in a seasonally flooded soil would become reduced upon saturation, go into solution, and drain out as the water table drops. This would result in an iron-depleted horizon, contrary to the condition of 2A.

Although aluminum content is higher in Stratum 2A than any other level, and its accumulation is a marker for terrestrial spodic horizons, two conditions argue against categorizing it as such. First is the overall heterogeneity of 2A, particularly the starkly contrasting black and white blotches. Spodic horizons form when organic carbon, aluminum, and (sometimes) iron in the soil solution move downward and coat mineral sand grains (De Coninck, 1980). In Florida, this movement takes place as a wetting front linked to the seasonal movement of the water table (Garman *et al*., 1981). This process would mask any pale grains or inclusions with a black or dark red coating. The resultant horizon would not contain the streaks and blobs of stripped white fine sand

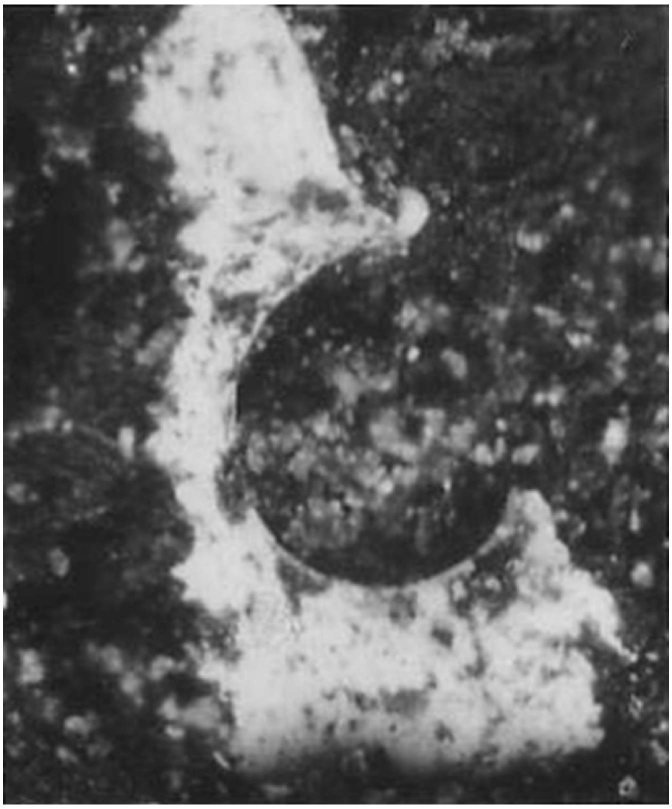


Figure 15.2 Embedded gastropod, Stratum 2A. Photo by Aucilla River Prehistory Project.

seen in the Bolen layer. Secondly, the tiny, articulated clams found in Stratum 2A appear much too delicate to have survived intact if they had endured all the physical and chemical processes leading to the formation of a terrestrial spodic horizon. The diminutive bivalves were so fragile that many disintegrated at the touch of a probe while still wet and in relatively undisturbed clumps of sediment. The scenario of cultural artifacts on top of a subsurface soil horizon could be explained by truncation and deposition: surface horizons eroded to expose the spodic horizon, on which the artifacts were then deposited. Although there is evidence of truncation of the modern riverbank soils and it is a common alluvial process, the lack of satisfaction of the two conditions just discussed effectively rules out the classification of Stratum 2A as a spodic horizon.

The very high aluminum and iron contents and elevated nitrogen content of Stratum 2A may be explained by the interactions of clay and organic matter with these elements. Both organic matter and clays (particularly smectite clays) have extensive

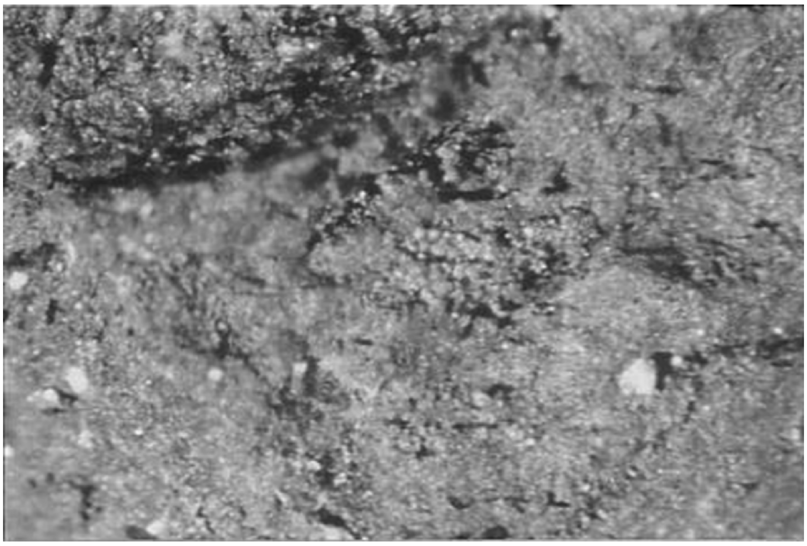


Figure 15.3 Possible aquatic insect droppings. Photo by Aucilla River Prehistory Project.

negatively charged surfaces that bind cations such as aluminum and iron into organomineral complexes (Bohn *et al.*, 1985). Smectites are also very effective in protecting nitrogenous compounds from attack by microbes (Bohn *et al.*, 1985:138). Stratum 2A has the highest organic carbon and clay contents of all levels tested and also the highest Al, Fe, and N contents, particularly pyrophosphate-extracted forms of Al and Fe which are bound by organics.

Evidence of accumulation of sulfur, a by-product of organic matter degradation not specifically tested for, presented itself in a surprising way. As subsamples of Stratum 2A were being scanned for faunal content, calcium sulfate crystals (gypsum roses) began forming on the drying surfaces (Fig. 15.4). This crystal formation is a result of dehydration, concentration, and combination of high levels of calcium and sulfur in the sediment solution. The high sulfur content is additional evidence for lack of leaching in the Bolen layer.

Lack of evidence of pedogenic processes also characterizes the strata bounding 2A. Some contain up to 25% clay but with no oriented or translocated clays evident under microscopic examination. Neither do they show genetic relationship to one another, in contrast to the horizons of the local floodplain soils. Furthermore, the stratum above 2A contains large numbers of molluscs, some of which are articulated bivalves or whole, tiny gastropods. The same question posed of the possibility of clams in a spodic horizon must be addressed here: How did these delicate, aquatic organisms end up intact in a terrestrial soil horizon?

All of the animals identified in this study, as well as those reported in Chapter 17 by McCarty and Schwandes, are freshwater species, with the exception of three terrestrial snails in one upper level sample. According to Abbott (1974) and Auffenberg

Table 15.5 Comparative phosphorus, iron, and aluminum contents

Soil series	*Horizon*	*Total phos. (mg/kg)*	*Fe-pyro (mg/kg)*	*Al-pyro (mg/kg)*
Chaires fine sand	Ap	22		
	E	15		
	Bh1	100	500	1500
	Bh2	83	1800	2100
	E1	45		
	Btg1	618		
	Btg2	642		
	Btg3	3614		
Leon fine sand	Ap	68		
	E	15		
	Bh1	112	200	500
	Bh2	42	400	300
	E′	75		
	B/E	100		
	B′h1	389	200	800
	B′h2	343	200	500
	B′h3	455	200	800
Aucilla sediments: N unit G	8	969	1000	150
	7	1015	1000	200
	6	1480	900	350
	5	1450	2150	3450
“Bolen”	4	951	5150	7400
	3	1820	500	150
	2	1780	400	100
	1	1860	350	100
Aucilla sediments: W unit G	14	230	1200	650
	13	1200	1100	100
	12	1060	700	150
	11	1520	1050	1300
“Bolen”	10	461	5550	7800
	9	1520	400	200
Aucilla sediments: W unit H	22	1340	1600	50
	21	1150	6150	100
	20	1060	950	350
	19	1710	2050	3900
“Bolen”	18	554	9600	7650
	17	1892	450	100
	16	1520	450	150
	15	1570	400	100

(personal communication) the molluscs prefer slow-moving, oxygenated waters. Vertebrates such as freshwater catfish and sunfish (family Centrarchidae) are also quiet water species. In addition, five of the seven species of sponges identified by McCarty and Schwandes prefer shallow, moving water relatively free of suspended silt.

The requirements of these animals indicate that the Bolen layer was always at least minimally covered by moving water. Coupled with the heterogeneous micromorphology

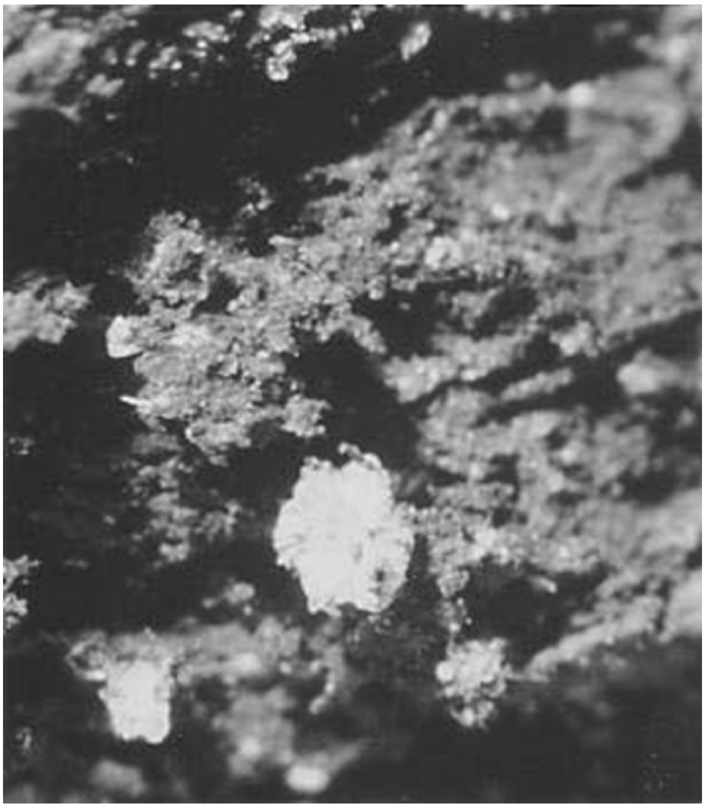


Figure 15.4 Calcium sulfate crystals, Page-Ladson Stratum 2A. Photo by Aucilla River Prehistory Project.

of Stratum 2A, the faunal data suggest that the environment of deposition was perhaps a sink with at least minimal inflow or a curve or backwater eddy of the river, acting as a trap for fine silts and clays and slow-moving enough to collect organics and support populations of the small freshwater molluscs, fish, diatoms, and sponges. The stringers of white sand and black silt suggest pulsed changes in water velocity, perhaps the result of seasonal fluctuations in rainfall.

When we turn to consider the human element, we envision Paleoindians in Florida were hunter-gatherers moving in small, mobile groups (Milanich, 1994). Similarly in the early Archaic it is difficult to imagine such cultures as having a significant impact on local soils. Because humans "... probably did not remain long in one place but continually moved among different camps and water sources to take advantage of concentrations of game ..." (Milanich, 1994:48), their impact on their immediate environment would be slight. Their ephemeral residence sites would not provide the sustained duration or intensity of settlement needed to produce lasting pedogenic evidence of their presence.

One potential marker of human impact on a soil is elevated phosphorus content (Arrhenius, 1929; Broadbent, 1981; Hassan, 1981; Lippi, 1988). Food refuse, human waste and animal manures, plant debris, all contribute phosphorus to the soil (Eidt, 1984, 1985; Lillios, 1992). In alkaline soils, that phosphorus is bound in place by calcium ions; in acid soils by aluminum and iron (Bohn *et al.*, 1985). In either case, the P does not move far from its point of deposition. This is what makes comparative soil P content such a powerful and dependable tool in identifying and interpreting anthropogenic soils. Although Stratum 2A is high in total P relative to local soils (Table 15.4), it is relatively low compared to the other Page-Ladson strata (approximately half that of adjacent layers). Using the logic that a relatively elevated P content signals human influence, the Bolen layer would definitely not qualify as anthropogenic in the context of the adjacent levels. A more plausible source of P than human activity is the high phosphorus clays of the Hawthorn Group and Miccosukee Formation that are cut by the Aucilla River. The higher organic matter content of Stratum 2A (Table 15.4) reduces the relative amount of phosphorus-enriched clay in that level and would account for at least some of the disparity in P content among the levels.

The pristine condition of the small molluscs in Stratum 2A which argues against identifying it as a terrestrial spodic horizon also begs the question of that stratum as a Paleoindian living floor or activity area. A standard marker used to identify living floors in southeastern U.S. aboriginal middens and mounds is a zone of relatively compacted and fractured bone and shell (Russo, 1991). In most cases the shell is oyster or hard-shell clam, both much more robust than the small clams and snails in the Page-Ladson sediments, yet those species succumb to foot traffic by fragmenting and compacting into a characteristically dense layer. The delicate molluscs in Stratum 2A are unlikely to survive those conditions intact. The high percentage of intact sponge spicules found by McCarty and Schwandes also suggests minimal impact on this area.

If, as the evidence suggests, Stratum 2A was always at least shallowly submerged, then the occurrence of cultural artifacts on its surface could be explained by colluviation: artifacts tumbling (or being thrown) into the shallow-water environment from adjacent uphill living areas. This scenario fits the most current and widely accepted interpretation of Paleoindian distribution, the “oasis hypothesis” (Neill, 1964; Webb *et al.*, 1984; Dunbar, 1991), which proposes that most sites were clustered around permanent or dependable water sources in Tertiary karst regions. Florida in Paleoindian times (10,000–7,500 B.C.) was cooler and drier than it is today (Watts and Hansen, 1988; Hansen, this volume) and such water sources would have been vital resources for all of the animals in the food chain, predator, and prey alike – including humans in both of those roles. The configuration of the modern Aucilla River bank and floodplain with its small terraces and sand-and-limestone ridges offers the possibility of reasonable habitation above the water source below.

The question of whether the Bolen layer may have been temporarily exposed and immediately inhabited has been raised. Again, the complete lack of evidence of pedogenesis and the very delicate and intact molluscs would indicate that if this were the case, people moved onto it the instant the water receded and lived on a soggy hydric soil with a high water table, making no impact. The rhetorical question in answer to the first might be: Why live on a periodically flooded hydric soil if upland soils are immediately available?

15.8 Conclusions

Standard soil analytical techniques, faunal identifications, and microphotography were applied to Stratum 2A – the Bolen layer – and related sediments at the Page-Ladson site in Jefferson County, FL. These analyses resulted in the characterization of Stratum 2A as a shallowly submerged sediment and not the surface horizon of a drowned terrestrial soil. Strong support for this characterization came from the lack of evidence of pedogenesis within the Bolen layer and among adjacent strata, and from the identification of intact, diminutive freshwater vertebrates and invertebrates from sediment samples. The extreme heterogeneity of Stratum 2A and the habitat requirements of its infauna suggest that it was covered by shallow, slow-moving water, received intermittent pulses of organic and mineral inputs, and was constricted or protected enough to act as a trap for fine silt- and clay-sized sediments.

The cultural artifacts found on the surface of the Bolen layer were probably deposited by colluviation-tumbling into the water from habitation sites on the slopes above, or thrown in by Paleoindians who frequented the water source.

References

Abbott, R. T. 1974. *American Seashells*, 2nd edition. Van Nostrand, Reinhold Co., New York.

Allen, W. J. 1989. *Soil Survey of Jefferson County*, *FL*. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 191 pp.

Arrhenius, O. 1929. Die Phosphatfrage. Zeitschrift fur Pflanzenernahrung, Dundung und Bodenkunde, 14A:185–194.

Birkeland, P. W. 1984. *Soils and Geomorphology*. Oxford University Press, New York.

Bohn, H., B. McNeal, and G. O'Connor 1985. *Soil Chemistry*, 2nd edition. Wiley-Interscience, John Wiley & Sons, New York.

Broadbent, N. 1981. Phosphate analysis in archaeology: anthropological uses of an old method. *Society of American Archaeology Proceedings,* 42:1–16.

Buol, S. W., F. D. Hole, and R. J. McCracken 1989. *Soil Genesis and Classification*, 3rd edition. Iowa State University Press, Ames, 446 pp.

Carlisle, V. W. (ed.) 1990. *Hydric Soils of Florida Handbook*. Published by FL Association of Professional Soil Classifiers, Gainesville, FL, 144 pp.

Conway, J. S. 1983. An investigation of soil phosphorus distribution within occupation deposits from a Romano-British hut group. *Journal of Archaeological Science*, 10:117–128.

Courty, M. A., P. Goldberg, and R. Macphail 1989. *Soils and Micromorphology in Archaeology*. Cambridge University Press, New York.

Day, P. R. 1965. Particle fractionation and particle-size analysis. In *Methods of Soil Analysis, part 1. Agronomy 9*, C. A. Black (ed.), pp. 548–567.

Dean, W. E. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *Journal of Sedimentary Petrology*, 44(1):242–248.

De Coninck, F. 1980. Major mechanisms in formation of spodic horizons. *Geoderma*, 24:101–128.

Dick, W. and M. A. Tabatabai 1977. An alkaline oxidation method for determination of total phosphorus in soils. *Soil Science Society of America Journal*, 41:511–514.

Dunbar, J. S. 1991. Resource orientation of Clovis and Suwannee age Paleoindian sites in Florida. In *Clovis: Origins and Adaptations*, R. Bonnichsen and K. Turnmier (eds.), pp. 185–213. Center for the First Americans, Oregon State University, Corvallis.

Eidt, R. C. 1984. *Advances in Abandoned Settlement Analysis: Applications to Prehistoric Anthrosols in Colombia*. S. A. Center for Latin American Univiversity of Wisconsin, Milwaukee.

——. 1985. Theoretical and practical considerations in the analysis of anthrosols. In *Archaeological Geology,* G. Rapp, and J. A. Gifford (eds.), pp. 155–191. Yale University Press, New Haven.

Foss, J. E., R. J. Lewis, M. E. Timpson, M. W. Morris, and J. T. Ammons 1993. Pedologic approaches to archaeological sites of contrasting environments and ages. *Proceedings of the First International Conference on Pedo-archaeology*, *Special Publication* 93–03, pp. 19–23. University of Tennessee.

Garman, C. R., V. W. Carlisle, L. W. Zelazny, and B. C. Beville 1981. Aquiclude related spodic horizon development. *Soil and Crop Science Society of Florida Proceedings*, 40:106–110.

Hassan, F. A. 1981. Rapid quantitative determination of phosphate in archaeological sediments. *Journal of Field Archaeology*, 8(3):384–387.

Holliday, V. T. 1992. Soil formation, time, and archaeology. Ch. 3 in *Soils and Archaeology*, V. T. Holliday (ed.), pp. 101–118. Smithsonian Institution Press, Washington.

Jenny, H. 1941. *Factors of Soil Formation*. McGraw-Hill, New York.

Joffe, J. S. 1949. *Pedology*. Pedology Publications, New Brunswick, NJ, 662 pp.

Konrad, V. A., R. Bonnichsen, and V. Clay 1983. Soil chemical identification of ten thousand years of prehistoric human activity areas at the Munsungun Lake Thoroughfare, Maine. *Journal of Archaeological Science*, 10:13–18.

Kuehl, R. J. and R. Denson 1993. Application of soil science to underwater archaeology: Oklawaha River project. *Proceedings of the First International Conference on Pedo-archaeology*, *Special Publication* 93–03, pp. 133–140. University of Tennessee.

Lippi, R. D. 1998. Paleotopography and phosphate analysis of buried jungle site in Ecuador. *Journal of Field Archaeology,* 5:85–97.

Lillios, K. T. 1992. Phosphate fractionation of soils at Agroal, Portugal. *American Antiquity,* 57(3):495–506.

Milanich, J. T. 1994. *Archaeology of Precolumbian Florida*. University Press of Florida, Gainesville, 476 pp.

Neill, W. T. 1964. Trilisa Pond, an early site in Marion County, Florida. *Florida Anthropologist*, 17:187–200.

Rich, C. I. 1968. Hydroxy interlayers in expansible layer silicates. In *Clays and Clay Minerals*, Vol. 16, pp. 15–30. Pergamon Press, London.

Rich, C. I. and S. S. Obenshain 1955. Chemical and clay properties of a red-yellow Podzolic soil derived from muscovite schist. *Soil Science Society of American Proceedings*, 19:334–339.

Russo, M. 1991. Archaic sedentism on the Florida coast: a case study from Horr's Island, pp. 396–397, Ph.D. dissertation, University of Florida.

Sandor, J. A. 1992. Long-term effects of prehistoric agriculture on soils: examples from New Mexico and Peru. Ch. 8 in *Soils in Archaeology*, V. T. Holliday (ed.), pp. 217–246. Smithsonian Institution Press, Washington.

Scott, T. M. 1988. The lithostratigraphy of the Hawthorn Group (Miocene) of Florida. *Geological Bulletin* No. 59. Florida Geological Survey, Tallahassee, 148 pp.

Scudder, S. J., J. E. Foss, and M. E. Collins 1996. Soil science and archaeology. Ch. 1 in *Advances in Agronomy*, Vol. 57, pp. 1–76. Academic Press, New York.

Soil Survey Staff 1975. *Soil Taxonomy*. U.S.D.A. Soil Conservation Service. Agricultural Handbook No. 436. U.S. Government Printing Office, Washington, D.C.

Soil Survey Staff 1981. Examination and description of soils in the field. In *Soil Survey Manual*, pp. 4–2 to 4–107. U.S.D.A. Soil Conservation Service, U.S. Government Printing Office, Washington, D.C.

Watts, W. A. and B. C. S. Hansen 1988. Environments of Florida in the late Wisconsin and Holocene. In *Wet Site Archaeology*, B. A. Purdy (ed.), pp. 307–323. Telford, Caldwell, NJ.

Webb. S. D., J. T. Milanich, R. Alexon, and J. S. Dunbar 1984. A *Bison antiquus* kill site, Wacissa River, Jefferson County, Florida. *American Antiquity*, 49:384–392.

White, W. A. 1970. The Geomorphology of the Florida Peninsula. Bureau of Geology, Florida Department of Natural Resources. *Geological Bulletin* No. 51:1–159.

Yon, J. W. 1966. Geology of Jefferson County, FL. *Geological Bulletin* No. 48, FL Geological Survey, Tallahassee, 119 pp.

Chapter 16

Early Holocene Vertebrate Paleontology

TANYA PERES and ERIKA SIMONS
Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.

16.1 Introduction

The richest concentration of vertebrate fossils and cultural remains in the Page-Ladson site was scattered on the upper surface of stratigraphic Unit 5. This bone layer was encountered most clearly in Test C and was worked, as the site was extended, during seven different field seasons. The two most intensive seasons were June and October, 1995. During that year the Aucilla River Prehistory Project (ARPP) made its primary goal to intensively map and collect on the surface of Unit 5, also known as "the Bolen surface". This extended Test C northward along the west bank of the Aucilla River. After removing the surface leaves and upper few meters of sediment with a 6-in. dredge, an area of 6 m was carefully mapped and excavated.

A second goal of the 1995 season was more carefully to distinguish the fine stratigraphic levels above and below the rich "Bolen surface". For that purpose four distinct levels each 10 cm deep were individually removed over the 6 m area. It became evident that a distinct unconformity separated the "Bolen surface" from the overlying sediments. These were assigned to tratigraphic Unit 6. The lowermost 10 cm consisted of nearly white shelly siliceous silts. The excavation teams very carefully "peeled" the shelly silt from the underlying compact dark gray clay of Unit 5 using dental picks and trowel tips.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 461–470

In this chapter, we describe the resulting collections of fossil vertebrates from the upper surface of Unit 5 and the lowermost 10 cm of Unit 6. In a bulk faunal study we list all identifiable vertebrates from all the field seasons that recovered material from that level. In some cases this may include material from the lower 10 cm of Unit 6 as well, since that distinction was not well understood in the first two seasons. We do not include equivalent aged material from Test B as that material came from a distinctly deeper water deposit from the opposite side of the Page-Ladson site.

Further more detailed analyses in this chapter are based on the 1995 material. There we clearly distinguished the two levels and, as noted above, we also mapped and point-plotted most vertebrate specimens. We first present the basic list of taxa from each unit, and then we develop further taphonomic analyses to shed light on the mode of deposition of these two strata and their vertebrate contents. We expected to see a heavy impact of human food procurement processes. As the following analyses will show, however, the vast majority of material must be considered naturally accumulated for lack of contrary evidence.

The age of the "Bolen surface" has been well determined by a set of four closely corroborative carbon dates with a pooled average of 9959 ^{14}C BP. Careful chemical studies (Chapter 15 by Scudder) show that it did not form a soil. There is nevertheless clear evidence from the development of hearths and charred wood that the surface was exposed subaerially for a time, perhaps as much as a century. Stratigraphic Unit 6 was initiated by a rising water table and a return of fully aquatic deposition over and above the "Bolen surface". In this chapter, we present vertebrate faunal and taphonomic evidence about the earlier and the later depositional phases.

16.2 Methods

16.2.1 Systematic Methods

The mapped and recovered vertebrate specimens were given field labels and bagged. The remaining bulk sediments from each square meter were passed through ¼ in. and ⅛ screens and bagged for subsequent picking under a microscope. We identified the vertebrate fossils to species or the next nearest higher categories that we could. We utilized the comparative collections in the Zooarchaeology Laboratory and the Vertebrate Paleontology Laboratory at the Florida Museum of Natural History. We then cataloged the material in the computerized system of the latter collection. The results could be organized by stratigraphic level, by systematic categories, or by element. In order to make as a comprehensive taxonomic survey as possible we studied all collections from stratigraphic Unit 5 surface. In some of the early seasons these collections included some material from lower Unit 6 as well.

16.2.2 Taphonomic Methods

The term taphonomy refers to the study of fossils during the process of deposition as a means of generating clues about their postmortem environmental conditions. In this study, we were particularly concerned to discover evidence of either human activity or natural environmental processes on and immediately above the “Bolen surface”. A second purpose of the taphonomic analyses was to determine what environmental differences and faunal differences might distinguish the “Bolen surface” from the lowermost 10 cm of Unit 6. The taphonomic analyses were based exclusively on the results of the two 1995 field seasons.

We carefully scrutinized each vertebrate element for any evidence of water-wear, gnawing, human use wear, thermal alteration, or butchering. For each lot of field specimens (i.e. all of one taxon from 1 m at one level), we calculated the Minimum Number of Individuals (MNI) determined by the most abundant element for that lot. All specimens of one taxon from one level were counted and weighed (in grams) and the data were recorded into an Access Database and an Excel Spreadsheet for further study.

16.3 Results

16.3.1 Faunal List

The vertebrate taxa identified in the combined samples from all field seasons are presented in Table 16.1. The vast majority of these taxa are aquatic species. Five classes of vertebrates included are Osteichthyes, Amphibia, Reptilia, Aves and Mammalia. The Osteichthyes, or bony fish, are represented by 12 freshwater species or genera. There are only four kinds of amphibians. Reptilia are the most diverse class with 11 taxa including 7 aquatic turtle genera or species, one terrestrial turtle species, alligators, and two kinds of water snake. Birds are very rare with only one humerus of an unidentified duck. Mammals are also rather rare, being represented by four living species. There are no extinct forms in this early Holocene fauna.

More detailed ecological discussions of individual taxa are not repeated here, as most of the same taxa are covered above in Chapter 8 by Webb and Simons. The overall indication is clearly one of a freshwater pond or lentic (quiet) stream environment with a suite of species quite familiar in most parts of Florida today.

16.3.2 Taphonomy

The principal results that might illuminate different environments of deposition between the “Bolen surface” at the top of stratigraphic Unit 5 and the subsequent

Table 16.1 Early Holocene vertebrate taxonomic list

Taxonomic name	*Common name*
Osteichthyes	Bony fishes class
Lepisosteidae	Garfish family
Lepisosteus sp.	Garfish
Amia calva	Bowfin or mudfish
Notemigonus chrysoleucas	Golden shiner
Catostomidae	Sucker family
Erimyzon sucetta	Lake chubsucker
Minytrema melanops	Spotted sucker
Ictaluridae	Freshwater catfish family
Ictalurus sp.	Freshwater catfish
Ameiurus natalis	Yellow bullhead catfish
Ameiurus nebulosus	Brown bullhead catfish
Esox sp.	Pike fish
Centrarchidae	Sunfish and bass family
Lepomis sp.	Sunfish
Lepomis microlophus	Shellcracker or redeared sunfish
Micropterus sp.	Bass
Pomoxis sp.	Crappie
Sciaenops ocellatus	Red drum
Archosargus probatocephalus	Sheephead
Mugil sp.	Mullet
Amphibia	Amphibians class
Anura	Frog and toad order
Bufonidae	Toad family
Bufo sp.	Toad
Rana sp.	Southern leopard frog
Caudata	Salamanders
Amphiuma sp.	Amphiuma
Siren sp.	Siren
Reptilia	Reptiles class
Testudines	Turtle order
Chelydra serpentina	Snapping turtle
Kinosternidae	Mud and musk turtle family
Kinosternon sp.	Mud turtle
Sternotherus sp.	Musk turtle
Emydidae	Cooter, slider, box turtle family
Deirochelys reticularia	Chicken turtle
Malaclemys terrapin	Diamondback terrapin
Pseudemys nelsoni	Florida red-bellied turtle
Pseudemys / Trachemys sp.	Pond turtle
Terrapene carolina	Eastern box turtle
Serpentes	Snake order
Crotalidae	Pit viper family
Agkistrodon sp.	Water moccasin
Natricinae	Water snake family
Nerodia sp.	Water snake
Crocodilia	Crocodile and alligator order
Alligatoridae	Alligator family

(*Continued*)

Table 16.1 Early Holocene vertebrate taxonomic list —(Continued)

Taxonomic name	*Common name*
Alligator mississippiensis	American alligator
Aves	Class of birds
Anatinae	Subfamily of ducks, geese and swans
Mammalia	Class of mammals
Didelphis virginianus	Opossum
Rodentia	Order of rodents
Sciurus niger	Fox squirrel
Lagomorpha	Order of rabbits and hares
Sylvilagus sp.	Cottontail or marsh rabbit
Artiodactyla	Order of even-toed ungulates
Cervidae	Family of deer, moose and elk
Odocoileus virginianus	White-tailed deer

shelly silt of lowermost Unit 6 are presented in Table 16.2. This displays the MNI, weight, count of identified specimens and percentage of the total count for all vertebrates, divided into seven taxonomic groups for each of the two stratigraphic levels.

Two principal differences distinguish the upper unit from the “Bolen surface”. First is the increase in the apparent importance of fishes; the relative number increases by more than 10 percent. The other striking difference is the total absence of mammals. Whatever terrestrial sources had delivered mammal elements onto the “Bolen surface” evidently had shifted too far from the area of excavation lie by the time the lower 10 cm of Unit 6 were deposited.

A more detailed comparison of the fish taxa presented in Table 16.3 shows only minor differences between the “Bolen surface” ichthyofauna and that of the lower part of Unit 6. In the latter, with an augmented fish sample, *Esox* (pike) increases whereas *Ictalurids* (freshwater catfish) and *Micropterus* (bass) decrease. The decrease in catfish might imply clearer, more swiftly running water and this would also fit the increase in pike. Together with the relative increase in the importance of fishes, these data suggest rising water table and, at least seasonally, more swiftly flowing water in the upper unit.

Table 16.2 Taphonomic data for vertebrate fauna from early Holocene levels

	Unit 5 surface				*Unit 6 lowest 10 cm*			
	MNI	*Weight*	*Count*	*Percent*	*MNI*	*Weight*	*Count*	*Percent*
Fishes	26	59.7	281	57	54	109.7	553	64
Amphibia	7	4.4	16	3	9	5.5	24	3
Turtles	18	188.6	177	36	36	229.3	261	31
Snakes	3	1.2	5	1	2	1.2	5	1
Alligators	1	1.2	2	1	1	1.9	2	1
Birds	1	0.2	1	1	–	–	–	–
Mammals	3	2.0	3	1	–	–	–	–

Table 16.3 Detailed taphonomic data for fish fauna from early Holocene levels

	Unit 5 surface				*Unit 6 lowest 10 cm*			
	MNI	*Weight*	*Count*	*Percent*	*MNI*	*Weight*	*Count*	*Percent*
Lepisosteus	4	3.3	8	3	3	1.9	6	5
Amia	10	25.1	63	25	6	8.2	33	27
Esox	3	0.7	4	2	3	5.1	13	10
Pomoxis	1	0.2	2	1	1	0.2	1	1
Micropterus	8	5.2	21	9	3	1.7	4	3
Ictalurus	22	42.4	144	58	6	22.5	64	52
Lepomis	5	0.8	5	2	3	0.3	3	2

16.3.3 Human Impacts

The most important evidence of human utilization of vertebrate species comes from a number of modified bones and antlers of *Odocoileus virginianus*. The simplest of these is a flaked and honed bone pin made from the metatarsal (hind cannon bone), the longest straight bone in the deer's skeleton. One end of the pin had been fractured by heavy impact after it had been manufactured.

Several modified pieces of antler were also recovered. One of these, previously described from Test B at about the same level as the "Bolen surface" in Test C, was from a curved part of the antler and was socketed at the thicker end as a probable tool handle (Dunbar *et al.*, 1989).

The most elaborate piece of worked vertebrate material from the "Bolen surface" is the partial cranium of a male *Odocoileus virginianus*. It consists of most of the convex portion of the frontal bone with an antler attached. The antler is truncated, cut rather than broken, rounded, and burned. The probable purpose of this apparatus is as a drinking cup, the inner (concave) surface serving as the container and the antler as the cup handle. This object is figured in the Appendix of color figures.

Two turtle carapace fragments show evidence of being drilled. Their function is not clear. These and all other artifacts are described in Chapter 18 by Carter and Dunbar.

16.4 Discussion

One of the primary interests in intensive excavation of the early Holocene strata at Page-Ladson was to discern what faunal subsistence patterns prevailed in early Archaic cultures after the extinction of the late Pleistocene megafauna. In the western United States a primary replacement for the megafauna was *Bison*, but there is no evidence of its utilization in the southeastern United States after the late Pleistocene (Webb *et al.*, 1984; Milanich, 1994; Anderson and Sassaman, 1996). A relatively rich scatter of cultural artifacts on the "Bolen surface" encouraged optimistic expectations that we could reconstruct a fairly complete vertebrate "menu" for the early Holocene at Page-Ladson.

As we undertook analysis of the assemblage from the "Bolen surface" and from the next higher level in the lowest 10 cm of stratigraphic Unit 6, we realized that we had first to distinguish what remains resulted from human activities and what were unmodified natural deposits. The fundamental question in this work was whether we would lean toward Type I errors ("false positive" results), or alternatively, whether we would lean toward Type II errors, ("false negative" results). Driven by our interests as archaeologists in cultural results we had initially expected to see mostly human impacts, but after careful reflection on the body of the evidence we determined to insist on a more conservative approach. We required definite evidence of human modification before we would consider any vertebrate element as culturally modified.

On balance we see the faunal remains from these levels at Page-Ladson as mostly natural, primarily aquatic deposits. This conclusion was strongly supported by the taphonomic results reported above, with a dozen species of fishes and half a dozen kinds of aquatic turtles strongly dominating the fauna. This position was reinforced by the close similarity between the "Bolen surface" fauna and the fauna from the next higher stratigraphic level with its much weaker cultural signal.

This is a classic dilemma for archaeological studies in partly to wholly natural depositional settings. And that is the reason that zooarchaeologists have devoted increased attention to the subject of taphonomy, originally developed by vertebrate paleontologists (Behrensmeyer and Hill, 1980). Such students as Klein and Cruz-Uribe (1984), Lyman (1984, 1994), Olsen (1989), Stahl (1996), and Thomas (1971) have advanced the theory and practice of such work. We carefully considered the procedures and pitfalls discussed by Grayson (1981). For example the use of MNI calculations may not accurately reflect the original number of animals living in an environment, unless the biases introduced by the particular depositional processes are reasonably well understood. Some of the problems inherent in such work are minimized in the present study by the fact that these aquatic assemblages appear to represent recognizable modern analogs in Florida freshwater environments (Page and Burr, 1991).

Our determination that we were sampling a mostly natural fauna presents an instructive contrast with the nearest equivalent early Holocene fauna. That is the Dust Cave vertebrate assemblage from Alabama, associated with an early side-notched lithic culture (Grover, 1994). The Dust Cave assemblage was a very rich and very diverse terrestrial sample, dominated by birds and mammals, from two 2 × 2 m excavations. The difference is that that fauna was clearly transported into the cave and deposited there strictly by human activity. The burden of discriminating what might have been natural was thus removed in the Dust Cave study by a clearly human context.

We considered the remote possibility that the Page-Ladson early Holocene fauna was entirely (or largely) generated by human processes, for example, the discarded products of a nearby human habitation site. If so, there was a strikingly diverse sample of fishes and turtles. The very different, largely terrestrial sample from Dust Cave, located adjacent to the Tennessee River, tends to support our conclusion that such a scenario is unlikely. There the only aquatic species utilized by humans are small aquatic mammals and birds, not fishes.

On the other hand, the Dust Cave data raise the possibility that we have erred on the conservative side by insisting on clear evidence of human modification for every terrestrial element. Quite possibly at Page-Ladson the non-modified elements of mammals and the one duck bone were introduced to the site by early Archaic people. Likewise the terrestrial box turtle, *Terrapene carolina*, may represent an element introduced by human activities. We simply cannot be sure.

The one species of vertebrates that clearly became a staple of the early Archaic people both at Page-Ladson and at Dust Cave was *Odocoileus virginianus*. Venison was surely an important source of protein and fat; and deer long bones and antlers were manufactured into hand tools and tool handles. In the most elaborate piece, the frontal bone with a carefully trimmed antler became a decorative culinary item. This last item closely resembles another deer cranium and antler piece from Little Salt Springs in Sarasota County, Florida at a roughly equivalent time in the early Holocene (Clausen *et al*., 1979).

It is also noteworthy that several specimens within the small sample of modified bones were charred. This observation comports well with the extensive evidence on the "Bolen surface" of the use of wood and fire, including hearths, woodworking tools such as adzes and wedges, and actual specimens of worked wood and charcoal. Clearly this interval of occupation on the surface must be slightly separated in time from the natural deposition of an aquatic vertebrate fauna. This chapter clearly shows that aquatic faunas occurred both earlier and later than the peak interval of Bolen activity. Presumably the human occupation encroached most when drought conditions led to subaerial exposure of this surface.

16.5 Conclusions

The early Holocene vertebrate fauna from the Page-Ladson site consists primarily of a naturally accumulated aquatic fauna. It is dominated by a dozen species of freshwater fishes and a half dozen kinds of aquatic turtles. The initial expectation that the upper surface of stratigraphic Unit 5, also known as the "Bolen surface", might produce a large sample of vertebrate specimens that were modified by humans was not supported by careful review of the extensive available samples, mapped and collected from 6 m^2 on that surface.

Stratigraphic Unit 6 lies unconformably on the surface of Unit 5. Its lower 10 cm produced a very similar aquatic fauna, with three minor differences. Pike were relatively more abundant and there were fewer bass and freshwater catfish. Another difference was that it produced no bird or mammal remains. The generally close resemblance between the dominant aquatic faunas of these two units tends to support the view that the "Bolen surface" sample was not primarily a product of human activities, but rather was mostly a natural accumulation in shallow, quiet water.

The "Bolen surface" did produce a few interesting examples of vertebrate specimens that clearly were modified by humans. The most numerous such items were made from limb bones, antlers and cranial material of *Odocoileus virginianus*. The most elaborate of these was a probable drinking cup made from the frontal bone with a truncated antler as its handle. A few additional specimens were modified turtle carapace scutes. These vertebrate artifacts presumably accumulated on the "Bolen surface" when it was exposed subaerially, along with hearths, worked wood and a diversity of lithic artifacts. They represent a distinctly different suite of vertebrate elements than the dominant freshwater aquatic fauna.

16.6 Acknowledgments

This chapter was derived in part from a Master's thesis by the first author in the Department of Anthropology at Florida State University in Tallahassee. We are deeply grateful for extensive help we received from Drs. Rochelle Maarinen and Elizabeth Wing, our mentors in zooarchaeology. We also received valuable encouragement from Dr. Brinnen Carter who first suggested this project.

References

Anderson, D. G. and K. E. Sassaman (editors). 1996. *The Paleoindian and Early Archaic Southeast*. The University of Alabama Press, Tuscaloosa, Alabama.

Behrensmeyer, A. K. and A. P. Hill (editors). 1980. *Fossils in the Making*. University of Chicago Press, Chicago.

Clausen, C. J., A. D. Cohen, C. Emiliani, J. A. Holman, and J. J. Stipp. 1979. Little Salt Spring, Florida: A Unique Underwater Site. *Science* 203:609–614.

Dunbar, J. S., S. D. Webb, and D. Cring. 1989. Culturally and Naturally Modified Bones from a Paleoindian Site in the Aucilla River, North Florida. *In Bone Modification*, edited by R. Bonnichsen and M. H. Sorg, pp. 473–498. Center for the Study of the First Americans, University of Maine, Orono.

Grayson, D. K. 1981. A Critical View of the Use of Archaeological Vertebrates in Paleoenvironmental Reconstruction. *Journal of Ethnobiology* 1(1):28–38.

Grover, J. 1994. Faunal Remains from Dust Cave. *Journal of Alabama Archaeology* 40(1–2):116–134.

Klein, R. G. and K. Cruz-Uribe. 1984. *The Analysis of Animal Bones from Archaeological Sites*. The University of Chicago Press, Chicago.

Lyman, L. R. 1984. Archaeofaunas and Butchery Sites: A Taphonomic Perspective. In *Advances in Archaeological Method and Theory*, vol. 10, edited by M. B. Schiffer, pp. 249–337. Academic Press, San Diego.

Lyman, L. R. 1994. *Vertebrate Taphonomy*. University Press, Cambridge.

Milanich, J. T. 1994. *Archaeology of Precolumbian Florida*. The University Press of Florida, Gainesville.

Olsen, S. L. 1989. On Distinguishing Natural from Cultural Damage on Archaeological Antler. *Journal of Archaeological Science* 16:125–135.

Page, L. M. and B. M. Burr. 1991. *A Field Guide to Freshwater Fishes North America North of Mexico*. Houghton Mifflin Company, Boston.

Stahl, P. W. 1996. The Recovery and Interpretation of Microvertebrate Bone Assemblages from Archaeological Contexts. *Journal of Archaeological Method and Theory* 3(1):31–75.

Thomas, D. H. 1971. On Distinguishing Natural from Cultural Bone in Archaeological Sites. *American Antiquity* 36(3):366–371.

Webb, S. D., J. T. Milanich, R. Alexon, and J. S. Dunbar. 1984. An Extinct Bison Kill Site, Jefferson County, Florida. *American Antiquity* 49:384–392.

Chapter 17

Biogenic Silica as an Environmental Indicator

RUSSELL MCCARTY[1] and LARRY SCHWANDES[2]
[1]Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.
[2]Soil and Water Science Department, Institute of Food and Agricultural Sciences,
University of Florida, Gainesville, FL 32611, USA.

17.1 Introduction

For more than a decade, archaeologists and paleontologists from ARPP (the Aucilla River Prehistory Project) assisted by a team of auxiliary researchers have examined strata, artifacts, and fossils from sites in the Aucilla River in Jefferson County, Florida. Not only are these sites important as records of Paleoindian habitation of late Pleistocene Florida, they also preserve a record of climatic and taxonomic changes that occurred at the end of the Wisconsin Glaciation 10,000 years ago.

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 471–491

These sites characterize a complex and dynamic area whose unique nature is due to seasonal and long-term variability, and to the multitude of other factors which are known to effect riverine environments. Sediments and soil types, along with ecological markers, such as shells, macroscopic plant remains, pollen, and biogenic silica can be moved from their original point of deposition in riverine sites creating impediments to our understanding of these sites. The multi-discipline approach taken by the ARPP researchers promises to answer many of the remaining questions about this historically significant site.

17.1.1 The Question

One of the first sites to be investigated by ARPP, in the late 1980s, was the Page-Ladson site near the confluence of the Wacissa and Aucilla rivers. The accumulated evidence gathered from the site shows changes in the climate, flora, fauna, and human cultural assemblages from the late Pleistocene Epoch through the early Holocene Epoch. Of particular interest to researchers involved with the ARPP is Stratum 2A at the Page-Ladson site, called the Bolen Level. This is a clearly defined dark brown layer whose surface lies 4 m below the river. The presence of charcoal, organic matter, and what it is possibly a stake made of wood found in this layer suggests human activity. Additional evidence to support this supposition comes from lithic flakes and Paleoindian tools scattered on the surface of the Bolen Level. Researchers from different disciplines, including palynologists, ethnobotanists, soil scientists, chemists, and the present authors have examined samples taken from different locations of Unit 2A, the Bolen Level, in an attempt to determine the exact nature of this life at the time this stratum was deposited. It clearly represents a unique and significant event in the history of the Aucilla River. The question is whether the Bolen Level represents a habitation surface reflecting human occupation and soil formed during an early Holocene dry period with lowered water levels, or is it a river sediment?

Change in the environment is a primary causal agent of variation in biotic communities. Environmental changes result from variations in such natural phenomena as temperature, salinity, pH, water supply, and rainfall patterns. Since the end of the Pleistocene in North America, human activities such as hunting, burning, clearing, horticulture, and agriculture have introduced a new source of environmentally disruptive activities. The objective of this investigation is to recover and examine biogenic silica found in sediments from the Bolen Level (Unit 2A), and, if possible, to determine the nature of this level. Because of the durability of biogenic silica (Schwandes, 1998), organisms which produce silica microfossils, such as some terrestrial plant cells, diatoms, and sponges, are excellent indicators of past environments and environmental change. By comparing the silica microfossils from the Bolen Level with those recovered from strata above and below this level, and by applying accepted principles of environmental interpretation, it should be possible to characterize the local environment at the time of the Bolen Level (2A) deposition.

The investigators also hope to document changes in the biotic community, as expressed by silica microfossils recovered from Page-Ladson sediments.

17.1.2 Biogenic Silica

Biogenic silica recovered from sediments found at Page-Ladson site is produced by several groups of plants and by at least one group of animals. Silicon, as silica (silicon dioxide, SiO_2), is the most common element in the earth's crust. As such, it is present in dissolved form in almost all fresh and marine waters. Biogenic silica refers to silica structures within an organism that have been fabricated by the organism itself through the extraction and processing of naturally occurring silica or silicon. Plants and animals use silica in diverse ways structurally and defensively, usually in the form of hydrated opal, SiO_2–H_2O. This form is identical to gem opal, a non-crystalline substance, which has a specific gravity of 1.90–2.1 (Pearsall, 1989). Because of its strength, and resistance to acidity and temperature, silica structures manufactured by living organisms have the potential to survive long after the organism's death. These qualities of silica, and the fact that silica building organisms are the most common life-forms on earth, provide us with a tool for recording change in environmentally sensitive organisms, and thus the environment itself.

At the Page-Ladson site, fossil silica structures representing vascular plants have been found in the Bolen Level and other strata. Vascular plants ingest silica in the dissolved form of monosilicic acid. As water is lost through natural processes such as transpiration and evaporation, the remaining silica is deposited in the walls of plant tissues, most commonly, leaves, roots, stems, and seeds, where it acts to strengthen the plant and protect it against predation by fungi, bacteria, insects, and herbivorous mammals. When the plant dies, these deposited silica structures, which are called phytoliths, can survive intact, under the right conditions, for millions of years.

Phytoliths range in size from 10 to 100 μm, similar in size to the durable exine skeleton of pollen grains. Like pollen, many phytoliths are sufficiently unique morphologically, that they can be used to identify the parent plants down to family, or even genus level. Identification based on the unique morphology of phytoliths is especially applicable to monocots, such as grasses (see Fig. 17.1), sedges, palms (see Fig. 17.2), and bamboo, but may also be applied to some dicots, such as the hardwoods and common herbaceous plants like cocklebur, ragweed (see Fig. 17.3), and dog fennel (Herendeen, 1985).

In addition to their value as taxonomic markers, some of the phytoliths produced by grasses can also provide information about changing environmental conditions. Grasses forced to grow in "water-logged" conditions produce larger, wedge-shaped motor-cell phytoliths called bulliform cells (see Fig. 17.4). These specialized cells allow the growing leaf or grass blade to unroll. When subjected to wetter than normal conditions, many grasses will deposit excess silica in these bulliform cells. The presence or relative absence of these easily recognized phytoliths can be clues to flooding, changes in river channels, water table variation, or protracted climate change.

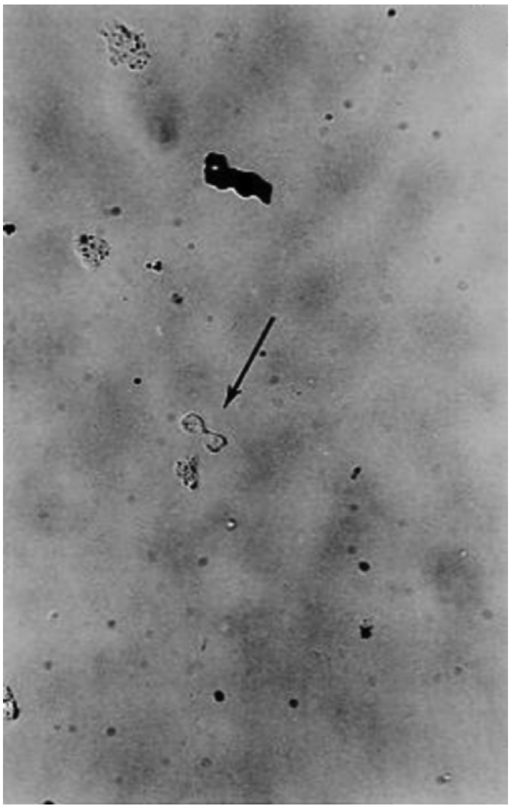


Figure 17.1 Phytolith of grass ×100. Photo by Aucilla River Prehistory Project.

Another group of plants that produce biogenic silica structures are the single-celled algae called diatoms. The silica skeletons of these plants, which range in size from 5 to 300 µm, are found in most levels sampled at the Page-Ladson site. Diatoms are extremely abundant in freshwater, marine, and brackish ecosystems, and are considered to be one of the most sensitive environmental indicators. Wilding and Drees (Bozarth, 1993) estimate that under ponded, or poorly drained conditions, from one third to one half of the total biogenic opal recovered from a sediment or soil is represented as diatoms.

This group of plants is divided into two main classes based on structure; the centrate diatoms, which are generally round and radially symmetrical, and the pennate diatoms whose long, stretched-out ovals, or crescents, are bilaterally symmetrical. Centrate diatoms are the predominate forms found in marine habitats. Pennate forms are found in both freshwater and marine environments, but are more common in freshwater.

Diatoms can be planktonic (free-floating), benthic (fastened to an animate or inanimate substrate), or even, freely moving bottom dwellers.

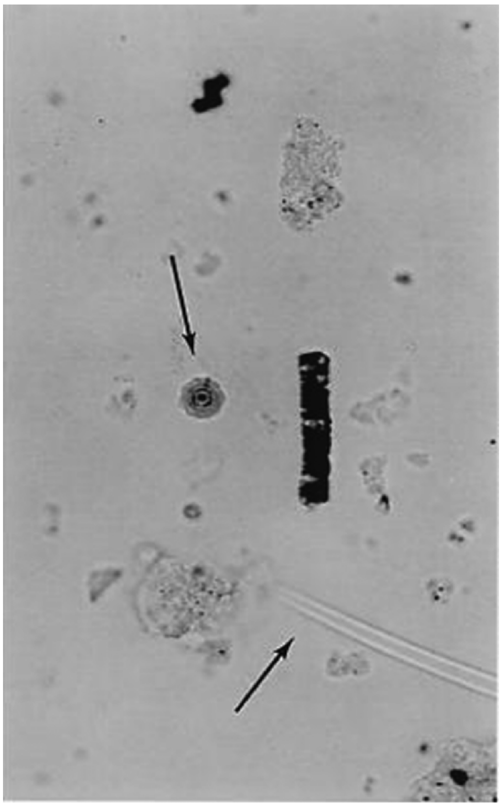


Figure 17.2 Phytolith, *Serenoa repens* ×250. Photo by Aucilla River Prehistory Project.

In addition to their affinity for either freshwater, or marine habitats, other diagnostic aspects of diatoms make them useful as environmental indicators. Diatoms can show clear preferences, or tolerance, for eutrophic, nutrient-rich environments, or nutrient-poor, oligotrophic waters. Some diatoms can help determine whether a water environment is lentic or lotic. The genus, *Cymbella*, for instance, contains species that prefer the moving water of rivers and streams. Other species, such as *Navicula pupula*, are found only in ponds.

A third group of organisms found at the Page-Ladson site that produce biogenic silica are the fresh water sponges. Sponges are plant-like multi-celled animals that inhabit both freshwater and marine habitats. From silica extracted from the water in which they live, sponges build durable, long-lasting skeletons composed of distinctive needle-like spines called spicules. Sponges produce three types of spicules: megascleres (see Fig. 17.5), microscleres, and gemmoscleres. Megascleres are needle-shaped and are 200–300 µm in length. Microscleres are rod-shaped or needle-shaped and are

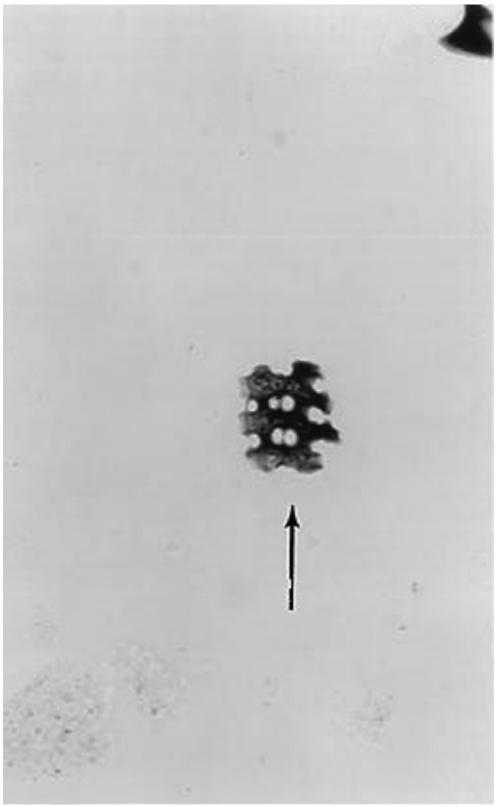


Figure 17.3 Phytolith, *Ambrosia taxera* ×700. Photo by Aucilla River Prehistory Project.

smaller than megascleres. Gemmoscleres (see Fig. 17.6) are produced in the asexual reproductive bodies called gemmules, and are small, frequently, dumbbell-shaped objects <60 µm long. The assemblage of spicules produced by any given species of sponge is unique to that species, thus, providing the researcher with keys to identify different species.

Sponge researchers, Schwandes and Collins (1994), have discussed the significance and distribution of freshwater sponge spicules in Florida soils. These researchers observed that the degree of fracturing and pitting seen in sponge spicules provides evidence of transport by water or wind. A high percentage of unbroken spicules in a sediment sample suggests that the spicules were not transported very far, but were, instead, formed and deposited near the site where they are found. Schwandes and Collins (1994) also noted that large numbers of sponge spicules in soils or sediments indicate aquatic habitats that favor sponge growth.

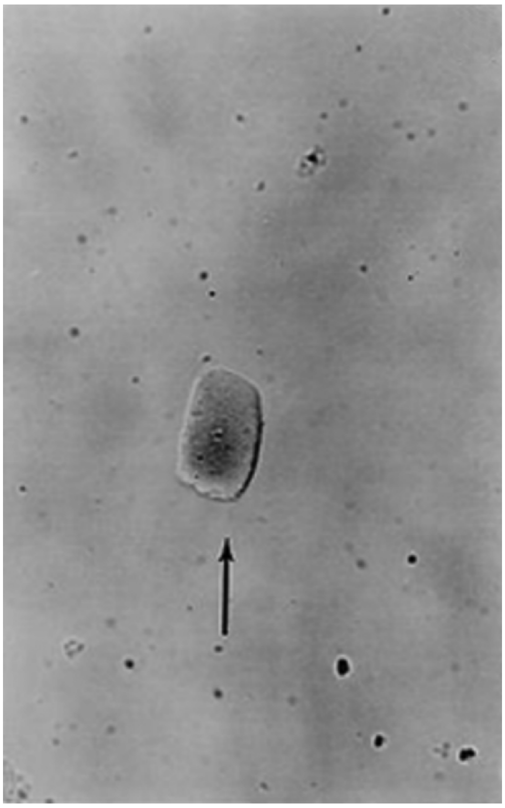


Figure 17.4 Bulliform cell of grass ×250. Photo by Aucilla River Prehistory Project.

17.2 Methods and Materials

17.2.1 Collection of Samples Tested for Biogenic Silica

The samples which were tested for biogenic silica were taken from Test C at the Page-Ladson site, approximately 4 m below the river surface near the west bank of the Aucilla River (Table 17.1). A 1-l sample (4) was removed from Unit 2A on the north face of Test G in the Bolen Level. One-liter samples were also removed at 15-cm distances above sample 4, and 15 cm below sample 4. These were labeled samples 5 and 3, respectively. One-liter samples were also extracted from the west face of Units G and H in the Bolen Level (2A), laterally, 1 m apart. These were samples 18 and 10 also studied for analyses of soils (see Chapter 15 by Scudder). The samples were transported to the Environmental Archaeology Laboratory at the Florida Museum of Natural History, University of Florida, Gainesville. Here they were cataloged and stored wet.

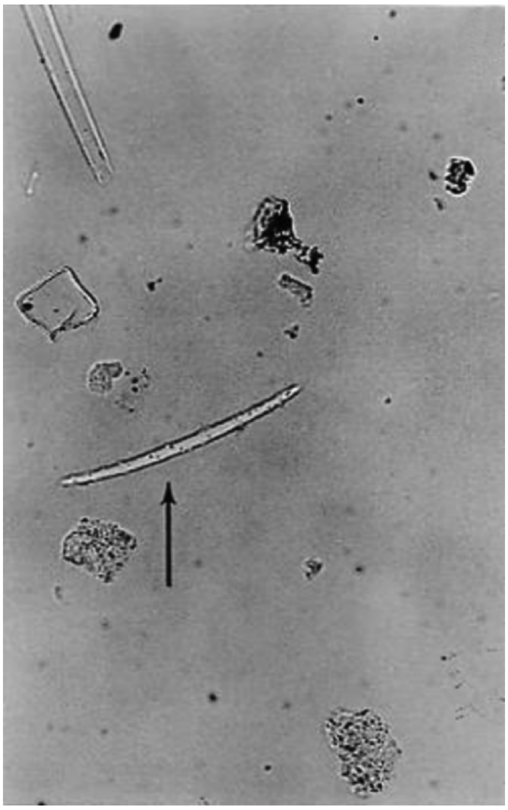


Figure 17.5 Megasclere of sponge ×100. Photo by Aucilla River Prehistory Project.

17.2.2 Processing Samples for Biogenic Silica

Subsamples were transferred to paper bags and dried in an oven at 100°C. When dry, 10 g of the sample was placed in a beaker to which 25 ml of 30% hydrogen peroxide and 300 ml of distilled water were added and stirred. The mixture in the beaker was heated on a hotplate for 2 days to digest organic matter present in the sample.

After removal of the organic matter, 50 ml of 5% sodium metaphosphate was added to the sample to suspend clay particles. The sample was stirred and allowed to sit for 90 min. After this period, the clay solution was siphoned off and more water added and stirred. After 90 min the suspended clay particles were siphoned off once again. This process was repeated several more times until all of the clay was removed from the sample. It is important to thoroughly mix and stir the sample during this step since some silica structures have a tendency to adhere to clay particles and may be unknowingly discarded with the siphoned off solution.

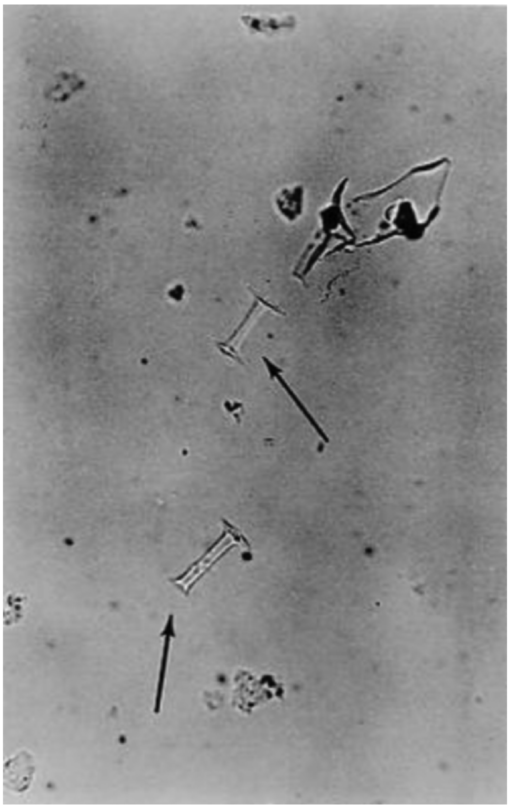


Figure 17.6 Gemmosclere of sponge ×250. Photo by Aucilla River Prehistory Project.

Next, the solution was filtered through a 325 mesh sieve (45 µm). Sand and larger particles were collected in the sieve, while the smaller washings of silt and other filtrate passed through the sieve and were collected and stored in another beaker. This beaker containing the silt, water, and fine filtrate was heated in an oven until all water was evaporated from the specimen.

The dried specimen was transferred to a centrifuge tube to which 5 ml of 72% solution of zinc bromide (specific gravity = 2.3) was added. The sample was stirred thoroughly, then centrifuged for 10 min. Silt with a specific gravity greater than 2.3 is forced to the bottom of the tube and becomes packed in a concentrated layer. The biogenic silica from the sample is suspended, floating in the solution, and can now be poured off of the tightly packed silt. This solution containing the silica is poured into another centrifuge tube and water added to reduce the specific gravity of the zinc

Table 17.1 Comparative biogenic silica counts in tested Page-Ladson sediments

P-L sample number	*Sponge spicules (per gram)*	*Diatoms (per gram)*	*Phytoliths*[1] *(per gram)*	*Phytoliths*[2] *(per gram)*
3	28,000	23,000	20,000	12,000
4 Bolen Level (2A)	576,000	36,000	36,000	54,000
5	40,000	10,000	<1,000	<1,000
10 Bolen Level (2A)	<1,000	<1,000	<1,000	<1,000
18 Bolen Level (2A)	<1,000	<1,000	<1,000	<1,000

[1] Phytolith count minus bulliform cell count.

[2] Bulliform cell (motor cell) phytolith count.

Notes: Biogenic silica counts in this table were made using a hemacytometer grid and counts represent the number of identified specimens per gram of sample. Bulliform cells are motor cells found in leaves of grasses (Gramineae). Grasses produce more bulliform cells when the plants are subjected to high water levels.

bromide to below 1.4. This solution is again centrifuged for 10 min at 2000 rpm. At this lowered specific gravity, the biogenic silica will be thrown to the bottom of the centrifuge tube. Washing and centrifuging the specimen several more times will produce a clean sample that contains mostly silica and distilled water. A subsample of this prepared sample can be used for counting, identification, or photographic purposes.

17.2.3 Preparing Microscope Slides

While identification, photography, and counting of silica microfossils may be performed without permanent slides, it is often necessary and desirable to make permanent mounts for future reference. Permanent mounts allow the researcher to repeat counts, or to re-photograph specimens when necessary.

Permanent microscope slides are made by placing a 20-µl sample on a standard microscope slide. A fixed-volume 20-µl pipette with disposable tips is used to ensure that a uniform sample is placed on the slide. One drop of melted glycerol gelatin is added to the sample already on the slide, then mixed with a disposable stirring stick. A 22 × 22 mm cover glass is placed over the glycerol–sample mixture. The slides are inverted until the glycerol cools, at which time, the edges around the coverslip can be coated with a bead of clear fingernail polish to seal the sample. Slides made by the authors have been used to identify and count biogenic silica structures, and to make satisfactory photographs of these specimens. After two years, the optical quality of slides made in this manner remains high.

17.2.4 Analyses and Counting Methods

Biogenic silica analysis was accomplished by two methods: counting and quick scanning. In the first method, a hemacytometer, normally used for blood cell counts, was utilized to tabulate biogenic silica present in the sediment samples. A 20-µl drop of processed sample containing silt and water was placed on the hemacytometer and examined microscopically at 100× magnification. Silica structures were quantified using the etched counting grid of the hemacytometer. Counts produced from the 20-μl drop of processed sample can be extrapolated to yield the concentration of biogenic silica per gram of soil using a formula derived by other researchers (Schwandes and Collins, 1994).

The second method, used to produce relative counts and to give a general description of the slides, was the quick scanning method. Here, a 20-μl drop of processed sample is placed on a microscope slide, then systematically scanned at 400× magnification. The results of the quick scanning method provide a measure of relative concentrations and allow the researcher to detect environmental changes through time.

17.3 Results

17.3.1 Sponges

Sediments from the Page-Ladson site produced seven species of sponges (Table 17.2). All are shallow freshwater sponges, commonly found in the rivers and lakes of the Eastern United States (Penney and Racek, 1968; Pennak, 1978). Identifications were made by comparing the type and configuration of spicules recovered from Page-Ladson sediments with known reference spicules (Johnson, 1945; Penny and Racek, 1968). No spicules representing marine sponges were observed, nor did any of the recovered spicules appear to be weathered out of the local Eocene limestone, which outcrops near the site.

Five species of sponges were recovered from the Bolen Level (2A) sediments. Sample 4 produced *Heteromeyenia tubisperma*, *Ephydatia fluviatilis*, *Ephydatia millsii*, *Spongilla alba*, and *Eunapius fragilis*, while samples 10 and 18, each yielded a single species, *Heteromeyenia tubisperma*.

Sample 3 from below the Bolen Level (2A) produced five species of sponges: *Heteromeyenia tubisperma*, *Ephydatia robusta*, *Ephydatia millsii*, *Eunapius fragilis*, and *Anheteromeyenia ryderi*. Sample 5, the younger level, resting on top of the Bolen Level (2A), yielded *Ephydatia fluviatilis*, *Ephydatia robusta*, *Ephydatia millsii*, and *Eunapius fragilis*.

17.3.2 Diatoms

Diatoms recovered from Page-Ladson sediments sampled by the authors are summarized in Table 17.3. All specimens are freshwater diatoms (Weber, 1966; Lowe, 1974). Other environmental preferences are shown in the table (Lowe, 1974; Platt-Bradbury, 1978; Round *et al.*, 1990). Preservation of diatoms in the Bolen Level (2A) was better in some samples tested than in others. Numbers 4, 18, and 10 are the three Bolen

Table 17.2 Sponges recovered from tested Page-Ladson sediments

P-L sample number	*Species*	*Salinity preference*	*Water depth preference*	*Other environmental indications*
3	*Heteromeyenia tubisperma*	Freshwater	Shallow <1 m	Alkaline water, lotic, light tolerant
	Ephydatia robusta			Alkaline water, light negative
	Ephydatia millsii			
	Eunapius fragilis			Lotic, light negative
	Anheteromeyenia ryderi			Lentic, light negative
4 Bolen Level (2A)	*Heteromeyenia tubisperma*	Freshwater	Shallow <1 m	Alkaline water, lotic, light tolerant
	Ephydatia fluviatilis			Alkaline water, lotic, light negative
	Ephydatia millsii			
	Spongilla alba			
	Eunapius fragilis			Lotic, light negative
5	*Ephydatia fluviatilis*	Freshwater	Shallow <1 m	Alkaline water, lotic, light negative
	Ephydatia robusta			Alkaline water, light negative
	Ephydatia millsii			
	Eunapius fragilis			Lotic, light negative
10 Bolen Level (2A)	*Heteromeyenia tubisperma*	Freshwater	Shallow <1 m	Alkaline water, lotic, light tolerant
18 Bolen Level (2A)	*Heteromeyenia tubisperma*	Freshwater	Shallow <1 m	Alkaline water, lotic

Level samples that were tested for biogenic silica. Sample 4 taken from the north face of Unit G in Test C contained six species of diatoms. They are: *Nitzschia palea*, *Epithemia* sp., *Aulacoseira islandica*, *Fragilaria pinnata*, *Fragilaria pinnata* (*var. lancetula*), and *Aulacoseira italica*.

Sample 18 from the west face of Unit G in Test C contained two genera, *Pinnularia* sp. and *Coconeis* sp.

Sample 10 showed the single species, *Navicula pupula*.

Samples 5 and 3 were taken from the north face of Unit G in Test C, 15 cm above and 15 cm below sample 4 (Bolen Level).

Sample 5 produced the single genus, *Cymbella* sp.

Sample 3 produced the two genera, *Nitzchia* sp. and *Navicula* sp.

17.3.3 Phytoliths

Phytoliths from fewer than ten different plants were found in Page-Ladson sediments. Identifications were made by comparisons of recovered phytoliths with reference slides prepared by the authors, or with microphotographs of specimens made by other phytolith researchers (Pearsall, 1989; Bozarth, 1992; Mulholland and Rapp, 1992).

Table 17.3 Diatoms recovered from tested Page-Ladson sediments

P-L sample number	*Diatoms*	*Salinity preference*	*Nutrients*	*Water current indications*	*pH*	*General habitat*
3	*Nitzchia* sp.	Freshwater		Limnophilous	Neutral	
	Navicula sp.	Freshwater	Eutrophic	Alkaliphilous	Neutral	Ponds, lakes
4 Bolen Level (2A)	*Nitzschia palea*	Freshwater	Eutrophic	Limnophilous	Neutral	Ponds, lakes
	Epithemia sp.	Freshwater			Alkaliphilous	
	Aulacoseira islandica	Freshwater	Eutrophic		Alkaliphilous	
	Fragilaria pinnata (var. lancetula)	Freshwater	Eutrophic	Limnophilous	Alkaliphilous	Ponds, lakes
	Aulacoseira italica	Freshwater			Alkaliphilous	
5	*Cymbella* sp.	Freshwater		Alkaliphilous		Indiff-erent
10 Bolen Level (2A)	*Navicula pupula*	Freshwater	Eutrophic	Limnophilous	Neutral	Ponds, lakes
18 Bolen Level (2A)	*Pinnularia* sp.	Freshwater				
	Coconeis sp.	Freshwater			Alkaliphilous	

Seven phytoliths types representing at least five genera were observed from sample 4 from the Bolen Level (2A) sediments, including *Sabal palmetto*, *Serenoa repens*, *Ambrosia* sp., *Celtis* sp., and three types of Gramineae phytoliths, including bulliform or motor-cell phytoliths. Sample 5, taken from the level directly above the Bolen Level (2A), was with the exception of a few hair cell forms indicative of grasses, deficient in phytoliths. Sample 3, taken from the level directly below, the Bolen Level (2A), is more productive, and yields grass phytoliths (Gramineae), *Ambrosia* sp. and *Celtis* sp.

The two additional samples from the Bolen Level (2A), samples 10 and 18 yielded grass (Gramineae), and ragweed (*Ambrosia* sp.) phytoliths. These samples show a less diverse phytolith assemblage than sample 4, the most productive of all the Page-Ladson samples tested.

Grass (Gramineae) phytoliths found in Page-Ladson sediments are represented by several types of distinctive phytoliths. Two, and possibly three distinctive forms of bilobate, or dumbbell-shaped phytoliths, indicative of an equal number of grass species are found. Hair cell, and bulliform, or motor-cell phytoliths, associated with grasses are also observed in some samples.

Sample 4 from the Bolen Level (2A) yielded knobbed, spheroid phytoliths that are produced by the palms, *Serenoa repens* and *Sabal palmetto*.

Phytoliths, in the form of echinate platelets produced by the hackberry or sugarberry tree (*Celtis* sp.), were recovered from samples 3 and 4. This is the single most common phytolith type observed in those samples.

Another unique phytolith type observed frequently in Page-Ladson sediments is the opaque perforated platelet. This phytolith form is produced in the aerial portion of several members of the family Asteraceae (Bozarth, 1992), including *Ambrosia*, or ragweed, which has been identified from samples 3, 4, 10, and 18 at the Page-Ladson site.

17.4 Discussion

Page-Ladson site samples that were tested for biogenic silica were taken from three different levels. The oldest, sample 3, lies immediately below the Bolen Level (2A). Sample 5, the youngest, rests directly above the Bolen Level (2A). The Bolen Level (2A) itself is represented by samples 4, 10, and 18.

Table 17.1 shows total biogenic silica counts for those Page-Ladson sediments tested. This table lists counts for sponges, diatoms, non-bulliform cell phytoliths, and bulliform cell phytoliths. The counts for sponge spicules per gram of sample ranged from 576,000/g in sample 4 to <1,000/g in samples 10 and 18, all samples from the Bolen Level (2A). Samples 3 and 5 produced sponge spicule counts of 28,000/g and 40,000/g, respectively. The large number in sample 4 may indicate a concentration of sponges, such as might occur in a system with lowered water levels. Wetland ponds, closed systems, typically have sponge spicule counts above 250,000/g (Schwandes and Collins, 1994). While the greatest variation exists between sample 4, and samples 10 and 18, it should be noted that these three samples are located in the same level, within a meter's distance of one another.

Diatom counts listed in Table 17.1 show the same trends as the sponge counts: sample 4 produces the highest count (36,000/g), with samples 10 and 18, yielding <1,000/g, while other levels, represented by samples 3 and 5, yielded levels lower than sample 4.

Phytolith counts shown in Table 17.1 parallel the other biogenic silica data. Again, sample 4, Bolen Level (2A) shows the highest counts (90,000/g total phytolith count), with samples 10 and 18, from the same level producing a count of <1,000/g. Samples 3 and 5, above and below the Bolen Level (2A), yielded fewer phytoliths than sample 4.

Differences in biogenic silica counts observed in these samples may be explained in several ways. Rivers as complex systems exhibit great variability in sediments and the components that comprise these sediments. Observed discrepancies may fall within this range of variability. It is also possible that elevated pH levels of in-place sediments, and later, of bagged samples stored in the lab, may have promoted the dissolution of silica, affecting counts. Improperly performed processing methods used to recover biogenic silica from sediment samples can reduce silica counts as well. However, if possible errors in sampling, storage, and processing are eliminated, the variations observed in tested samples and levels from the Page-Ladson site should reflect valid changes in the environment of the Aucilla River from the period preceding the end of the last glaciation to the period following that event.

17.4.1 Concentrations

The number of different plants represented by phytoliths recovered from the Page-Ladson site sediments is quite small (Table 17.4). In contrast, Barbara Hansen, who discusses pollen found at the Page-Ladson site elsewhere in this publication, has recovered pollen from at least 18 different plants. Since both pollen and phytoliths can be produced by the same plant, and are approximately the same size, their frequency and distribution should be very similar; however, these researchers did not find this assumption to be true of Page-Ladson sediments. Limiting factors discussed elsewhere in this chapter may effect phytolith recovery.

Grass phytoliths recovered from Page-Ladson sediments fall into three main groups: hair cells, bilobate forms, and bulliform cells. All three groups are representative of Panicoid grasses, the most common group of grasses in Florida today. The absence of phytoliths representing Festucoid grasses indicates that the climate at the time of the Bolen Level (2A) sediments was similar to that of present day north Florida. The most notable difference might be increased rainfall at the time of the Bolen Level (2A) as indicated by the bulliform grass phytoliths from that level.

A very distinctive phytolith produced by the hackberry or sugarberry tree (*Celtis* sp.) was recovered from samples 3 and 4. This particular phytolith is produced in the pit or stone of the fruit and can be distinguished by the echinate (spiny) sculpturing that covers one side of the phytolith (Bozarth, 1992). These phytoliths have been found at numerous New World archaeological sites (Piperno, 1988), and in the Page-Ladson samples 3 and 4, it is the most common phytolith type observed.

Phytoliths representing terrestrial vascular plants such as palm (*Sabal* sp.), ragweed (*Ambrosia* sp.), and grass (Gramineae) are found in Bolen Level (2A) sediments, but not in concentrations that reflect a terrestrial soil. Phytoliths associated with soils

Table 17.4 Phytoliths recovered from tested Page-Ladson sediments

P-L sample number	*Plants*	*Morphology*	*Environmental indications*
3	Gramineae	Hair cells	
	Ambrosia sp.	Perforated platelets	Pioneer plant
	Celtis sp.	Echinate platelets	Moist, alkaline soil
4 Bolen Level (2A)	Gramineae	Dumbbells	
	Gramineae	Bulliform cells	Flooded or wet area
	Gramineae	Hair cells	
	Ambrosia sp.	Perforated platelets	Pioneer plant
	Celtis sp.	Echinate platelets	Moist, alkaline soil
	Sabal palmetto	Spheroid	Subtropical climate
	Serenoa repens	Spheroid (with dot)	Subtropical climate
5	Gramineae	Hair cells	
10 Bolen Level (2A)	*Ambrosia* sp.	Perforated platelets	Moist, alkaline soil
18 Bolen Level (2A)	Gramineae	Hair cells	
	Gramineae	Bulliform cells	Flooded or wet area
	Ambrosia sp.	Perforated platelets	Moist, alkaline soil

are typically most abundant in the "A" horizon which incorporates decayed plant matter. There is little evidence to show that vertical displacement of phytoliths in soils occurs (Rovner, 1986). If the Bolen Level (2A) represents a terrestrial, or even a "swamped" hydric soil, there should be a greater number of phytoliths found in the sediment samples from this level. The fact that this is not the case argues against this hypothesis. The observed phytolith distribution is more consistent with terrestrial colluvium that has washed into a still water sheltered area.

Phytoliths are introduced into still water sediments in a number of ways. Jacobson and Bradshaw (1981) discuss the primary sources. First, there is a regional source generally more than 200 m away. Air currents transport phytoliths above the vegetable canopy. The second source is extra-local. Phytoliths from these sources come from plants growing within a range of 20–200 m and are carried by air currents below the vegetable canopy. The third and most productive source comes directly from vegetation growing within 20 m of the water. Floodwaters and run off from heavy rains carry high amounts of pollen (and presumably phytoliths) into lakes and other sheltered waters.

The overall scarcity of diatoms observed in all samples may indicate dissolution by alkaline conditions, or that the material is not exactly sediment from a water body, but has instead been deposited by flooding, or somehow received outflow from standing waters (Tom Whitmore, 1998, personal communication).

17.4.2 Rainfall, Water Levels, and Movement

The number of bulliform cell phytoliths found in sample 4 of Bolen Level (2A) provides evidence of grasses which have been water-stressed. Bulliform, or motor cells, which are found in the leaves of grasses, and are thought to aid the leaf in the process of unrolling, normally silicify only under wet conditions (Piperno, 1988). At the Page-Ladson site, the presence of these phytoliths in such great numbers (60% of total phytolith count) in sample 4, suggests that the grasses were growing in extremely wet conditions. It does not appear that the plants producing these bulliform cell phytoliths are aquatic grasses, since the total phytolith count would be much higher if that were the case. Sample 4, which has the highest phytolith count of all Page-Ladson samples, still produces a relatively low phytolith count when compared with other sites. This finding, thus, suggests that the bulliform phytoliths seen in Page-Ladson sediments are not derived from aquatic grasses, but rather from normal terrestrial grasses growing in wetter than normal conditions. Since the concentrations of phytoliths do not indicate the parent plants were growing on the Bolen Level (2A), it is most probable the phytoliths were washing in from the river banks, or from higher ground overlooking the river.

The four-fold increase in the number of bulliform cell phytoliths through time from sample 3, below the Bolen Level (2A), to sample 4, the Bolen Level (2A) provides evidence of progressively higher rainfall. Higher levels of rainfall mean higher water levels in rivers and streams, and flooding. Biogenic silica concentrations and distribution at the Page-Ladson site provide evidence of flooding.

The diatoms found in the sample 3, below the Bolen Level (2A), and in the Bolen Level (2A), itself (samples 4, 10, 18), do not indicate a rapid moving stream or a deeper body of water, but instead, suggest a shallow, slow moving, almost ponded, body of water that may have contained some macrophytes. Sample 5, the level above the Bolen Level (2A), contains diatoms from the genus, *Cymbella.* This genus contains species that prefer lotic, rheobiontic habitats such as flowing rivers and streams. Diatom genera from samples 3, the Bolen Level (2A), 10, and 18, are indicative of shallow, productive, or eutropic conditions (Lowe, 1974). The small number of diatoms found in these sediments may indicate that this stratum was deposited by floodwater, the diatoms washing into the Bolen Level from another source location. (Tom Whitmore, 1998, personal communication).

Five species of freshwater sponge found in the Bolen Level provide additional evidence of shallow water at the time of deposition. All of these species prefer shallow habitats ranging from 10 cm to a few meters in depth (Johnson, 1945). Most of these sponges are also light negative, preferring darker water, or the undersides of submerged limbs (Harrison, 1988). The exception is *Heteromeyenia tubisperma*, which is the only light positive sponge found in Page-Ladson sediments. It occurs in all levels tested at the Page-Ladson site.

The condition of the sponge spicules also provides information about the site. A significant percentage of the spicules counted was intact and whole indicating that they had not been transported very far from their point of origin.

Sponges are also good indicators of water current. With the exception of one species, all sponges recovered from Page-Ladson sediments are lotic, preferring moving water (Harrison, 1988). The single species considered lentic, i.e. preferring still water, is *Anheteromeyenia ryderi* (Harrison, 1988). It is found only in sample 3, from the level below the Bolen Level (2A). The presence of this species in the level producing sample 3 indicates the river, at this location and time, had very little movement. Its absence in the youngest level, which produced sample 5, argues for an increase in water current velocity after the Bolen Level (2A) was deposited.

17.4.3 Siltation

High silt levels are limiting factors for many sponge species. Silt clogs pores and canal systems of sponges resulting in death of the organism. Sponges which survive high levels of siltation generally show habitat preferences for the undersurface of a substrate, and belong to a few silt tolerant genera such as *Ephydatia* and *Eunapius* (Harrison, 1988). In Page-Ladson sediments, sample 5, located in the level above the Bolen Level (2A), yields the highest percentage (71%) of silt (see Scudder, this volume). It should be noted that sample 5 produced sponges only from the two silt tolerant genera, *Ephydatia* and *Eunapius*. Sample 4, from the Bolen Level (2A), and sample 3, from the level below, show much lower silt levels and also produce non-silt tolerant sponge species such as the light-positive sponge, *Heteromeyenia tubisperma*, and the lentic sponge, *Anheteromeyenia ryderi*, and *Spongilla alba*. The sponge species succession observed over the time period represented by samples 3, 4, and 5 also provides an evolutionary view of the Aucilla River at the Page-Ladson site. The slower moving, less turbid river, with lower levels of siltation, seen in samples 3 and 4, evolves into a faster moving river with higher levels of siltation.

17.4.4 pH of Samples

The small number of diatoms in the samples from the Bolen Level may indicate high pH levels, since alkaline environments are known to dissolve silica. The pH of the samples ranged from 7.4 to 7.9 with the average at 7.5. Some researchers (Pearsall, 1989) have said that biogenic silica starts to dissolve rapidly at pH = 9. However, others (Jorgensen, 1955; Schwandes, 1998) have found that the critical value is nearer, pH = 8, and dissolution will occur more slowly at lower values. Further evidence of dissolution of silica can be seen in the widened axial canals of many sponge megascleres recovered from Page-Ladson sediments (see Fig. 17.2). Because of their unique shapes and dimensions, diatoms dissolve even faster in alkaline environments than do sponge spicules (Schwandes, 1998). As a result of dissolution, many diatoms may have been lost from the Page-Ladson samples. This could also be true of some smaller phytoliths.

The species list of sponges recovered from Page-Ladson sediments (Table 17.2) also shows evidence of an alkaline environment. All sponges observed prefer neutral to alkaline water (Harrison, 1988).

17.4.5 Salinity

The Page-Ladson site is presently about 7 miles inland from the Gulf of Mexico at an elevation of 10 feet above sea level. Although it occasionally exhibits tidal movement, the Aucilla River at the Page-Ladson site is today, freshwater. With conditions of lowered sea level existing throughout most of the Pleistocene, the Page-Ladson site was freshwater during this time period as well. In fact, sea level had come very close to its present level by 8000 B.P. (Palmer and Abbott, 1986; Watts and Hansen, 1988), so that even sample 5, from the younger level above the Bolen Level (2A), was freshwater.

Supporting these hypotheses is the fact that all diatoms recovered from Page-Ladson sediments represent freshwater species. Sponge species in these sediments also indicate a freshwater environment during the periods of deposition (Harrison, 1988).

17.5 Conclusions

The Bolen Level (2A) represents a unique event in the chronology and evolution of the Aucilla River at the Page-Ladson site. It is doubtful whether this event can be definitively evaluated on the basis of the biogenic silica recovered from Page-Ladson samples. These samples yielded smaller numbers of silica microfossils than expected; however, the biogenic silica that was recovered and identified provides important clues to the past environments at the Page-Ladson site.

Today, the Page-Ladson site is part of an active river channel that experiences normal seasonal variations in water flow-rate and volume. The Aucilla River belongs to the group of north Florida rivers that follow karst faults. This geological phenomenon results in rivers that virtually "disappear", following underground channels through the limestone for stretches, and then "reappear" to continue on their surface course until they disappear once again.

Geologists, who have studied the Aucilla River, and, in particular, the Page-Ladson site believe that the "bottleneck" at the south end of the Page-Ladson site where the Aucilla River narrows from 50 m in width to 15 m was once blocked (Kendrick, this volume). If this is true, the Aucilla River did not flow southward from this point until after it broke through the natural barrier at some point in time during the Bolen Level (2A) deposition. Prior to that time, it is likely that the Aucilla River flowed into the deep, wide sinkhole that represents the Page-Ladson site. Instead of flowing south, out of the site as it does today, the incoming water lost much of its velocity and exited more slowly, through another channel, perhaps the extinct channel marked on Page-Ladson site maps. The diatom, *Fragilaria pinnata*, found only in the Bolen Level (2A) samples, is limnobiontic, preferring standing water (Lowe, 1974). Another diatom found in Bolen Level (2A), sample 10, *Navicula pupula*, prefers ponded habitats. The succession of sponge species seen at Page-Ladson, from the oldest to the youngest levels, is consistent with this view of the Page-Ladson site history. Lentic, and light-positive, low silt tolerance sponge species found in the oldest samples are replaced by light-negative, silt tolerant, lotic sponges in the levels above the Bolen Level (2A). Evidence from both diatoms and sponges sustains the hypothesis that the Page-Ladson site evolved from a slow, almost limnobiontic environment to one that is characterized as rheobiontic.

The biogenic silica evidence is consistent with the possibility that human cultures were living very close to the Bolen Level (2A), but not on its surface. The numerous sugarberry phytoliths (*Celtis* sp.) found in the Page-Ladson sediments provide evidence of sugarberry trees growing along the moist, alkaline banks of the river. Sugarberry has a long association with human occupation, and is well known from archaeological sites (Piperno, 1988). Phytoliths produced by the plant, ragweed (*Ambrosia artemisiifolia*), are common in Page-Ladson sediments. Ragweed is an aggressive, early succession, pioneer plant that can be associated with forest clearing land use and human occupation (Dana Griffin, 1998, personal communication). The high percentage of bulliform grass phytoliths recovered from sample 4, Bolen Level (2A), indicates a period of high rainfall that water-stressed terrestrial grasses. Using this same criterium, sample 3, below the Bolen Level (2A), shows higher rainfall also. In contrast, sample 5, from the level above the Bolen Level (2A), exhibits a very small percentage of bulliform grass phytoliths, indicating a much drier period. The absence of *Ambrosia* in sample 5 sediments, from the level above the Bolen Level (2A), could indicate that humans abandoned cleared areas adjacent to the Page-Ladson site. These areas were then reclaimed by forest.

The Bolen Level (2A) samples have the highest organic carbon content of all levels measured at the Page-Ladson site ranging from 8.9% to 10.9% (see Scudder, this volume). Supporting this finding, the diatoms found in the Bolen Level (2A) and in the sample below, sample 3, are species showing affinity for eutropic, organic-rich water.

In summary, the Bolen Level (2A) represents a *cul de sac*, into which organic-rich sediments were carried by waters of the Aucilla River. These sediments were deposited in shallow still water along the edge of a deep sinkhole. The moderately eutrophic nature of this *cul de sac* created a favorable environment for freshwater sponges and certain groups of diatoms. Samples from the level *below* the Bolen Level (2A) show some similarities to the Bolen Level with regard to silica microfossils recovered from sediments. Samples from the level *above* the Bolen Level (2A), however, are sufficiently different to indicate a significant change occurred in the Page-Ladson environment. The evolution of the Aucilla River, at the Page-Ladson site, can be characterized by a north Florida karsted river system that had begun ceasing its subterranean flow at the time of the pre-Bolen Level (sample 3). The cessation becomes complete during the time period represented by the Bolen Level (2A), and the incoming water is now backing out of Page-Ladson to find a new south-flowing channel. The level above the Bolen Level (2A) represents a resumption of southward water flow from Page-Ladson following a breakthrough at the bottleneck on the south side of the site.

References

Bozarth, S.R., 1992. Classification of opal phytoliths formed in selected dicotyledons native to the Great Plains, in: Phytolith systematics, eds. G. Rapp, Jr. and S.C. Mulholland, Plenum Press, New York.

Bozarth, S.R., 1993. Biosilicate assemblages of boreal forests and aspen parklands, in: Current research in phytolith analysis: applications in archaeology and paleo-ecology, eds. D.M. Pearsall and D.R. Piperno, MASCA Research Papers in Science and Archaeology, vol. 10.

Herendeen, P.S., 1985. The alvars of the Maxton Plains, Drummond Island, Michigan present community. Thesis. Michigan State University, Lansing, Michigan.

Harrison, F.W., 1988. Utilization of freshwater sponges in paleolimnological studies, *Palaeogeo., Palaeoclim., Palaeoecol.* **62**:387–397.

Jacobson, G.L. Jr., and R.H.W. Bradshaw, 1981. The selection of sites for paleoecological studies, *Quat. Res.* **16**:80–96.

Johnson, M.C., 1945. The freshwater sponges of Alachua county, with a summary of the known Florida forms. Thesis. University of Florida, Gainesville, Florida.

Jorgensen, E.G., 1955. Solubility of silica in diatoms, *Physio. Plant.* **8**:846–851.

Lowe, R.L., 1974. Environmental requirements and pollution tolerance of freshwater diatoms. Environmental Monitoring Series, EPA-670/4-74-005, Cincinnati, Ohio.

Mulholland, S.C., and G. Rapp, Jr. 1992. A morphological classification of grass silica-bodies, in: Phytolith systematics, eds. G. Rapp, Jr. and S.C. Mulholland, Plenum Press, New York.

Palmer, A.J.M., and W.H. Abbott, 1986. Diatoms as indicators of sea-level change, in: Sea-level research: a manual for the collection and evaluation of data, ed. Orson van de Plassche, Geo Books, Norwich, Connecticut.

Pearsall, D.M., 1989. Paleoethnobotany: a handbook of procedures, Academic Press, New York.

Pennak, R.W., 1978. Fresh-water invertebrates of the United States, John Wiley and Sons, New York.

Penney, J.T., and A.A. Racek, 1968. Comprehensive revision of a worldwide collection of freshwater sponges (Porifera: Spongillidae), United States National Museum Bulletin 272, Smithsonia Institution Press, Washington, D.C.

Piperno, D.R., 1988. Phytolith analysis: an archaeological and geological perspective, Academic Press, San Diego.

Platt-Bradbury, J., 1978. Diatom stratigraphy and human settlement in Minnesota, Geol. Soc.of Am. Spec. Pap. No. 171, pp. 1–65.

Round, F.E., R.M. Crawford, and D.G. Mann, 1990. The diatoms, Cambridge University Press, Cambridge.

Rovner, I., 1986. Downward percolation of phytoliths in stable soils: a non-issue, Plant Opal Phytolith Analysis in Archaeology and Paleoecology, Proceedings of the 1984 Phytolith Research Workshop, Occasional Papers no. 1 of The Phytolitharian, ed. I. Rovner, pp. 23–27, Raleigh, North Carolina, North Carolina State University.

Schwandes, L.P., 1998. Environmental durability of biogenic opal, *Soil Crop Sci. Soc. Florida Proc.* **58**:115–118.

Schwandes, L.P., and M.E. Collins, 1994. Distribution and significance of freshwater sponge spicules in selected Florida soils, *Trans. Am. Microsc. Soc.* **113**:242–257.

Watts, W.A., and B.C.S. Hansen, 1988. Environments of Florida in the late Wisconsinan and Holocene, in: Wet site archaeology, ed. B.A. Purdy, pp. 307–323, Telford Press, West Caldwell, New Jersey.

Watts, W.A., B.C.S. Hansen, and E.C. Grimm, 1992. Camel Lake: a 40,000-yr record of vegetational and forest history from northwest, Florida, *Ecology*. **73**(3):1056–1066.

Weber, C.I., 1966. A guide to the common diatoms at water pollution surveillance system stations, Federal Water Pollution Control Administration, U.S. Department of the Interior.

Chapter 18

Early Archaic Archaeology

BRINNEN C. CARTER[1] and JAMES S. DUNBAR[2]
[1]Southeast Archaeological Center, National Park Service, Tallahassee, FL 32399, USA.
[2]Department of Historical Resources, Gray Bldg, Tallahassee, FL 32399, USA.

18.1 Introduction

One of the obvious prehistoric, stone-tool-making transitions in the Southeastern United States was the abandonment of lanceolate Paleoindian projectile point types in favor of Early Archaic notched point forms. In the coastal states of South Carolina, Georgia, Florida, Alabama, and eastern Mississippi a notched point type referred to here as Bolen replaced older lanceolate forms by ~10,000 ^{14}C BP.

Predecessors to the Bolen type include notched forms such as the Greenbriar type, which co-occured with Late Paleoindian lanceolate types at Dust Cave in Alabama from ~10,500 ^{14}C BP to ~10,000 ^{14}C BP (Driskell, 1994).

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 493–515

18.2 History of Early Archaic Site Investigations

18.2.1 The Bolen Type

The diagnostic *Bolen* type is a basely ground, notched point with lateral blade edges that are often but not always resharpened by pressure flaking on the opposite side of each blade face. Recurrent rounds of resharpening in this manner caused the point to become beveled and rhomboid in cross section. The type has been recognized in Florida and Georgia as Bolen (Bullen, 1958), *Big Sandy* in Alabama, Mississippi, and Tennessee (Cambron *et al*., 1990), and *Taylor* in South Carolina and Georgia (Michie, 1996). The use of the type name Big Sandy for Early Archaic notched points is considered incorrect because the Big Sandy name was originally assigned to a similar-looking Middle Archaic notched point type from a different cultural and temporal horizon (Lewis and Kneberg-Lewis, 1961). Dan Morse pointed to this mistake and suggested the "need to use the name *Bolen* ..." (Morse, 1994:233). The type name Taylor has been applied in South Carolina (Michie, 1996); however, its usage post-dates that of Bolen and is restricted to a geographically small part of the overall Bolen range of distribution. For these reasons this type of Southeastern Early Archaic notched point is hereafter referred to as Bolen, supplanting and encompassing the Early Archaic expression of Big Sandy and Taylor.

18.2.2 Identification of the Stone Toolkit

As early as the 1930s, indication that notched projectile points might occupy an early chronological position was suggested by the discovery of extinct Pleistocene fauna in ambiguous association with a Bolen or Bolen-like point at Bonn Terra Farm site in Flagler County, Florida (Connet, 1932; Neill, 1953). Bullen (1958) was the first to stratigraphically demonstrate that notched points dated to the "Early Preceramic" (Early Archaic) and represented the successor of Suwannee points, the older, Paleoindian type. He named the notched point Bolen, after the Bolen Bluff site (8AL439). Other distinctive stone tools in the Bolen toolkit were subsequently recognized. For example, the Bolen component of the Dixie Lime Caves site (8Mr67) yielded bifacially chipped, Dalton-like adzes (Clear Fork-like gouges) undeniably associated with Bolen points (Bullen and Benson, 1964). As the name implies, Dalton adzes are considered probable woodworking tools (Morse and Goodyear, 1973). Surface collected artifacts from the Nalcrest site (8PO15) yielded a multitude of distinctive uniface tools including triangular in cross section hafted end scrapers, spoke shaves, and notched Waller knives. These tools were understood to be part of the Bolen toolkit (Bullen and Beilman, 1973). Elsewhere in the Southeast hafted spoke shaves are associated with Late Paleoindian Dalton sites. Triangular-shaped spoke shaves are believed to have functioned as woodworking implements (Goodyear, 1973). Yet another distinctive Bolen-age tool, the Edgefield scraper, is another proposed woodworking tool (Goodyear *et al*., 1980).

Thus certain implements of the Bolen toolkit suggest a distinctive change and retooling compared to earlier Paleoindian toolkits, particularly compared to those tools belonging to Early and Middle Paleoindian tool-making traditions. Several forms of specialized, curated tools that were either absent, not abundant, or not so obviously crafted for particular function(s) in Paleoindian times became abundant by the onset and during Bolen times. Researchers have come to regard several Bolen tool types as woodworking tools based on comparative and replicative means in the absence of undeniable and direct archaeological evidence (Bullen and Benson, 1964; Bullen and Beilman, 1973; Goodyear, 1973; Morse and Goodyear, 1973; Goodyear *et al.*, 1980; Purdy, 1981). As we shall see below, the Page-Ladson site is the first site to provide direct archaeological evidence of Early Archaic, Bolen-age woodworking.

18.2.3 Identification of Faunal Associations and the Bone Toolkit

Indications of what was included in the non-lithic Bolen toolkit and the kinds of associated faunal remains were slow to develop due to the general absence of bone and other organic preservation in upland archaeological sites. Typically the upland sediments in the Southeast are acidic, a factor that is not favorable for long-term organic preservation of wood, bone, or animal tissue. There are areas, albeit, much smaller in geographic extent, that offer greater preservation potential either due to alkaline sediments, saturated settings, or a combination of both. Paleontologists have long recognized the differences in preservation potential and focus their search to areas favoring good preservation. In Florida for example, karst features such as sediment filled sinkhole, submerged and wetland settings represent primary areas that favor preservation (Webb, 1974). The first Bolen site to yield bone preservation was the Dixie Lime Caves site. The faunal remains included numerous extant Holocene species, but extinct forms of Pleistocene megafauna were not present (Bullen and Benson, 1964).

Other Bolen sites with bone preservation include Warm Mineral Springs near Sarasota (8So19) (Cockrell and Murphy, 1978), Cutler Ridge near Miami (8Da2001) (Carr, 1987; Emslie and Morgan, 1995), and Wakulla Lodge near Tallahassee (8Wa329) (Jones and Tesar, 2000, 2004), in Florida, and Dust Cave, in the Middle Tennessee River Valley of northwestern Alabama (Driskell, 1994, 1996). Little Salt Springs in Sarasota County, Florida (8So18) (Dietrich and Gifford, 1996, unpublished paper) also have preserved faunal remains; however, this site is believed to post-date Bolen and range in age from ~9000 ^{14}C BP to ~8500 ^{14}C BP. All of these sites have yielded the remains of extant Holocene species from their respective Bolen and younger Early Archaic components. The remains of extinct Pleistocene megafauna are conspicuously absent in their Early Archaic components. Warm Mineral and Little Salt Springs are inundated karst feature sites, Cutler Ridge and Dust Cave terrestrial karst feature sites, and Wakulla Lodge overlooks a karst feature, Wakulla Springs, and is a terrestrial site with a pit feature containing calcine bone.

Bone tools associated with Bolen sites include flaked and honed long bone expedient tools along with curated, worked antler tines, bone atlatl handles, peg, or nipple topped tool handles, and splinter-groove manufactured bone pins and eyed bone needles. Although made from marine shell and probably manufactured using the thick lip or possibly columella section of *Strombus gigas* (queen conch,), an atlatl spur was also recovered from the Bolen component at Warm Mineral Springs (Cockrell and Murphy, 1978).

18.2.4 Differences of Interpretation and Terminology

There is a decade-old problem in the Southeastern US related to the placement of the Paleoindian–Early Archaic temporal–cultural boundary along a continuum of cultural change (Milanich, 1994).

Many archaeologists place the beginning of the Early Archaic at the Younger Dryas–Preboreal geological boundary (Anderson and Sassaman, 1996; Anderson *et al*., 1996; Ellis *et al*., 1998), which also represents the International Commission on Stratigraphy's placement of the Pleistocene–Holocene boundary (Ogg, 2003). This placement is in agreement with the oldest Bolen dates that fall just under ~10,000 ^{14}C BP (Driskell, 1994, 1996; Hornum *et al*., 1996; Dunbar, 2002; Carter, 2003).

Prior to the existence of more than one dated Bolen site it was correctly asserted that there were "too few excavated data to resolve all issues" related to cultural–temporal boundary (Milanich, 1994). Likewise Purdy (1981) stated that "because the … acidic [upland] soils have not preserved carbon-containing artifacts" absolute chronologies based on radiocarbon dating were at best tenuous. To confound matters, an incorrect evaluation of the radiocarbon data from the Warm Mineral Springs site placed notched points at ~10,300 ^{14}C BP; it was much the oldest date among 13 other radiocarbon dates from Burial 1 (Cockrell and Murphy, 1978; Cockrell, 1980). As a result, archaeologists in Florida began recognizing Bolen points as belonging to the Late Paleoindian which was followed by the beginning of the Early Archaic at ~9,500 ^{14}C BP (Cockrell and Murphy, 1978; Cockrell, 1980; Milanich and Fairbanks, 1980; Purdy, 1981; Milanich, 1994). The carbon dates from Burial 1 at Warm Mineral Springs range between ~10,300 ^{14}C BP and ~8,700 ^{14}C BP (Tesar, 1997, unpublished paper).

In yet another view, the Southeastern cultural–temporal transition from Paleoindian to Early Archaic is placed much earlier at ~10,500 ^{14}C beginning with the advent of lanceolate Dalton and other contemporary Dalton-like tool traditions (Daniel, 1998). Placement of the Paleoindian–Early Archaic boundary in this older timeframe is based on Meltzer's (Meltzer and Smith, 1986; Meltzer, 1988, 2004) hypothesis of adaptive continuity and is opposed to the notion that cultural readaptation was brought about by Pleistocene megafauna extinction. The archaeological record from several Florida sites as well as Dust Cave in Alabama suggests that adaptive continuity and gradual cultural change did not place (see Chapter 14 Sections 14.6 and 14.7). The continuity of cultural development was disrupted from a Southeastern Paleoindian Tradition that relied on Pleistocene megafauna and other speices (Dunbar *et al*., 2006; Vojnovski and Dunbar, in press) to an Early Archaic Tradition that did not (Bullen and Benson, 1964; Cockrell and Murphy, 1978; Clausen *et al*., 1979; Carr, 1987; Walker, 1998; Carter, 2003). The necessity for transition toward Archaic life ways took place during the Late Paleoindian (Driskell, 1994) sometime after ~10,500 ^{14}C BP and lasted to ~10,000 ^{14}C BP when Pleistocene megafauna were no longer available (Driskell, 1994; Walker, 1998), and was followed by the Early Archaic Bolen culture which represented the first successful adaptation to Holocene circumstances.

Therefore, we place the Late Paleoindian–Early Archaic boundary at the beginning of the Holocene with the Bolen peoples representing the first culture adapted to new Holocene circumstances. This is in agreement with most of the current literature that addresses the placement of the Southeastern Paleoindian to Early Archaic cultural–temporal boundary (Anderson *et al*., 1996; Ellis *et al*., 1998; Goodyear, 1999).

18.3 The Early Archaic Archaeology of the Page-Ladson Site

18.3.1 Early Archaic Site Components

Underwater excavations at the Page-Ladson revealed two areas of Bolen artifact concentrations: (1) Test B and (2) Test C see location and stratigraphic profiles see Figure 3.1, 3.4 and 3.5. Other areas of underwater investigation were conducted in areas where Bolen-age sediments had been eroded away.

Bolen levels and suspected Bolen levels in Test B represent sediments that accumulated underwater in a persistently inundated part of the site that now lies ~8 m below the present low river stage. Test B represents accumulations of artifacts that were either transported by flowing water from the upstream, Test C area and redeposited in Test B (Level 12a and possibly Levels 11 and 10c), or represents incidental losses or discards related to human activity on elevated ground above the sinkhole rim (in Levels 10a and b, 9, and 8). Incidental artifact losses and discards accumulated in the Test B area because that area of the sinkhole was directly adjacent to the bank.

In contrast, the Test C Bolen components are located in shallower water (~5 m) and represent an upslope expression of the site that was subaerially exposed at least once in Bolen times. The period of subaerial exposure endured sufficiently to allow oxidation of the Unit 5 surface. Evidence that human activity took place in the sinkhole includes cultural features among which are fire hearths (Muniz and Hemmings, Chapter 19).

The primary Bolen level in Test C is located on the surface of Unit 5 and in the bottom most 10–15 cm of Unit 6L. The primary Bolen level represents an assemblage of related artifacts and archaeological features that accumulated on a subaerial surface as well as artifacts and possibly other features, the wooden stakes, that accumulated afterward, when the Unit 5 surface was intermittently or otherwise, shallowly inundated. The occurrence of gastropods in the bottom of Unit 6L indicates a relatively clear, shallow water habitat very unlike the Aucilla River today. The Bolen occupation continued after the floor of the sinkhole was re-inundated in the Test C area. The sinkhole was no longer accessible, but the area surrounding the sinkhole continued to be utilized. Only a few artifact losses accumulate in the Test C area after inundation because it was farther away from the sinkhole margin, being located more in the central sinkhole.

Stratigraphic Unit 5 lies directly below the Bolen components and contains a Late Paleoindian component. The primary Bolen component lies on the surface of Unit 5 and represents a preserved archaeological activity surface that developed during an interval of subaerial exposure of the sinkhole bottom. Subsequently, the sinkhole was intermittently exposed and inundated, and finally inundated permanently in the Test C area. The gastropod-rich shelly silt formed above the Unit 5 surface during an interval of continued human utilization of the sinkhole. Thus, the Bolen components in Test C are the activity surface and the shelly silt level that was deposited after the interval of subaerial exposure.

18.3.2 Timing of Significant Events

The deep (Test B) and shallow water (Test C) components have provided quality radiocarbon dates and the depositional history of both provides a picture of dramatic regional water table change during an interval of generally arid to dry conditions.

The duration of subaerial exposure of the Test C area is understood in an imperfect way due to the limited resolution of the radiocarbon dating method. The period of prolonged subaerial exposure is believed to have been brief, perhaps lasting through the Preboreal onset; a 100 radiocarbon interval that took place prior to the Preboreal oscillation.

Using CALIB 4.4, yielded a pooled average of 9,959 ± 38 ^{14}C BP ($n = 4$) for the combined Bolen components of Test C. The spread in calendar years increased considerably falling within 11,558 cal BP to 11,226 cal BP (two sigma); a 332-year interval (under a 100% probability distribution). Two other Bolen sites are almost the same age, an unnamed site, Le2105, in Leon County and Warm Mineral Springs in Sarasota County. Using two sigma results for Le2105 provides a pooled average of 9,948 ± 40 ^{14}C BP ($n = 3$) with a calendar span of 11,553 cal BP to 11,224 cal BP (329-year span under a 100% probability distribution) and 9,967 ± 58 ($n = 5$) for Warm Mineral Springs with a calendar span of 11,644 cal BP to 11,204 cal BP (440-year span under a 98.3% probability distribution).

Artifacts from Test C that accumulated after ~9500 ^{14}C BP include the coincidental loss of a Kirk Corner Notched point just above the primary Bolen level (Unit 5 surface and the bottom of Unit 6L) and above that a Kirk Stemmed point from the contact of Unit 6U and Unit 7. Kirk and Kirk-like Stemmed points recovered with Early Archaic human burials at the Windover site (8Br246) in Brevard County, Florida date from ~8120 ^{14}C BP to ~6990 ^{14}C BP (Doran, 2002:71). The Kirk Corner Notched variety predates the stemmed type and, at Dust Cave in northern Alabama, was identified in post-Bolen context. At Dust Cave the age of the Kirk Corner Notched type was placed at ~9000 ^{14}C BP to ~8000 ^{14}C BP based on dates derived from above and below that component (Driskell, 1994:26).

In deeper water, one of the Bolen levels in Test B consisted of an uninterrupted still water peat deposit that yielded a single radiocarbon assay of 9697 ± 130 ^{14}C. Still water conditions at the Page-Ladson site meant that the local water table was more than 3.5 m below present, probably more. However, other Early Archaic levels in Test B yielded evidence that the water table also fluctuates above and below 3.5 m indicating the sinkhole experienced episodes of intermittent flowing water conditions. A single date brackets the approximate end of the interval of fluctuating still and flowing water episodes at 9466 ± 105 ^{14}C BP (Beta-011905).

18.3.3 The Artifact Assemblage and Evidence of Human Activity in the Sinkhole

18.3.3.1 Bolen Activity Area: Unit 5 Surface (Bolen Surface) and Shelly Silt Unit-6L

Excluding debitage, the 19 m^2 area that encompassed Test C (Fig. 18.1) plan view map led to the recovery of 57 artifacts including three Bolen points and five biface, Dalton-like adzes (Table 18.1). Five archaeological features were also encountered. Other than the 11,392 ± 166 cal BP to 10,950 ± 353 cal BP activity surface surviving, more or less intact, the most significant findings, largely due to extraordinary preservation of the Bolen component were:

(1) The first direct evidence of Bolen-age woodworking including a number of associated tools that archaeologists had correctly hypothesized were woodworking related (Bullen and Benson, 1964).
(2) The occurrence of two fire pits, structural elements (wooden stakes), and the chopped cypress log, that represents unequivocal evidence of human activity on that surface that had survived in fully datable context.

The two fire pits (Chapter 19, Hearths) on the surface of Unit 5 (the Bolen surface) represent some of the earliest human activity that took place after the subaerial exposure of that surface and prior to its burial by the shelly silt (bottom 10–15 cm of Unit 6L). Through time and successively, the Bolen surface was inundated sufficiently enough and allowed the shelly silt buildup. Even so, Bolen artifacts occur with abundance in the shelly silt indicating that human activity continued. Because the wooden stakes originated in the shelly silt, they appear to post-date the initial site activity that had taken place on the Unit 5 surface.

The Dalton-like adzes that came from the Bolen surface include two complete and three broken specimens (bit ends). The adze bits along with a section of adze-cut log indicate adze breakage due to heavy chopping. Hammerstones and abrading stones may also have been used for woodworking. The hammerstones from the Bolen level display extensive and controlled placement of battering damage created by repeated blows and long-term use.

Wood-wedge tools have not been recognized previously in the Bolen tool assemblage. Two stone tool specimens from the Bolen level are wedge-shaped on one end and battered on the other. They appear to have been used for splitting wood and the

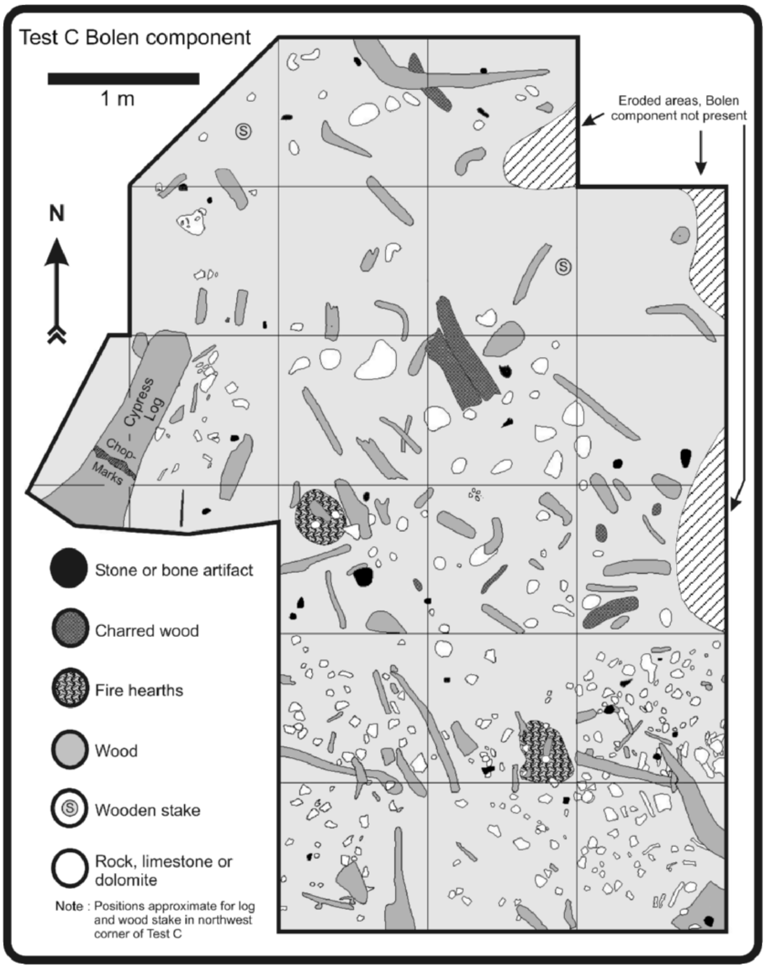


Figure 18.1 Plan view of Test C Bolen component.

occurrence of numerous plank-shaped wood slats supports this view. One of the specimens was manufactured from an oblong, biface, 11 cm long and weighing 473.7 g. The other specimen is smaller and was manufactured from a utilized flake 5.2 cm long and weighing 61.0 g. Both form relatively thick, stubby wedges with a blunt striking end opposite the bit (Fig. 18.2). The wedge or bit ends of both specimens are formed from microcrystalline chert, although the blunt end of the larger specimen consists of large-grained chert. The wedge tool's only diagnostic attributes are the obviously battered end opposite the bit; all other morphological features, other than their thickness for presumed sturdiness, seem rather random. The controlled placement of impact blows is lacking on the blunt end, which tends to display battering scars and breakage,

Table 18.1 Artifacts and cultural features from Test C at the Page/Ladson site

Artifact–feature identification	*Unit 7–6 contact Level 0–1b*	*Unit 6U upper silt level (with root casts)*	*Unit 6L above shelly silt level (without root casts)*	*Unit 6L basal shelly silt, Bolen level*[1]	*Unit 5 surface (Bolen surface)*	*Totals, artifacts and features*
Biface, Bolen Side and Corner Notch	0	0	1	2	1	4
Biface, Kirk Corner Notch	0	0	1	0	0	1
Biface, Kirk Serrated Stemmed	1	0	0	0	0	1
Biface, preforms	0	0	0	9	2	11
Biface, Dalton-like adzes	0	0	0	4	1	5
Biface, wedge	0	0	0	1	0	1
Uniface, wedge	0	0	0	1	0	1
Uniface, scraper	0	0	0	2	2	4
Uniface, utilized	1	1	0	7	1	10
Biface and uniface, cores	0	0	0	7	1	8
Random pecked, hammerstones	0	0	0	3	0	3
Ground stone, dimple stones	0	0	0	2	0	2
Ground stone, dimple stone preforms	0	0	0	3	0	3
Ground stone, abraders	0	0	0	10	0	10
Debitage, flake and fragments	2	2	13	35	3	55
Deer bone, pins–points	0	0	0	1	0	1
Deer bone, cut-marked antler-skull	0	0	0	1	0	1
Turtle bone, drilled plastron	0	0	0	2	0	2
Feature[2], chopped log	0	0	0	1	0	1
Feature[2], wooden stakes	0	0	0	2	0	2
Feature[3], fire pits	0	0	0	0	2	2
Totals, per unit and level	4	3	15	93	13	128

[1] The chopped log feature occured the primary Bolen level includes the basal shelly silt level of Unit 6L, and the surface of Unit 5.

[2] Both the chopped log features occurred on the surface of Unit 5 and extended upward into the shelly Bolen level. Both wooden stakes had been driven into the ground from the shelly silt and penetrate Unit 5 and/or upper most part of Unit 4. These are features that post-date the period of Unit 5 subaerial exposure and are therefore younger than the fire hearths on the Unit 5 Bolen surface.

[3] Two fire hearth features were identified on the surface of Unit 5 and contained both charcoal as well as partially burned and unburned wood. These hearths were buried under the shelly silt and represent features on the Bolen surface.

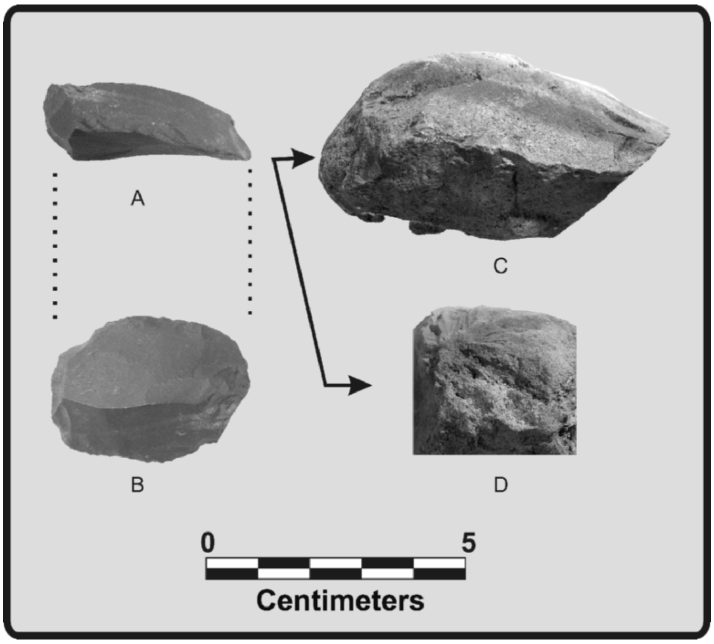


Figure 18.2 Wood wedges, A and B lateral (A) and top (B) views of small wedge, and C and D lateral (C) and proximal (D) views of large wedge. Note the battering damage on the proximal end of the large wedge. Photo by Aucilla River Prehistory Project.

both indicators of high attrition rate and short life expectancy. Their random appearance is likely due to multiple events of repeated breakage.

Plank-shaped sections of wood occurred on the Bolen surface and in the shelly silt Bolen level. The plank-shaped sections of wood on the Bolen surface were oxidized; some were burned while others displayed desiccation cracks characteristic of subaerial exposure. What purpose, if any, the plank-shaped slats may have served, remains uncertain. There is no sensible pattern of distribution (Fig. 18.1), although it is possible they were used to provide a working platform, particularly during wet intervals. If so, the platform would have had its greatest utility during the interval of shelly silt deposition. Another possibility is that bolts of wood were extracted for the cut cypress log and taken out of the sinkhole for finishing. This may indicate that the plank-shaped sections are nothing more than the discarded waste of less desirable pieces.

Two wooden stakes (Fig. 18.3) from the Bolen level might also have been part of a platform. The wooden stakes are indicative that some type of structure once existed, perhaps a windbreak, shelter foundation, or platform.

Other formalized tools recovered from the Bolen surface include Bolen points, a bone pin or projectile point, worked turtle and deer bone, and dimple stones. Dimple

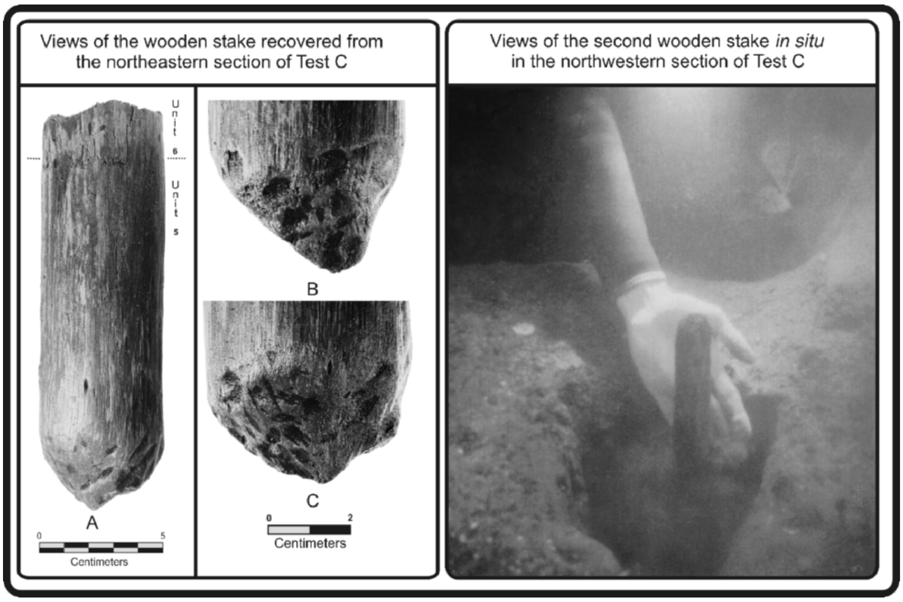
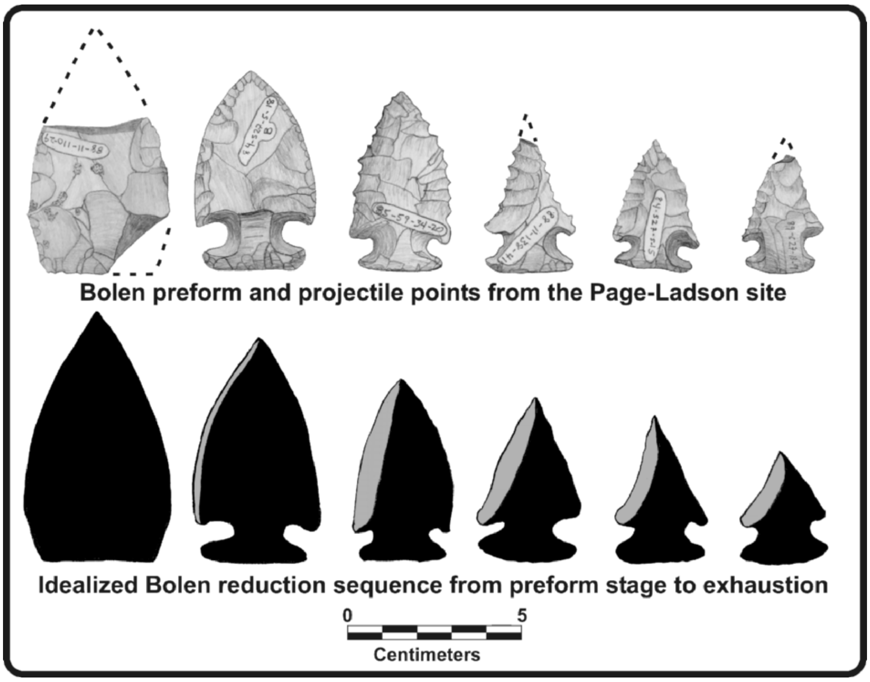


Figure 18.3 Carved wooden stakes found *in situ* in the Bolen component. Views A, B, and C are of the stake recovered in the northeastern section of Test C. The stake from the northwestern section of Test C is depicted *in situ* as it was uncovered during the excavation of this feature. Photo by Aucilla River Prehistory Project.

stones represent a ubiquitous ground stone artifact type not previously recovered from stratigraphic context.

Three Bolen projectile points were recovered from the Bolen surface; two were on the Bolen surface (surface of unit 5) and the other was in the shelly silt about 5–10 cm above Unit 5. One of the points from the Bolen surface was an un-beveled, corner-notched form. The other was a newly completed point with a heavily impact fractured on the distal (Fig. 18.4). It is a side-notched variety with its lateral edges sharpening and subsequent resharpening – the blade above the haft is responsible for the Bolen types distinctive rhomboid cross-section.

Nine bifacially flaked preforms came from the Bolen level and two others from the Bolen surface. Two of the specimens are in the late stage of production and appear to represent the preform intended for side-notched point production. A range of resharpening stages seen on the side-notched Bolen points recovered from the Page-Ladson site, and the preforms collected from the Bolen level, provides evidence of tool-life history. It began with the late stage preform, continues through several rounds of maintenance resharpening, and ended with a point fractured beyond repair or in the final stage of tool-life exhaustion (Fig. 18.4). The opposite beveling of a Bolen point's margins was accomplished by 3–7 mm wide pressure flakes of about the same length removed from the opposite lateral margin of the blade. The pressure flake extractions



Bolen preform and projectile points from the Page-Ladson site

Idealized Bolen reduction sequence from preform stage to exhaustion

Figure 18.4 Bolen reduction sequence.

were spaced in a way that allowed peaks between the flake-scars thereby resulting in a serrated blade margin. Subsequent to the first round of blade sharpening the margin does not appear beveled, even though small first-round flake scars and serrations are present. After additional rounds of resharpening, the blade becomes noticeably beveled and serrated. It should also be mentioned that there is a variety of Bolen points without beveled blade margins. The serrated, side-notched form detailed above represents the prevalent variety recovered at the Page-Ladson site.

A single bone pin was recovered with a longitudinal, greenstick-fractured end suggesting it was used as a projectile (Fig. 18.5). The bone pin was either bi-pointed or of the one-end-blunted variety, the most common types found in the Aucilla River (Willis, 1988:467). These types of bone pins are not diagnostic of age and were manufactured using the splinter-groove technique to score and snap off longitudinal splinters, typically 1/4 sections from a white-tailed deer metatarsus. The splinters were then ground into a rounded, cylindrical shape, and sharpened at one of both ends. They are noticeably smaller in all proportions compared to the bone and ivory shafts that were made during the preceding Paleoindian interval.

Only the remains of extant Holocene species were identified in the Bolen levels at the Page-Ladson site. Two pieces of turtle drilled plastron and a partial deer skull,

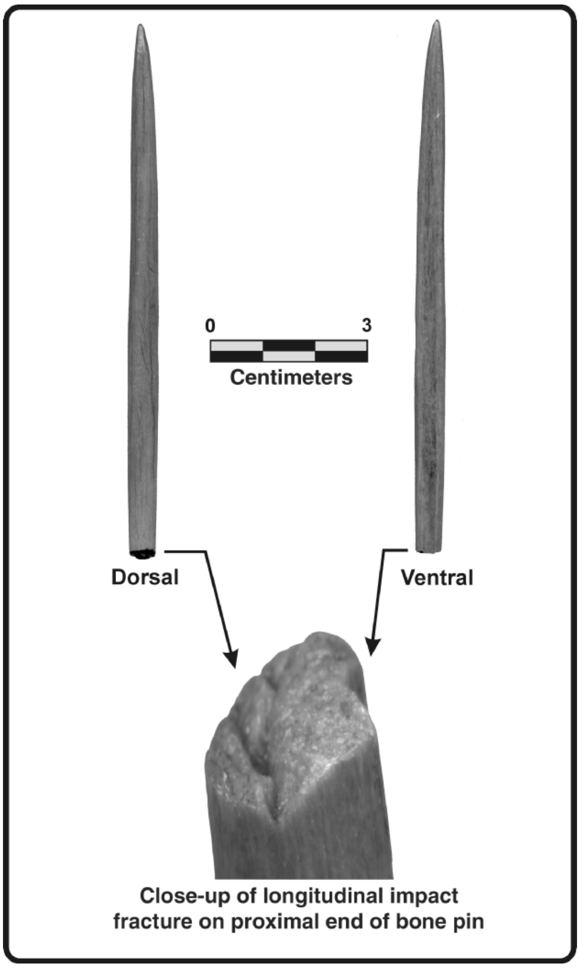


Figure 18.5 Bone pins unstained. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

which had been heavily worked, were among the faunal remains recovered. The deer antler had been cut, snapped, rounded and burned, and the crania modified with cuts (Fig. 18.6). The modified skull may have functioned as a drinking container and is similar to others recovered from the slightly younger Little Salt Springs site (Carter, 2003) located in Southwest Florida near Warm Mineral Springs.

Yet another class from the Bolen surface was the occurrence of dimple stones, a ground stone implement (Rachels and Knight, 2004). This is the first *in place* occurrence of dimple stones in datable context with a diagnostic artifact assemblage. Here we adopt the term dimple stones as defined by Rachels and Knight (2004) in favor of the other terms such as club heads, plummets, net sinkers, atlatl weights, charm

Figure 18.6 Deer skull. Colour version of this figure can be found in Appendix on page 553. Photo by Aucilla River Prehistory Project.

stones, gaming stones, or, the most common name, bola stones. The term dimple stones is used simply because the other terms infer function to an artifact whose function is clearly not understood (Rachels and Knight, 2004:67). Dimple stones are often but not always egg-shaped. They have also informally been referred to as dimple stones due to the existence of a single dimple, either flat or concave, placed on one end of a dimple stone's otherwise spheroid to ovoid shape. This artifact type was first described by Simpson (1948) and Neill (1971) and was assumed to be Paleoindian. More recently, Gerrell (1990, unpublished paper) conducted an analysis of 59 dimple stones, and Rachels and Knight an analysis of 86 dimple stones in an attempt to determine function. Although Gerrell was able to determine the function he did identify attributes related to manufacture and shape. He documented dimple stones manufactured from hematite, limestone, quartz, sandstone, and chert with sandstone representing the most frequently identified material (Gerrell, 1990, unpublished paper). Rachels and Knight furthered the effort by identifying post-manufacture use damage occurring most extensively around the sides of the stones caused by impact. Impact damage is insufficient to break the stones, yet sufficient enough to cause severe fracturing of the out surface (Rachels and Knight, 2004:65–66).

Specimens from the Bolen level appear to provide additional information related to dimple stone manufacture, but resolve nothing about their function. Two broken dimple stones and two dimple stone preforms came from the Bolen level. A third, complete dimple stone was recovered from the Bolen levels in Test B, Unit 6, Level 12a. All of the specimens from the Page-Ladson site are made of local dolomitic limestone. They were apparently manufactured by flaking the rock into rough shape,

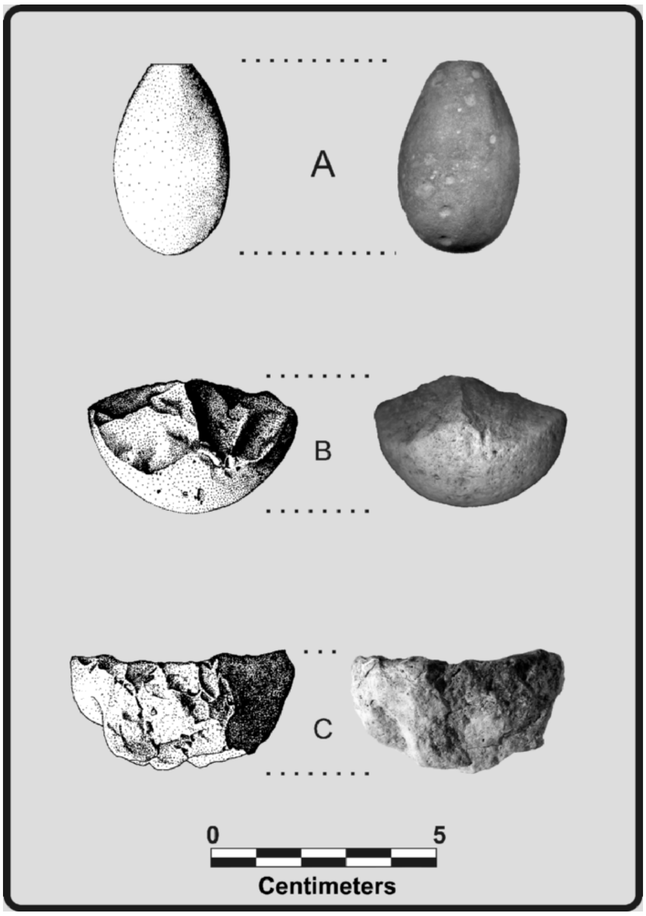


Figure 18.7 Proposed dimple stone manufacture sequence: A – finished specimen, B – specimen broken during manufacture, and C – late preform stage of dimple stone manufacture. Photo by Aucilla River Prehistory Project.

then were repeatedly peaked by impact into a spheroid shape, and finally finished by grinding (Carter, 2003) (Fig. 18.7).

Abraders made from vuggy, pumice-like rock (Fig. 18.9) display substantial use-wear. These are not the type of abraders that have worn grooves or elongate indents; the types of wear that result from honing objects such as tool shafts or bone pins. Rather, the rock surface was used in sandpaper-like fashion with the working face worn to relatively flat surface.

Artifact counts noticeably decrease in the Test C area subsequent to the deposition of the shelly silt (Table 18.1). No doubt, the area became too deeply inundated for continued human activity directly on or nearby the Test C area. The isolated occurrences of a Bolen Side Notched point and a Kirk Corner Notched point on and

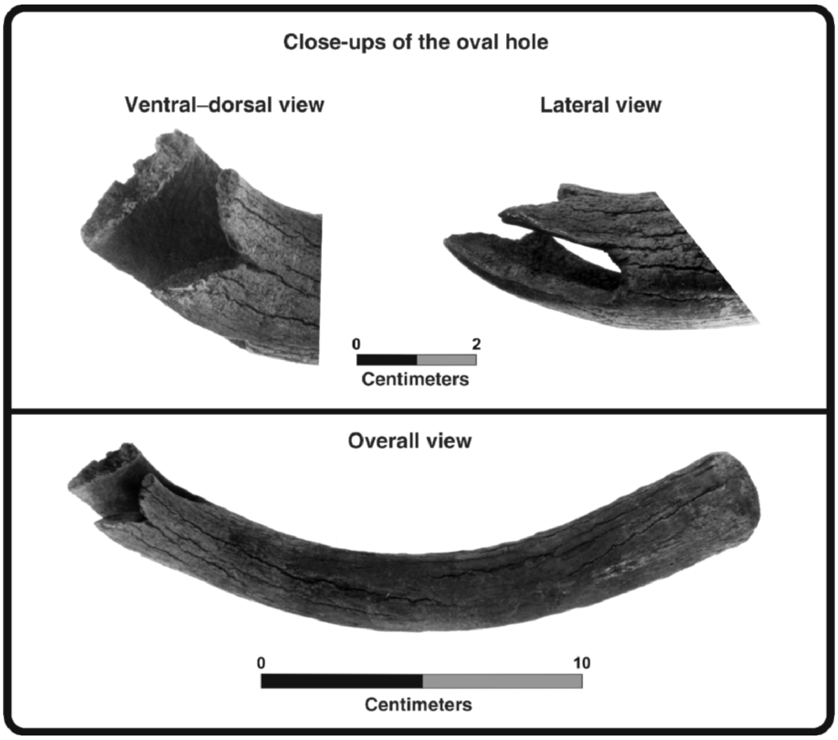


Figure 18.8 Antler tool handle. Type 1, recovered from Test B. Photo by Aucilla River Prehistory Project.

just above the shelly silt provided the relative age of ~9500 ^{14}C BP for the termination of shelly silt deposition. The Kirk Stemmed recovered on the contact of Unit 6U–Unit 7 indicates that some degree of human activity was taking place around the periphery of the sinkhole during the late Early Archaic, perhaps as late as ~7000 ^{14}C BP.

18.3.3.2 Test B Artifacts from the Bolen Levels of Unit 6

The Bolen levels of Test B Unit 6L represent an artifact assemblage believed to span the Bolen timeframe and, above that in Unit 6U extend into younger, unidentified Early Archaic levels (Table 18.2). Unfortunately the youngest component yielded no diagnostic artifacts and was not dated radiometrically. As mentioned, the Bolen levels do not represent accumulations due to human activity in the Test B area; rather they represent incidental losses from nearby human activity areas adjacent to the sinkhole in most levels of Units 6L and 6U as well as a level of redeposited materials transported from the Test C area in Level 12a, Unit 6L. With few exceptions, the artifacts from Test B mirror the assemblage from Test C. Test B included recoveries of Bolen points (beveled and plain), a Dalton-like adze, bone pins, and two types of antler tools handles, one of which represents a heretofore undocumented style (Type 1).

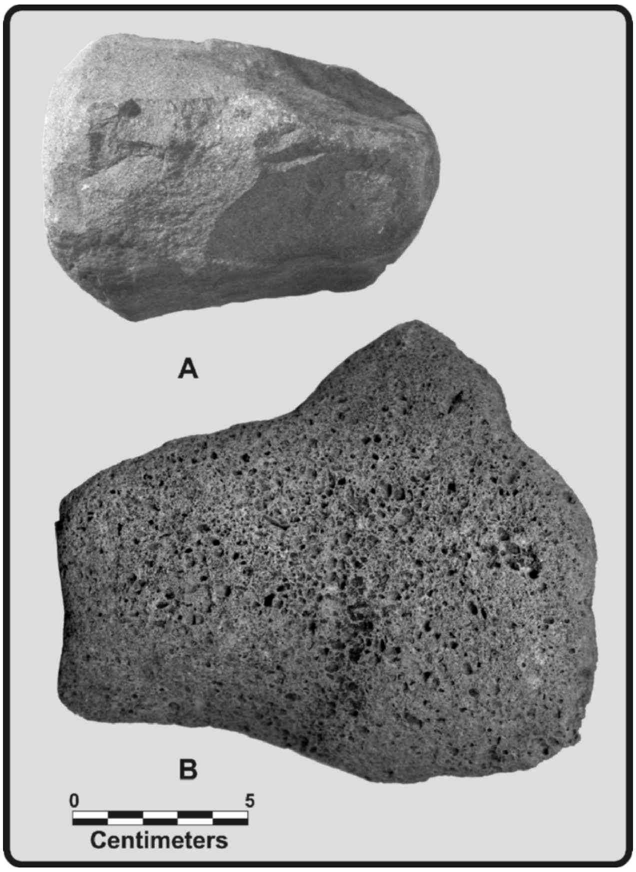


Figure 18.9 Battering and abrading lithic artifacts: A – hammerstone and B – sandpaper-like heavily worn abrader stone. Photo by Aucilla River Prehistory Project.

The only unique Bolen tool from Test B was manufactured from a section of curved deer antler and used as a tool handle. The base of the antler had been shaped and rounded and may have been used as a flint knapping billet, though the attrition from having been used in that manner seemed non-existent. The antler section is U-shaped and broken at the distal end of an oval hole purposely cut and drilled through the antler (Fig. 18.8). The oval hole is at the apex of the U-shape bend and was placed there to haft a stone tool. There is little doubt that a stone tool was hafted in the hole since one side of the interior of the hole is scarred by hafted tool damage while the opposite side is not. The type of hafting damage is consistent with a blade tool that has a triangular cross section. The dorsal ridge of a triangular flake or blade scratched and scarred one side of the hafting hole while the flat side of the blade, opposite the ridged side, did not. A blade tool with a triangular cross section was recovered from the same

Table 18.2 Artifacts from Test B at the Page-Ladson site

Artifact identification	*Unit 6U*		*Unit 6L*			*Totals artifacts*
	Level 8	*Level 9*	*Levels 10a and b*	*Levels 10c and 11*	*Level 12a*	
Biface, Bolen side and Corner Notch	0	0	1	1	0	2
Biface, preform	4	0	0	0	0	4
Biface, Dalton-like adze	0	0	0	1	0	1
Uniface, scrapers	1	1	0	0	0	2
Uniface, Aucilla adze	1	0	0	0	0	1
Uniface, utilized	2	0	1	2	0	5
Ground stone, dimple stone	0	0	0	3	0	3
Deer bone, antler handle type 1	0	0	0	0	1	1
Deer bone, antler handle	0	0	1	0	0	1
Deer bone, pins–points	0	0	0	2	0	2
Deer bone, antler handle type 2	2	0	0	0	0	2
Deer bone, antler handle	0	0	0	1	0	1
Fox bone, ulna pressure flaker	1	0	0	0	0	1
Totals, per unit and level	11	1	3	10	1	26

stratigraphic level as the antler tool handle. Bolen tools manufactured on prismatic blades, blade sections, or flakes include Waller knives, and teardrop-shaped end scrapers and spokeshaves as well as utilized blades. Assuming the original tool handle extended beyond the break for another 10 cm or so, the antler would have provided handle grips on either side of the tool bit hafting hole. A stone bit hafted towards the outer part of the U-shaped curve would have provided an effective slotting tool for burin or burin-like cutting. Conversely, a stone bit mounted in the opposite direction on the inside of the curve would have provided an effective drawknife or spokeshave-like implement. It is possible that a variety of stone tool bits including burins, end scrapers, spokeshaves, and scrapers were fitted interchangeably as needed into a handle of this type.

18.4 Discussion and Conclusions

At the dawn of the Holocene, Early Archaic, Bolen people not only utilized the exposed sinkhole bottom, they used a stone toolkit that included the introduction of formalized, chipped-stone woodworking tools (Carter, 2003). Woodworking tools are absent from the Paleoindian components at the Page-Ladson (Dunbar, 2002), though they are known to occur in Late Paleoindian context in the Southeast (Purdy, 1981). Evidence of human activity in the sinkhole includes archaeological features such as fire hearths (Chapter 19), worked wood including a chop-marked cypress tree, as well as numerous stone tools and the remains of extant Holocene fauna, notably white-tailed deer. The Bolen component also yielded a number of side- and corner-notched Bolen projectile points both beveled and plain. Woodworking appears to have been a primary reason for humans to exploit the sinkhole floor; therefore, the overall accumulation of features and artifacts represents, in part at least, a special use area for the procurement of wood.

Evidence from the Page-Ladson site fulfils the assumptions of previous research carried out by Bullen *et al.* (1964), Morse and Goodyear (1973), and Goodyear *et al.* (1980), and serves to validate their approach and the proper application of both the comparative and replicative methods.

Progressive resharpening or maintenance throughout the life of a formalized stone tool is to be expected. Yet Bolen points, with beveled blade edges caused by pressure flaking on opposite sides of opposing lateral edges, seem to have offered a particularly efficient way to conserve tool-life by efficiently maintaining blade length (Daniel and Wisenbaker, 1987:55). The Bolen Beveled point type was not the only Bolen tool designed for longevity while fundamentally maintaining proportional shape and useful function. For example, the resharpening stages of Dalton-like adze (Morse and Goodyear, 1973) as well as the Aucilla adze (Gerrell *et al.*, 1991:14–15) were maintained in a similar manner. Resharpening of the edges of these stone tools was accomplished in a way that minimally reduced the tools' size while maintaining morphological shape proportionally. This aspect of Bolen stone tool manufacture efficiently maintained functionality and longevity. It represents a distinct departure from the stone tool manufacturing methods utilized by Paleoindians.

Early and Middle Paleoindian toolkits tend to consist of an assortment of multipurpose stone tools (Jones and Tesar, 2000) including carefully prepared large biface and uniface forms (Jones and Tesar, 2004) that functioned as hand tools, cores to derive flakes for tool making, or that were further reduced to make projectile points when necessity demanded (Gramly, 1990:10–11). The development of specialized stone tools with a single or few, similar uses seems to be a characteristic of the Southeastern Early Archaic. Bolen points were made from small, thin bifaces, whereas Dalton-like adzes were made from large, thick biface preforms. Early and Middle Paleoindian uniface tools are often akin to Swiss Army knives in that graver spurs, spokeshaves, cutting, and/or scraping edges are often found in combinations on one artifact. The Bolen toolkit has segregated many of those tool functions into single tool forms. These represent distinctly different strategies, one that is a more generalized, multipurpose Paleoindian approach and the other a more formalized, subsequent Early Archaic development.

Prior to the late Younger Dryas, shifts in the depositional environment occurred at the Page-Ladson site in succession with global climatic change that was regionally modified in the Southeastern US depending on the direction and volume of glacial meltwater discharge to the eastern seaboard of North America. These changes took place at periodicities from about 100 years to as many as 1000 years. For example, Unit 4, the youngest stratigraphic unit containing Pleistocene megafaunal, accumulated during the Allerød through the middle Younger Dryas. However, during the late Younger Dryas, abrupt shifts in local water level took place in more rapid, staccato-like fashion that resulted in an episode of fluvial erosion, followed by an episode of shallow water deposition (Unit 5), and another episode of fluvial downcutting. By the beginning of the Holocene (Preboreal onset), the most dramatic climatic shift took place in synchrony with the accumulation of glacial melt water in the Gulf of Mexico during Meltwater Pulse 1B. Water tables throughout Florida dropped several meters below their already low, late Younger Dryas position.

Important to this consideration is the early Holocene human utilization of the Page-Ladson sinkhole during a time when the sinkhole floor in the Test C–F area was dry. It is also important to note that the sinkhole in the Test B area remained inundated indicating that the water table was more than 6 m below present, but not more than 8 m below present. The maximum decline in regional water tables took place during the Preboreal onset ~10,000 ^{14}C BP to ~9,900 ^{14}C BP, which preceded the Preboreal Oscillation. During the Preboreal Oscillation water tables began to rise, albeit, slowly. The Preboreal Oscillation was a Heinrich or Heinrich-like climatic downturn coinciding with ice-rafting generated along a 200-km calving margin of the Gold Cove lobe of the Laurentide ice-sheet from ~9,900 ^{14}C BP to ~9,600 ^{14}C BP (Kaufman *et al*., 1993).

The rapid pulse of late Pleistocene to early Holocene environmental change is reflected both locally in the Page-Ladson sediments (Dunbar, 2002) as well as continentally, circum the North Atlantic (Kaufman *et al*., 1993; Behling *et al*., 2000; Behling *et al*., 2002; Kovanen and Easterbrook, 2002). The impulse for cultural change due to factors related to prey animal extinction as well as climate change appears to have begun sometime around the middle to late Younger Dryas and had fully taken place by the Holocene Preboreal in the Southeastern US (Dunbar, 2002). At the Page-Ladson site, Bolen people congregated around and utilized the exposed land surface in the sinkhole 9953 ± 40 ^{14}C BP ($n = 3$). By 9466 ± 105 ^{14}C BP ($n = 1$), probably before, the sinkhole had re-flooded to a depth that no longer supported human use. Contemporary with the Bolen activity in the Page-Ladson sinkhole are Burial 1 at Warm Mineral Spring site in Southwest Florida at 9967 ± 58 ^{14}C BP ($n = 5$) and the Bolen hearth at Le2105 in North Florida at 9948 ± 40 ^{14}C BP ($n = 3$). The pooled averaged dates from all three of these sites are virtually identical. Like the Page-Ladson site, the burial at Warm Mineral springs is inundated more than 6 m below the modern water table. The Preboreal onset water tables of six or more meters below present represents the period of the Bolen Drought and fits Neill's concept for the Florida Oasis hypothesis (Neill, 1964).

References

Anderson, D. G., and K. E. Sassaman. 1996. *The Paleoindian and Early Archaic Southeast.* University of Alabama Press, Tuscaloosa, AL.

Anderson, D. G., L. O'Steen, and K. E. Sassaman. 1996. Environmental and Chronological Considerations. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 3–15. University of Alabama Press, Tuscaloosa, AL.

Behling, H., H. W. Arz, J. Patzold, and G. Wefer. 2000. Late Quaternary Vegetational and Climate Dynamics in Northeastern Brazil, Inferences from Marine Core GeoB 3104-1. *Quaternary Science Reviews*, 19 (10):981–994.

Behling, H., H. W. Arz, J. Patzold, and G. Wefer. 2002. Late Quaternary Vegetational and Climate Dynamics in Southeastern Brazil, Inferences from Marine Cores GeoB 3229-2 and GeoB 3202-1. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 179 (3–4):227–243.

Bullen, R. P. 1958. The Bolen Bluff Site on Paynes Prairie, Florida. *Contributions of the Florida State Museum*, Social Sciences (Number 4):1–38 and plates.

Bullen, R. P. 1975. *A Guide to the Identification of Florida Projectile Points.* Revised edition, Kendall Books, Gainesville, FL.

Bullen, R. P., and L. E. Beilman. 1973. The Nalcrest Site, Lake Weohyakapka, Florida. *Florida Anthropologist*, 26 (1):1–22.

Bullen, R. P., and C. A. Benson. 1964. Dixie Lime Caves Numbers 1 and 2, a Preliminary Report. *Florida Anthropologist*, 17 (3):153–138.

Cambron, J. W., D. C. Hulse, and D. L. DeJarnette. 1990. *Handbook of Alabama Archaeology: Part I, Point Types.* Archaeological Research Association of Alabama, Moundville, AL.

Carr, R. S. 1987. Early Man in South Florida. *Archaeology*, 62–63.

Carter, B. 2003. *Page-Ladson (8Je591): Excavation of an Early Holocene Occupation Site in the Aucilla River, Florida*, Ph.D. dissertation, University of Florida, Gainesville, FL.

Clausen, C. J., D. A. Choen, Cesar Emiliani, J. A. Holman, and J. J. Stipp. 1979. Little Salt Springs: A Unique Underwater Site. *Science*, 203:609–614.

Cockrell, W. A. 1980. Drowned Sites in North America. *Archaeology Under Water*, editor K. Muckelroy, pp. 138–145. McGraw-Hill Book Company, London, UK.

Cockrell, W. A., and L. Murphy. 1978. Pleistocene Man in Florida. *Archaeology of Eastern North America*, 6:1–12.

Connet, J. H. 1932. Recent Find of Mammoth Remains in the Quaternary of Florida, Together with Arrow-head. *Science*, 75:516.

Daniel, I. R. 1998. *Hardaway Revisited.* University of Alabama Press, Tuscaloosa, AL.

Daniel, I. R., and M. Wisenbaker. 1987. *Harney Flats: A Florida Paleo-indian Site.* Baywood Publishing Co., Farmingdale, NY.

Dietrich, P. M., and J. A. Gifford. 1996. *Early–Middle Archaic Paleoenvironments and Human Populations at Little Salt Springs, Florida*. pp. 1–22, Unpublished paper presented at the GSA, Southeast section, 46th annual meeting.

Doran, G. H. 2002. *Windover: Multidisciplinary Investigations of an Early Archaic Florida Cemetery.* University Press of Florida. Gainesville, FL.

Driskell, B. N. 1994. Stratigraphy and Chronology at Dust Cave. *Journal of Alabama Archaeology*, 40 (1 & 2):17–34.

Driskell, B. N. 1996. Stratified Late Pleistocene and Early Holocene Deposits at Dust Cave, Northwest Alabama. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 315–330. University of Alabama Press, Tuscaloosa, AL.

Dunbar, J. S. 2002. *Chronostratigraphy and Paleoclimate of Late Pleistocene Florida and the Implications of Changing Paleoindian Land Use*, Masters of Sciences Thesis, Florida State University, Tallahassee, FL.

Dunbar, J. S., C. A. Hemmings, P. K. Vojnovski, S. D. Webb, and W. Stanton. 2006. The Ryan/Harley Site 8Je1004: A Suwannee Point Site in The Wacissa River, North Florida. *Paleoamerican Prehistory: Colonization Models, Biological Populations, and Human Adaptations*, College Station, TX, Center for the Study of the First Americans, Texas A&M University.

Dunbar, J. S and Vojnouski, P.K. In Press. Early Floridians and Late Mega Mammals: Some Technical and Dietary Evidence from Four North Florida Paleoindian Sites. *Foragers of the Terminal Pleistocene*, editors Rence B. Walker, and Boyce N. Driskell. University of Nebraska Press, Lincoln, Nebraska.

Ellis, C., A. C. Goodyear, D. F. Morse, and K. B. Tankersley. 1998. Archaeology of the Pleistocene–Holocene Transition in Eastern North America. *Quaternary International*, 49–50:151–166.

Emslie, S. D., and G. S. Morgan. 1995. Taphonomy of a Late Pleistocene Carnivore Den, Dade County Florida. *Late Quaternary Environments and Deep History: A Tribute to Paul S. Martin*, editors D. W. Steadman, and J. I. Mead, pp. 65–83. The Mammoth Site of Hot Springs, South Dakota, Inc., Hot Springs, South Dakota 57747-0606.

Gerrell, P. R. 1990. *Analysis of 59 Bola Stones from Florida.* pp. 27, Unpublished paper on file at the Department of Anthropology, Florida State University, Tallahassee, FL.

Gerrell, P. R., J. F. Scarry, and J. S. Dunbar. 1991. Analysis of Early Archaic Uniface Adzes from North Florida. *Florida Anthropologist*, 44 (1):3–16.

Goodyear, A. C. 1973. Archaic Hafted Spokeshaves with Graver Spurs from the Southeast. *Florida Anthropologist*, 26 (1):39–44.

Goodyear, A. C. 1999. The Early Holocene Occupation of the Southeastern United States: A Geoarchaeological Summary. *Ice Age Peoples of North America: Environments, Origins, and Adaptations*, editors R. Bonnichsen, and K. L. Turnmire, pp. 432–481. Oregon State University Press, Corvallis, OR.

Goodyear, A. C., J. L. Michie, and B. A. Purdy. 1980. The Edgefield Scraper: A Distributional Study of an Early Archaic Stone Tool in the Southeastern US. 37th annual meeting Southeastern Archaeological Conference, A. C. Goodyear, and R. W. Jefferies, chairpersons of, *Problem Oriented Lithic Studies in the Southeastern United States*. New Orleans, LA.

Gramly, R. M. 1990. *Guide to the Paleo-indian Artifacts of North America.* Persimmon Press, Buffalo, NY.

Hornum, M. B., D. J. Maher, C. Brown, J. Granberry, F. Vento, A. Fardkin, and M. Williams. 1996. *Phase III Data Recovery at Site LE2105 for the Proposed Florida Gas Transmission Phase III Expansion Project, Leon County, Florida*. R. Christopher Goodwin and Associates, Inc., New Orleans, LA.

Jones, B. C., and L. D. Tesar. 2000. The Wakulla Springs Lodge Site (8WA329): A Preliminary Report on a Stratified Paleoindian Through Archaic Site, Wakulla County, Florida. *Florida Anthropologist*, 53 (2–3):98–115.

Jones, B. C., and L. D. Tesar. 2004. *Wakulla Springs Lodge Site (8Wa329) in Edward Ball Wakulla Springs State Park Wakulla County, Florida.* Florida Bureau of Archaeological Research, Tallahassee, FL.

Kaufman, D. S., G. H. Miller, J. A. Stravers, and J. T. Andrews. 1993. Abrupt Early Holocene (9.9–9.6 ka) Ice-stream Advance at the Mouth of Hudson Strait, Arctic Canada. *Geology*, 21:1063–1066.

Kovanen, D. J., and D. J. Easterbrook. 2002. Timing and Extent of Allerød and Younger Dryas Age (ca. 12,500–10,000 ^{14}C Yr B.P.) Oscillations of the Cordilleran Ice Sheet in the Fraser Lowland, Western North America. *Quaternary Research*, 57 (2):208–224.

Lewis, T. M. N., and M. Kneberg-Lewis. 1961. *Eva: An Archaeological Site.* University of Tennessee Press, Knoxville, TN.

Meltzer, D. J. 1988. Late Pleistocene Human Adaptations in Eastern North America. *Journal of World Prehistory*, 2 (1):1–51.

Meltzer, D. J. 2004. Peopling of North America. *The Quaternary Period in the United States*, editors A. R. Gillespie, S. C. Porter, and B. F. Atwater. Elsevier, Amsterdam.

Meltzer, D. J., and B. D. Smith. 1986. Paleoindian and Early Archaic Subsistence Strategies in Eastern North America. *Foraging, Collecting, and Harvesting: Archaic Period Subsistence and Settlement in the Eastern Woodlands,* Center for Archaeological Investigations Occasional Paper No. 6:3–31.

Michie, J. L. 1996. The Taylor Site: An Early Occupation in Central South Carolina. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 238–269. University of Alabama Press, Tuscaloosa, AL.

Milanich, J. T. 1994. *Archaeology of Precolombian Florida.* University Press of Florida, Gainesville, FL.

Milanich, J. T., and C. H. Fairbanks. 1980. *Florida Archaeology.* Academic Press, New York, NY.

Morse, D. F. 1994. Comments on the Dust Cave Investigation. *Journal of Alabama Archaeology*, 40 (1 & 2):232–236.

Morse, D. F., and A. C. Goodyear. 1973. The Significance of the Dalton Adze in Northeast Arkansas. *Plains Anthropologist*, 18–62 (1–2):316–322.

Neill, W. T. 1953. Notes on the Supposed Association of Artifacts and Extinct Vertebrates in Flagler County, Florida. *American Antiquity*, 19:170–171.

Neill, W. T. 1964. The Association of Suwannee Points and Extinct Animals in Florida. *Florida Anthropologist*, 17:17–32.

Neill, W. T. 1971. A Florida Paleo-indian Implement of Ground Stone. *Florida Anthropologist*, 24 (2):61–70.

Ogg, G. 2003. *International Stratigraphic Chart.* International Commission on Stratigraphy, Statoil, Norway.

Purdy, B. A. 1981. *Florida's Prehistoric Stone Technology.* University Presses of Florida, Gainesville. FL.

Rachels, T., and R. L. Knight. 2004. Dimple Stones – An Unique and Early Ground Stone Artifact Type. *The Amateur Archaeologist*, Fall:57–76.

Simpson, J. C. 1948. Folsom-like Points from Florida. *Florida Anthropologist*, 1 (1):11–15.

Tesar, L. 1997. *Notes Concerning the Age of Human Remains at Warm Mineral Springs*. pp. 1–3, Unpublished research paper on file at the Florida Bureau of Archaeological Research.

Vojnovski, P. K., and J. S. Dunbar. In press. Early Floridians and Late Mega-mammals: Some Technological and Dietary Evidence from Four North Florida Paleoindian Sites. *Foragers of the Terminal Pleistocene*, editors R. B. Walker, and B. N. Driskell. University of Nebraska Press, Lincoln, NE.

Walker, R. B. 1998. *The Late Paleoindian Through Middle Archaic Faunal Evidence from Dust Cave, Alabama.* Doctoral dissertation, 302 pages, University of Tennessee, Knoxville, TN. Also available through University Microfilms International, Ann Arbor, MI.

Webb, S. D. 1974. Underwater Paleontology of Florida's Rivers. *National Geographic Society Research Reports*, 1968. Projects: 479–481.

Willis, C. 1988. Controlled Surface Collection of the Little River Rapids Site (8Je603): A Stratigraphically Deflated Site in the Aucilla River, North Florida. *Florida Anthropologist*, 41 (3):453–470.

Chapter 19

Hearths

MARK P. MUNIZ[1] and C. ANDREW HEMMINGS[2]
[1]Department of Anthropology, University of Colorado, Boulder, CO, USA.
[2]Texas Archeological Research Laboratory, University of Texas, Austin, TX, USA.

19.1 Introduction

During the October, 1995 field season the Aucilla River Prehistory Project conducted excavations in Test C on the "Bolen surface". This work, under the direction of Brinnen Carter, extended the work of several previous seasons. Near the southern edge of this season's operation an oval hearth feature was recognized. The hearth is of great import to our understanding of both the geologic formation and the cultural habitation of this site.

At Page-Ladson the earliest work in the upper part of stratigraphic Unit 5 had taken place in Test B and revealed no evidence of a subaerial surface. At Test C, however, the so-called "Bolen Surface" was about 2 m higher than equivalent sediments in Test B. Because Page-Ladson was predominantly an inundated site during most of its history, the hearth feature is the clearest indication that part of the site was subaerially exposed during at least part of the Early Holocene.

The archaeological significance of well-preserved organic material *in situ* in a short-duration occupation site of Early Archaic hunter-gatherers cannot be understated. Early Holocene hunter-gatherer peoples, subsisting within a fairly mobile lifestyle, leave a light footprint on the landscape. Pedogenic soil development, and even basic modifications to soil chemistry, will be faint to non-existent at a site occupied for no more than a few days and perhaps as briefly as a few hours. It is worth looking for phosphate increases or accumulation of humates, but they are unlikely at short-duration use sites. On the other hand, production of waste material from resource processing (such as knapping, butchering, and bone tool manufacture), intentional discard, and loss of items by site occupants are the typical forms of data recovered from Paleoindian and Early Archaic sites in the

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 517–521

Southeastern United States. For these reasons the Bolen level hearth provides an additional rare glimpse into the behavior of Early Floridians.

In this chapter, we describe the hearth features and then offer a brief interpretation of its role in the Early Archaic (Bolen) Culture.

19.2 Methods

In a previous season excavators working at Test C on the "Bolen Surface" had encountered a hearth feature about 2 m northwest of the one described here. They were thus alerted to the need to take special care with any such discovery. The objective was to expose by trowelling and to carefully map all objects within a 2 m × 3 m grid frame set above the Bolen Surface (= stratigraphic Unit 5). Excavation procedures also entailed removal of the thin shelly silt of Unit 6L immediately overlying Unit 5, and to some extent illuminating the irregular surface of that contact.

The hearth feature was immediately recognized. Four centimeters of ashy silt sediment were removed from within the depression, revealing a charred wood fragment at the bottom. No other specimens were collected within the hearth feature.

FLMNH ARPP 95E.88.1m is the hearth charcoal piece. It is one of the numerous specimens of wood collected from the Bolen level for future radiocarbon and macrobotanical analysis and curated in the Florida Museum of Natural History. Three additional charcoal samples have been retained from across the Test C Bolen surface, as well as 31 wood specimens (Appendix A in Carter 2003:207). Easily recognizable botanical remains from this stratigraphic level included a cypress log that was extensively cut, an unidentified seed husk (95E:243.2 Unit U), and numerous acorns and hickory nuts. Direct evidence of resource utilization within the hearth is limited to the unidentified charred wood fragment.

Discrimination between rocks composed of limestone and those of dolomite was made using a 10% HCL wash "fizz" test. Specimens that had highly angular surfaces and were darker gray than most were considered to have been thermally altered. These criteria followed Lovick (1983:42) by whom "lithic materials ... were classified as burned or fire-cracked rock if they exhibited flat, angular, unweathered fractures which lacked features associated with external force application ...". The observed range of variation in these features led us to make a further arbitrary division of the stones from the southern hearth area into those that were excellent examples and those that were ordinary examples of thermally altered stones.

19.3 Results

The southern hearth was immediately recognized as the second such feature during excavation of the southernmost 6 m in Test C. It is illustrated in Fig. 19.1. The other hearth had been uncovered in 1988 about 2 m northwest of the southern hearth. This

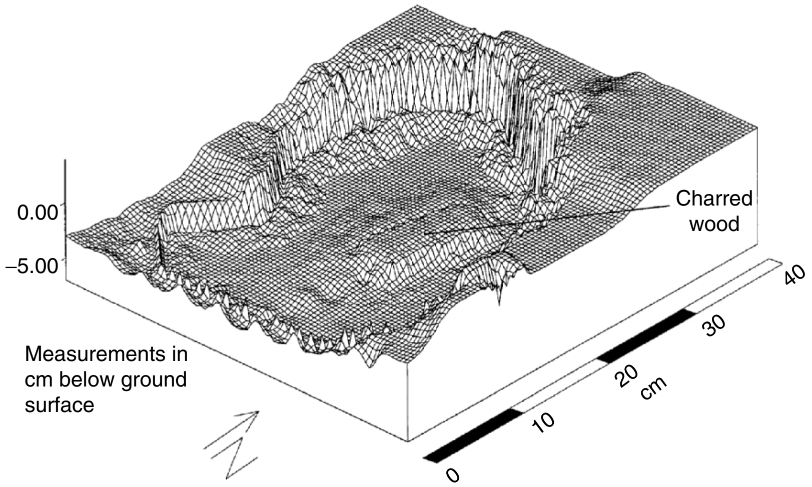


Figure 19.1 The southern hearth.

roughly oval, flat-bottomed, depression had a north–south length of 40 cm. Its width ranged from 27 to 35 cm west to east. Depth was from 8 to 10 cm across the irregular oval hearth depression.

The bulk of geological and potentially archaeological materials recovered on the Bolen layer of Test C were unshaped pieces of limestone and dolomite. A large number of gravel to cobble sized stones were recovered in the vicinity of the hearth, of which 150 were numbered and mapped. In the sample of 224 rocks tested, 65.6% were limestone, 33.5% were dolomite, and 0.9% were classified as other (*N* = 147, 75, and 2, respectively). No clear architectural alignment of stones survived to the time of inundation by the shelly silt of Unit 6L, at which time their positions were sealed. Of the 224 rocks of strongly cemented limestone or dolomite recovered in the 6 m^2 in the vicinity of the southern hearth, 150 specimens were numbered and point plotted prior to collection. Of these, 51 specimens were subsequently identified as thermally altered. Of these 30 were considered excellent examples.

Of the 30 excellent examples of thermally altered stones, 25 were dolomite, and 5 were limestone. The dolomite was naturally grayer than the limestone and this raises the possibility that some of the stones considered to have been heat-altered may in fact be natural. This possibility is contrasted with the weight and length data presented below.

The weight of individual specimens ranged from 2.5 to 1240 g (mean 141.6 g). In the sub-sample of 30 clearly heat-altered rocks, the weight range was 12.9–560 g (mean 212.8 g). Length measurements of the whole sample ranged from 2.2 to 17.4 cm (mean 9.8 cm). The sub-sample of 30 specimens, considered to have been clearly heat-treated, ranged in length from 5.1 to 17.4 cm (mean 10.2 cm). Thus, the sample of rocks considered heat-altered fell well above the mean of the whole sample both in weight and in overall length. While not conclusive, these data suggest a plausible trend.

The distribution plots of heat-altered rocks and the other 173 unmodified rocks overlap and obscure any patterning in their dispersal. Quite possibly both sets were parts of one or several complete rings of stone. Only 150 of the 224 (67%) were mapped *in situ*. At least 13% and more probably 23% of the rocks give evidence of heat alteration. And these heat-altered rocks are typically larger than the other rocks recovered.

19.4 Discussion

The distributional array does not indicate any clear pattern, even among the stones considered to be modified by heat. It is possible that the hearth was originally lined with stones. It is notable that the two intact stone rings of Dust Cave, studied by Collins *et al*. (1994), had only five to nine heat-altered limestone rocks. This suggests that the much larger number of similar stones scattered about the “Bolen Surface” may be derived from a considerable number of hearths that were scattered after use. Another hypothesis, namely that the rocks were later fluvially translocated, seems improbable. The number of low-density botanical specimens that remained on the Bolen Surface militates against any substantial current action. Subsequent deposition of Unit 6L gives every appearance of a very quiet, lentic setting. The most parsimonious explanation for the presence of heat-modified rocks in the vicinity of the hearth features is that they were displaced from serving as stone rings. All of the heat-altered stones in the vicinity of the recorded hearth feature may have circumscribed one or more hearths, later becoming disarticulated prior to their final inundation.

The hearth features and the abundance of thermally altered stones in its vicinity clearly indicate the presence of two or more hearths on the Bolen surface. The overall nature of that surface, presumably an occupation and habitation, is clearly compatible with the presence of stone-lined hearths. Use of fireplaces is also compatible with the evidence of burned bone and wood on that surface. Furthermore, as discussed in Chapter 6 by Hansen, there is a notable increase in charcoal in two of three samples taken from the Bolen level.

Two of the rocks from this same excavation have battered surfaces that were likely produced through use as hammerstones. They are particularly important culturally as evidence of manufacturing or butchering processes engaged in during use of Page-Ladson as a short-term occupation and habitation site by Bolen people in the early Holocene.

The nearest similar evidence of early Holocene hearth features come from Dust Cave in northern Alabama. The features 87 and 92 were recognized as stone-lined hearths (Collins *et al*., 1994). Only nine stones surrounded the first hearth feature and only five the second. The surrounding limestone specimens, as well as the inner clay, still in presumed original position, were subjected to thermal demagnetization studies.

The low temperature component from the stones, representing a temperature of about 300°C, agreed in its orientation with the clay. This evidence is taken to suggest a relatively modest size and temperature for these early hearths (Collins *et al*., 1994). These Early Archaic hearths are regarded as smaller and less substantial than the Middle Archaic hearths in Dust Cave and elsewhere in the region (Goldman-Finn, 1994).

19.5 Conclusions

The evidence of two or more hearths on the buried and inundated terrestrial surface represented by the Bolen layer of Page-Ladson falls nicely in line with the full breadth of anthropological material from that level in Test C. Two sharpened wooden stakes are pounded through the terrestrial sediment. A smattering of formal bone tools and diagnostic Bolen projectile points are found surrounding a hearth feature with fire-cracked rock, burned wood, and charred bone of deer and turtle. And small amounts of lithic debitage are found resting on this terrestrial soil. In addition to the superb contextual preservation, the radiocarbon chronology of Page-Ladson allows us to refine our placement of the Early Archaic cultural adaptation locally known as Bolen in both space and time. The hearths add to this relatively full picture of habitation and occupation by the Bolen culture at the Page-Ladson site.

References

Carter, B. 2003. Page-Ladson (8Je591): Excavation of an Early Holocene Occupation Site in the Aucilla River, Florida, Ph.D. Dissertation, Dept. of Anthropology, University of Florida.

Collins, M. B, W. A. Gose, and S. Shaw. 1994. Preliminary Geomorphological Findings at Dust and Nearby Caves, *Journal of Alabama Archaeology* 40:35–56.

Goldman-Finn, N. 1994. Dust Cave in Regional Context, *Journal of Alabama Archaeology* 40:212–231.

Lovick, S. K. 1983. Fire-cracked Rock as Tools: Wear-pattern Analysis, *Plains Anthropologist* 28:41–52.

SECTION E: CONCLUSIONS

> "The exciting information recovered from the Page-Ladson Site shows the great potential of underwater sites to produce extraordinary data on Paleoindians."
>
> **Jerald T. Milanich**.

The most important contribution of this book is not to draw bold conclusions. Rather it is to represent a full array of relatively specific details by more than a dozen outstanding specialists. We have all attempted to integrate some major features of this considerable compilation. But it is easy to get seduced by one coincidence, or to stretch one line of reasoning into a grotesque exaggeration.

The two of us who led the Aucilla River Prehistory Project through two decades of endeavors are pleased to offer a few final ideas. But we both recognize that the results of this work must be integrated with other evidence from other regions before its full significance can be understood. New paradigms regarding the "Peopling of the Americas" are emerging, and we are convinced that this volume represents one cornerstone of that new edifice. Likewise, the lifeways of the Pleistocene megafauna are becoming more richly detailed, especially with independent data from stable isotopes. We trust that our contributions to aspects of their lives during their last few centuries will help illuminate the processes that led to their final extinction and extirpation.

Reference

Jerald T. Milanich. 1994. *Archaeology of Precolumbian Florida*, 476 pp, University Press of Florida, Gainesville, FL. (Quotation from p. 46.)

Chapter 20

Paleoindian Land Use

JAMES S. DUNBAR
Senior Archaeologist, Public Lands Archaeology, Florida Bureau of Archaeological Research
Mailing Address: R. A. Gray Bldg, 500 South Bronough Street, Tallahassee, FL 32399-0250, USA.
Street address: B. Calvin Jones Center for Archaeology, 1001 DeSoto Park Drive,
Tallahassee, FL 32301, USA.
E-Mail: jsdunbar@dos.state.fl.us, Phone: (850) 245-6307, Fax: (850) 245-6463

20.1 Introduction

The preceding presentations in Chapters 5, 15, and 18 were undertaken in order to adapt the guidelines and methodologies of the INTIMATE Group and Desert Southwest approach to a regionalized chronostratigraphic and geoclimatic model for the Southeastern US. In this concluding chapter, I explore beyond that boundary, and consider the implications of settlement options based on resource fluctuations in terms of their accessible distribution. Among the advantages of recognizing times when prehistoric options were limited in some ways while remaining abundant in others, is the opportunity to more accurately predict techno-environmental behaviors and how those behaviors might be reflected within geographic land use activity spheres.

Building on the rich record at Page-Ladson which spans some six millennia of human prehistory from latest Pleistocene into early Holocene, I attempt more accurately to understand the constraints placed on populations who lived during the various late glacial and postglacial climatic intervals. This approach is based on presumed vital

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 525–544

resource availability, but not all resources may have been vital or available. For example, potable water is a vital resource, but the fish that live in the water may not be a vital resource. Expending energy for fishing when surface water and fish are scarce is less efficient than the pursuit of other, more abundant sources of protein. Resources needed for maintenance and/or adapting a culture's techno-environmental repertoire of tools represent other candidates likely to be vital for continued exploitation during times of limited availability. In the Southeast, potable water is a vital resource of archaeological significance because its availability can expand or contract settlement options, particularly during the time of Paleoindian hunter-gatherer societies.

A study investigating the influences of water availability on large mammal communities in the semi-arid savannahs of Africa, documents game animal dispersal patterns. "The carrying capacity of the [East African savanna] country as a whole is closely related to the carrying capacity of land within 'cruising range' of the dry season water supplies" (Lamprey, 1964). Three categories of large herbivores species are recognized: (1) *migratory*, (2) *dispersal*, and (3) *resident*. Migratory and dispersal species are water-dependent (obligatory drinkers) where as resident species are water-independent and can obtain sufficient moisture from the local browse they consume. The habits of dispersal species are worth considering here. During dry times, dispersal species gradually migrate into confined range areas surrounding water holes. Their range is therefore limited by potable water. Unless there is a mass die-off during extreme conditions, predators, including human hunters, are afforded the luxury of finding their prey confined in small range areas. Conversely, following rains and the onset of the wet seasons, game animals undertake a sudden migration, dispersing from water holes to occupy a much larger, unified range (Western, 1975).

The late Pleistocene transgressions and regressions of inland water tables not only affected the availability of potable surface water, but also affected the availability of other resources. Protein resources are vital to humans and are likely to have varied through time in the proportion of upland, wetland, and underwater species exploited. Bone was another vital resource important to Paleoindian technology and was largely derived from the long bones and tusks of large Pleistocene mammals (Dunbar and Webb, 1996; Webb and Hemmings, 2001; Hemmings, 2004). The availability of lithic resources for stone tool manufacture varied inversely with that of potable water. When water tables were high, chert outcrops in lowland basins and channels were drowned and when the local water tables dropped many outcrops became exposed and were available for exploitation (Dunbar, 1981).

20.2 Old Paradigms and New Thoughts

Late Pleistocene climatic episodes in the Southeastern region should be considered within the context of two models developed to characterize Paleoindian settlement patterns in Florida. These are the "Oasis hypothesis" (Appendix Figure 5/1) (Neill, 1964) and the "River-crossing hypothesis" (Waller, 1970). In the former, Neill (1964:17–32), attempted to portray concentrations of underwater Paleoindian artifacts and Pleistocene fossils as evidence of lower water tables and limited potable water supplies. In the latter, Waller (1970:129–134) proposed that Paleoindians purposely hunted large Pleistocene animals at river fords because the animals were at a disadvantage when impeded by the water. Implicit in Neill's hypothesis is the concept of substantially lower than present water tables as opposed to Waller's hypothesis that proposes water tables were near modern levels during the late glacial recession. With the geoclimatic evidence presented in Chapter 5, it appears that both models are correct during certain climatic phases of the late glacial recession. During other climatic phases the environmental conditions fell somewhere between these extremes.

20.3 Past and Present Environments in the Lower Aucilla and Wacissa Rivers

It is obvious that the Half Mile Rise section is an emergent subterranean system. In many places along its course, large blocks of limestone attest to the roof collapses of former subterranean passages. The Half Mile Rise channel has risen to the surface as karst collapse has cut from the subsurface upward. As a result, the banks of the Half Mile Rise section are mostly vertical cliffs that descend several meters to the channel bottom. At low river stage, the limestone banks ascend 2 m or more above the modern water level. Adjacent to the Half Mile Rise section, extinct spring runs and other surface paleo-channels, such as extinct and extant sections of the Wacissa River, have incised the landscape by down-cutting. Where active and paleo-channels intersect the Half Mile Rise channel, they breached the limestone walls of the riverbank. It appears that many of the surrounding incised-surface channels had developed well before the late glacial maximum and created broad pathways leading into the Half Mile Rise channel. These pathways acted as access points in and out of the river channel for Pleistocene mega-mammals when the post-glacial maximum water table was low.

Evidence supporting this scenario occurs at the Page-Ladson (8Je591), Log Jam (8Je607), Aucilla Cove (8Je122) and Gingery Cache (8Ta99) sites in Half Mile Rise section (Fig. 20.1). All of these sites have pathway entrances as well as the remains of proboscideans. Remains of *Mammut americanum* are the more abundant and have been found, but those of *Mammuthus columbi* are also documented. Virtually all of the major fossil beds in the lower Aucilla–Wacissa basins are located in and around accessible sinkholes. Pleistocene megafauna, as well as smaller species, utilized the sinkholes when potable water was largely confined to oasis-like conditions.

In sharp contrast to the lower Aucilla River, its tributary the Wacissa River, occupies a wide, shallow karst basin having substantially fewer deep sinkholes or spring vents (Fig. 5.1). Today the Wacissa River forms a swamp-forest and partially flooded savanna-marsh environment sustained by spring discharge. The Wacissa River originates in a series of at least 18 springs (Rosenau *et al*., 1977:190–197). Located below the Cody Escarpment, in the lowland Coastal Plain, the water in the Wacissa River flows through

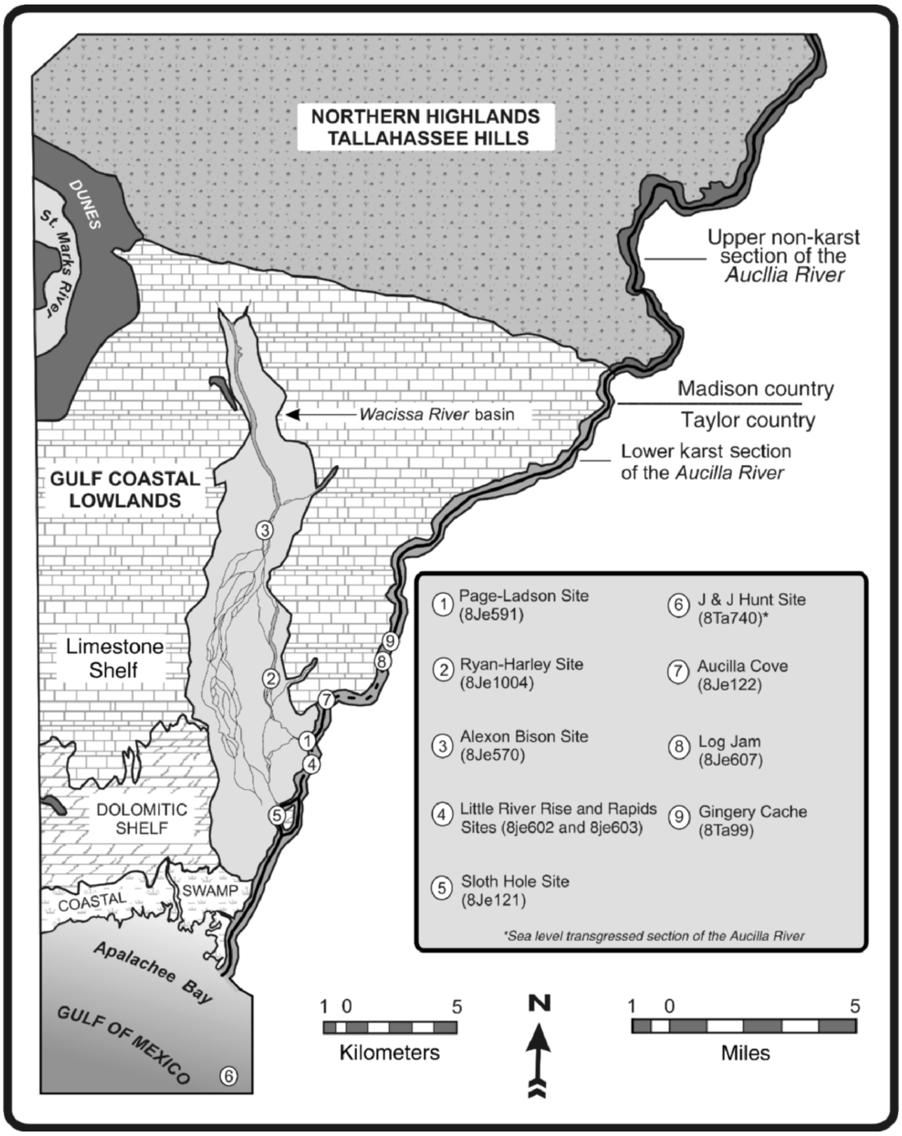


Figure 20.1 Map depicting selected site locations in the karst section of the Aucilla and Wacissa River, in Jefferson and Taylor County, Florida.

forested wetlands in a series of low energy, braided channels or through savanna wetlands as a wide shallow channel partially choked by lush, aquatic vegetation.

During the late Pleistocene, inland water levels altered the environment of the Aucilla and Wacissa River basins that also reflect episodes of resource expansion and contraction. Surface water exposures appeared or disappeared depending on precipitation. The Page-Ladson site in the Aucilla River has yielded evidence of intervals during which it was either exposed as a subaerial surface, an isolated water hole, a catch-basin intermittently refreshed by overflow from up-gradient sinkholes or a deeper segment in a through-flowing channel.

Episodes of human activity in the Page-Ladson sinkhole and adjacent banks took place primarily during low water table intervals. The first human activity at the site began possibly as early as Meltwater Pulse 1A, but clearly by the onset of the Older Dryas ~12,500 ^{14}C BP, which coincides Unit 3 deposition. Shallow pond conditions endured until the sinkhole flooded too deeply ~12,300 ^{14}C BP. The first human activity at the Page-Ladson site also coincides with a period of mega-mammal activity in the central sinkhole. The Page-Ladson site was, in fact, a water hole during the interval (Fig. 20.2). Only a few isolated artifacts were recovered from subsequent Allerød-age sediments (Unit 4) suggesting incidental human activity around the central sinkhole. The next interval of substantial human activity took place ~10,300 ^{14}C BP when water tables again markedly declined and Unit 5 deposition took place. Meltwater Pulse 1B occurred from ~10,000 ^{14}C BP to ~9,900 ^{14}C BP and, as a result, the water table declined even more radically dropping the below Unit 5 sediment column in the sinkhole. A second episode of human activity in the central sinkhole took place during and after Meltwater Pulse 1B until ~9,500 ^{14}C BP. Bolen people utilized the interior of the sinkhole conducting activity on

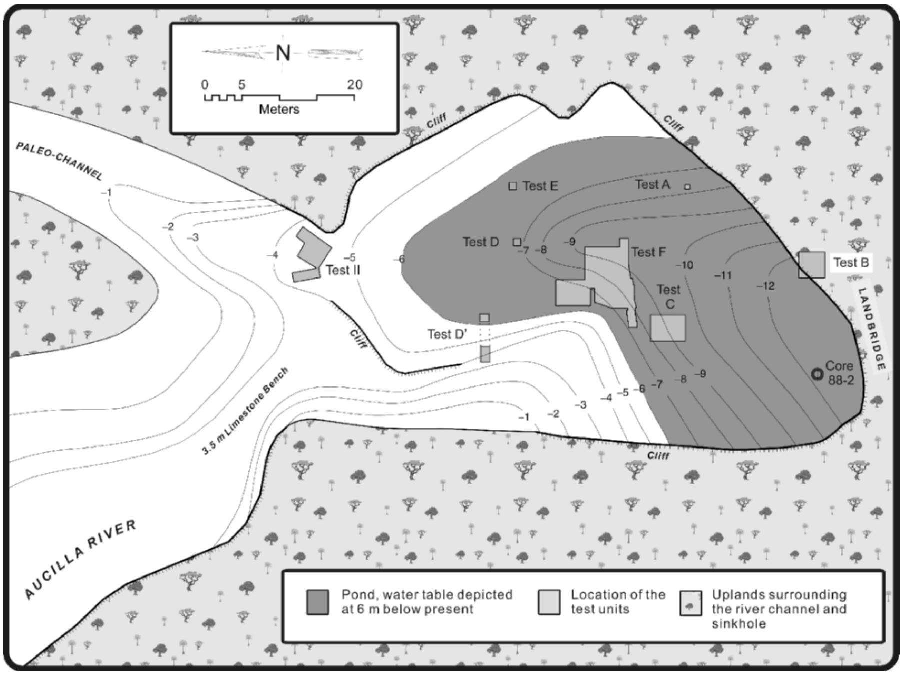


Figure 20.2 Map depicting reconstructed topographic contours and estimated water table at ~12,400 ^{14}C BP in the Page-Ladson site sinkhole. Contours are based on the elevation of Unit 3. Note that a natural land bridge spanned the southern end of the sinkhole at that time.

the Bolen surface (Unit 5 surface) and afterward when the site Unit 5 surface was again shallowly inundated. The Bolen level shelly silt (Unit 6L) was deposited after the inundation of the Bolen surface. As long as the water table remained depressed during the early Holocene, human activity continued around the sinkhole. Sites such as the Page-Ladson and Little River Rapids site were abandoned around the time that the water table rose and permanently flooded the Aucilla channel, ~8,900 ^{14}C BP.

The distribution of sites in the shallower Wacissa River provides an interesting contrast to the Page-Ladson archaeological components. The Alexon Bison and Ryan–Harley sites date to the late Allerød and Younger Dryas and were formed during time when the water table was elevated. Both are inundated sites that lie a meter or so below modern extreme low water stage of the Wacissa River (Fig. 20.1).

The Paleoindian site data from the Aucilla and Wacissa Rivers suggest that the low water table and dry conditions focused human and game animal ranges to areas surrounding consistent water supplies. Conversely, during wetter intervals and elevated water tables, site options as well as hunting ranges expanded.

20.3.1 North Florida Geographic Land Use Activity Spheres

East of the Mississippi River, it is uncommon to find preserved organic materials in Paleoindian sites and even less common within large geographic areas having multiple Paleoindian sites. A large area of the lower Aucilla and Wacissa River basins is a notable exception. Site preservation in the Aucilla–Wacissa area is good to excellent and allows geographic land use modeling based on ecological factors including changes in climatic conditions, physiographic elevations, and resource availability. These variables are reflected in a resource availability matrix as Table 20.1.

There are a number of important implications that can be extrapolated from the matrix. The geo-hydrologic setting changed substantially through time, particularly during the last Pleistocene glacial recession and the first phases of the early Holocene Preboreal. These most radical climatic changes took place during the Paleoindian and Early Archaic occupation of Florida. Thus, populations of animals and people were attempting to respond and adjusting to climatic shifts when they happened. The reprieve between changes in the climate lasting from about 100 to as many as 1000 years gave little time for dominant habitats to become established. On another level, sediment accumulations in sinkholes, including the Page-Ladson site, varied because they reflect point source stratigraphies dependent on localized source inputs, but were shaped by Pleistocene climatic events.

20.3.2 Contrast of the Southwest US

In other words the localized sediment-fills of the Southeastern US are unlike the broad, regional stratigraphies such as the analogous arroyo sequences so familiar in the Southwestern US.

Table 20.1 Resource availability matrix for North Florida late Pleistocene climate intervals

Climatic setting	*Physiographic elevations*	*Water*	*Lithic*	*Fauna*					
				Upland species (mainly mammals)		*Wetland species (variety of vertebrates and invertebrates)*		*Aquatic species (greatest variety of vertebrates and invertebrates)*	
				Dispersal	*Populace*	*Dispersal*	*Populace*	*Dispersal*	*Populace*
Dry	Steep ravines and sinkholes, karst features are largely exposed and cavernous	Oases in recessed karst features	Most abundant in quality and quantity	Range restricted to areas around deep waterholes and/or the species are migratory	Abundant, at least seasonally	Range restricted to deep karst features	Low – species potential restricted	Range restricted to deep karst features and still water habitats	Low – species potential restricted
Moderate	Intermediate ravines and sinkhole elevations due to the inundation of deeper areas	Wetlands and wet savannas	Abundant but lowest lying sources in karst features are drowned and unavailable	Spread throughout wider ranges centered around wetlands	Abundant	Range expansion into lowland shallow basins like the Wacissa	Moderate to abundant – species potential diversifies	Range restricted to karst features and still water ponds in the wetlands	Low to moderate – species potential restricted
Wet	Flat terrain, karst features mostly inundated	Flowing streams, wetlands and wet savannas	Abundant in uplands but lowland sources unavailable due to inundation	Dispersed throughout the country-side, potable water abundant	Abundant	Range expansion of lowlands most extensive	Abundant – species potential most diversified	Largest range expansion, including fluvial habitats in river basins	Moderate to abundant – species potential most diversified

C. Haynes has dedicated his professional career to developing and refining the chronostratigraphy and geoclimatic data for the Paleoindian Desert Southwest and recent proxy data apparently confirm his interpretations. The utilization of the chronostratigraphy and geoclimatic data has played a major role in the interpretation of the Southwestern Paleoindian traditions, both Clovis and Folsom.

However, there was disagreement regarding the interpretation of proxy data for the Desert Southwest (Haynes, 1971; Holliday, 1997). Haynes (Haynes, 1991; Haynes *et al*., 1999) argued that geoarchaeological data from Paleoindian sites is indicative of drought conditions during the late Allerød between ~11,500 ^{14}C BP and ~11,000 ^{14}C BP. This is the time during which late Pleistocene species such as mammoths, mastodons, camels, horses, tapirs, dire wolves, and other species became extinct in the Southwest (Haynes, 1984). Thus, not only does the Clovis drought hypothesis suggest a change to desert-like conditions, but also provides a possible explanation for a cause of species extinction or displacement to regions outside the Desert Southwest by the end of the Allerød.

In contrast, Vance Holiday (Holliday, 1997, 2000) found evidence of a different climatic change from some of the same data. He hypothesizes higher water tables, which means more abundant surface water, during the Allerød followed by a Folsom-aged drought during the Younger Dryas from ~10,900 ^{14}C BP to ~10,200 ^{14}C BP. Stratigraphic levels deposited during the Younger Dryas in the Southwest including the black mat levels found at Arizona Paleoindian sites such as Murray Springs, as well as contemporaneous diatomite levels at New Mexico and Texas Paleoindian sites such as Blackwater Draw, are evaluated under two differing assumptions about what the proxy evidence represents. Haynes (1984, 1991) interprets the data as evidence of climatic moderation and wetter conditions during the Younger Dryas, but Holliday's (2000) interpretation is contrary with the Allerød wet and the Younger Dryas dry.

The numbers of studies supporting Haynes' view for an arid Allerød followed by a wetter Younger Dryas have been increasing. For example, proxies from stable carbon and oxygen isotopes at the Aubrey Clovis site in North-Central Texas indicate the onset of dry conditions by ~12,000 ^{14}C BP and a return to wetter conditions by ~11,000 ^{14}C BP. The Aubrey site isotope data are also in agreement with the isotopic changes detected in core data from the Gulf of Mexico (Humphrey and Ferring, 1994). Another set of Southwestern proxy data comes from an alluvial sequence in Long Valley, Nevada. Here researchers (Huckleberry *et al*., 2001) are also in agreement with Haynes' Clovis Drought hypothesis:

> We believe that the Sunshine Locality [in Long Valley] records a period of increased effective moisture 9,800 to 11,000 ^{14}C BP that interrupts a period of overall drying during the deglaciation of the Northern Hemisphere. This adds to a growing list of geological evidence for a Younger Dryas affecting the western United States (Benson *et al*., 1997; Clark and Bartien, 1995). It also supports Ernst Antev's (1948) hypothesis that the Laurentide ice cap pushed the polar jet stream southward, thus diverting Pacific cyclonic storms over the Great Basin (see Miffin and Wheat, 1979; Oviatt, 1997). Interestingly, the alluvial sequence at Sunshine is remarkably similar to that approximately 400 km to the south in the southern Great Basin (Quade *et al*., 1998), suggesting a minimum latitudinal zone (36°–40° N) of enhanced moisture during the Younger Dryas in western North America (Huckleberry *et al*.:311).

The most compelling study identifies a dry period during the Allerød followed by a prolonged wet period in the Southwest during the Younger Dryas. This study is based on multiple speleothem dated by uranium-series on growth increments and interpreted by environmental growth conditions of stalagmites from New Mexico caves (Polyak *et al.*, 2004). Palynological and other proxies as well as computer models of the late glacial ocean and atmospheric circulation in the Gulf of Mexico and Western Caribbean also support the notion of a Clovis Drought followed by a wetter Folsom interval during the Younger Dryas (Grimm *et al.*, 1993; Heine, 1994; Leyden *et al.*, 1994; Watts and Hansen, 1994; Fanning and Weaver, 1997; Manabe and Stouffer, 1997).

Therefore it is within the context of Western chronostratigraphy and geoclimate that the Clovis–Folsom Paleoindian traditions are understood. However, it would be incorrect to adopt the Western, regionalized understanding of time, climate, and human colonization for a different region of the Americas because global climate shifts took place differently in different geographic regions. For example, we do not expect climatic conditions to be the same in the northern latitudes as they are in northern equatorial latitudes just because the northern hemisphere is experiencing winter. Neither should we be so broad as to project global climate changes as have taken place uniformly on a global scale because they did not.

20.4 Discussion

During dry episodes centered on Meltwater Pulse 1A and 1B, the Aucilla River basin was a deep ravine that contained the most persistent water holes. The Wacissa lowland basin is nevertheless more highly elevated and expansive compared to the narrow, rocky gorge-like channel of the Aucilla River. During dry episodes, the Wacissa held a few isolated water holes in deep spring vents such as Big Blue Springs and also had the potential to hold intermittent and perhaps seasonal perched surface ponds. Given the large grazer and browser herbivores that once occupied the area as migratory species (Koch *et al.*, 1998; Feranec and MacFadden, 2000), it is tempting to envision a mosaic of dry savannas and hammocks occupying the Wacissa basin but that landscape is unsubstantiated at this point.

Following Meltwater Pulse 1A, the water tables remained depressed throughout most of the Older Dryas. At the Page-Ladson site, Paleoindians removed the tusk from a mastodon and left behind lithic debitage. Stone projectile points of a distinctive, heretofore unclassified form, were recovered from displaced contexts at the Page-Ladson site (Fig. 14.5) and are the most likely suspects to represent a pre-Clovis or old Clovis form (Dunbar and Hemmings, 2004). One of these points appears to be manufactured from jasper originating from the Flint River basin in southern Georgia. It is the only identified Paleoindian imported artifact from the Page-Ladson site. The mastodon remains at the Page-Ladson site yielded strontium isotope ratios from a molar indicating that the animal migrated between Georgia and Florida. North-central Georgia has granitic charged water sources whereas Florida has calcium carbonate (limestone) charged water sources. Strontium isotopes within the annual growth bands of the mastodon tusk from Unit 3 at the Page-Ladson site showed that the animal's intake of water and browse originated from Georgia and Florida. This is the only evidence for long-range Proboscidean migration in the Southeast because the isotope evidence from mammoths indicates they did not migrate substantial distances and remained within the limestone range of Florida (Hoppe *et al.*, 1999:439–442). The Page-Ladson lanceolate point recovered from displaced context at the Page-Ladson site is the only, albeit uncertain, evidence of Paleoindian long-range movement and of stone tools imported from distant ranges. Paleoindian exotic import tools are otherwise unknown in Florida. The point is Clovis-like but it is not Clovis.

During periods of moderation, for instance during the early Younger Dryas, the water table was declining but deep sections of the Aucilla, such as the Page-Ladson site, experienced through-flowing water. Shallower sections of the Aucilla, such as at the Little River site, and much of the Wacissa basin were subaerially exposed. Yet the water table was sufficiently elevated and the precipitation rate adequate to support ponds and wetlands throughout the Wacissa basin. The Ryan–Harley site represents a Middle Paleoindian habitation of Suwannee point-making peoples. The site provided a rich faunal assemblage that included a mix of small and large, diurnal and nocturnal, extinct and extant, upland, wetland, and aquatic species. The only diagnostic wetland species were of the types that prefer a still water pond setting (Dunbar *et al.*, 2006).

Evidence that Suwannee people were present along the Aucilla River comes from isolated finds of diagnostic artifacts from displaced contexts. At the Page-Ladson site, a few Suwannee points were recovered from displaced contexts. In addition, a lost or discarded debitage flake from the upper part of Unit 4U is the only in-place find of suspected Middle Paleoindian age. The signature of Suwannee artifacts at the Page-Ladson site is one of the intermittent activities centered on the upland banks or shallow channel section above the sinkhole. Only an occasional loss or discard has been found in or near sinkholes.

During the periods of wet conditions such as the middle to late Allerød (~11,700 ^{14}C BP to ~11,000 ^{14}C BP), when flowing water coursed through the Aucilla and Wacissa Rivers, evidence of human activity appears to be most dispersed. In the Aucilla and Wacissa area and elsewhere in Florida, diagnostic Clovis artifacts are most frequently recovered as isolated finds. A few locations have produced more than one diagnostic artifact but few Clovis sites have been identified. Even so two important Florida Clovis sites are Sloth Hole (8Je121) in the Aucilla River and the Silver Springs site (8Mr392) overlooking the spring run (Silver River). At both sites, classic excurvate blade, Clovis fluted points and recurvate, Clovis waisted points (also fluted) have been recovered. At Sloth Hole numerous carved proboscidean ivory shafts and/or foreshafts were also recovered (Hemmings, 1999). Some bone and ivory artifacts from Florida provide insights into Clovis technology not documented elsewhere (Webb and Hemmings, 2001:6). The most unusual ivory artifact is a barbed harpoon point (Fig. 20.3)(Dunbar and Webb, 1996; Hemmings *et al.*, 2004). Such a hunting weapon suggests the exploitation of aquatic animals, including water-loving mammals such as tapirs (Webb and Hemmings, 2001) or animals that are still common in Southeastern river and pond settings such as long nosed garfish or alligators.

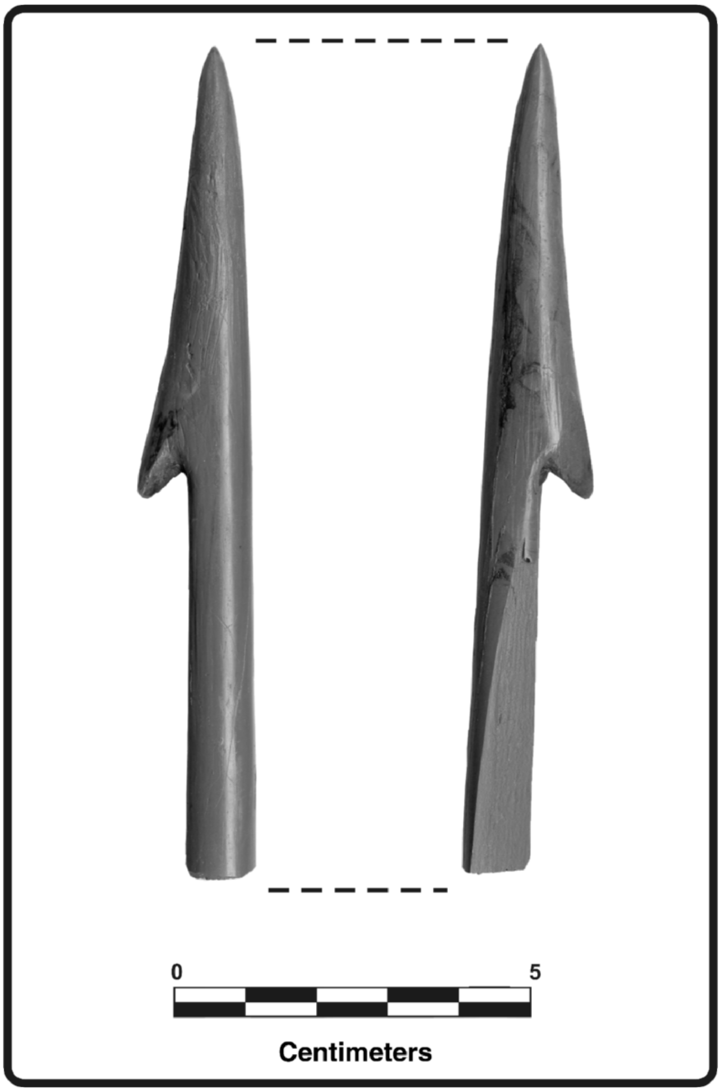


Figure 20.3 Left and right lateral views of a Proboscidean ivory barbed harpoon from the Glory Hole in the Aucilla River. The occurrences of harpoon points manufactured from late Pleistocene Proboscidean ivory tusk suggest that Paleoindian aquatic hunting was taking place. This represents one of nine different types of carved proboscidean ivory tool types documented in Florida (Hemmings, 2004; Hemmings *et al*., 2004). Photo by Aucilla River Prehistory Project.

The Alexon Bison site in the Wacissa River is Clovis age and the *Bison antiquus* cranium recovered has a fragment of a projectile point lodged in the frontal bone that snapped due to heavy impact (Webb *et al*., 1984). Numerous waisted Clovis points from Florida have heavy impact fractures on their distal ends (Dunbar and Hemmings, 2004) as do similar specimens recovered from the bison kill area of the Murray Springs Clovis site in New Mexico (Haynes, 1982).

Our understanding of Clovis peoples who lived in Florida during a wet Allerød interval remains admittedly sketchy. In part, this relates to the fact that Clovis sites and artifact finds are never abundant. Clovis points are most abundant in East of the Mississippi River (Anderson, 1996:30–37), particularly in the Southeastern US (Mason, 1962:234–235). If abundance is any indication of population density, then the potential for a much more substantial Clovis population in Florida is suggested. The Clovis population may have been dispersed throughout the countryside due to the relatively optimal climatic conditions during the Allerød.

If Clovis site scarcity represents sparsely populated, nomadic, hunter-gathers, with little potential to have developed stratified living floors containing faunal, floral, and cultural remains, it may support the assumption that Clovis represents the founding human population in the Americas. Given the chronostratigraphic evidence from the Page-Ladson, I argue that Clovis sites in Florida are elusive because climatic conditions allowed prey animals and the hunters who pursued them the opportunity to disperse and occupy much larger geographic ranges. As a result, human groups were scattered and their habitation sites dispersed. On the other hand, sites located in and along wetlands and waterways have yielded evidence of Clovis exploitation beyond the traditional notions of land-based big game hunting. Clearly, the descendants of the Clovis culture in Florida, the Middle Paleoindian Suwannee point-making peoples, exploited wetland habitats extensively even though wetland ranges were diminished. In all likelihood, continued exploitation of wetland habitats during Suwannee times is evidence of in place cultural continuity.

By ~8900 BP ^{14}C BP, the water table had rebounded once again in the Aucilla–Wacissa River basins. For a second time the rivers were reestablished fluvial environments surrounded by wetlands. Coinciding with reestablished wetland habitats, archaeological site visibility of post-Bolen, Early Archaic cultures again diminishes. I argue that the primary reason for this population dispersal was the need to expand into wider ranges to take advantage of more abundant, but dispersed resources. The Windover site in Brevard County provides evidence of such an Early Archaic culture adapted to the freshwater habitat.

In brief, it is apparent that sites of human activity during the low water table, dry Older Dryas and Preboreal oscillation phases, tend to be concentrated around sinkholes or other deep features where water was available. During the high water, wet Allerød and post-Preboreal phases, populations became more dispersed because water sources were abundant. Some Clovis sites and artifacts of Early Paleoindian age as well as sites of post-Bolen, Early Archaic age also suggest a broader range of adaptations during wet intervals or, at least, a greater variety of habitats exploited.

20.4.1 The Paradox

In Chapter 5, I argued that climate was an important aspect confronting and perhaps limiting or, at least, directing Paleoindian activity through the spectrum of dynamic and oscillating conditions reflected in Table 20.1. Attempting to identify predictable site patterns during any of the late Pleistocene climatic episodes is dependent on a better understanding of the resource options confronting the people during a given episode. Yet, to do so we must identify sites that are well preserved. Finding well-preserved Paleoindian sites has been and will continue to be a most difficult task and therein lies the paradox.

In Florida, Clovis sites appear to present the biggest challenge because optimal environmental conditions allowed for the most wide-ranging set of potential exploitive habitats. Paradoxically then, Paleoindian sites formed during dry climatic episodes are the most predictable. This leads to another point of consequence, if the pre-Clovis or, as I prefer, Old Clovis component at the Page-Ladson site is to be accepted by the followers of the Clovis First paradigm, similar sites must be identified. The signature of Old Clovis at the Page-Ladson sites is bracketed between ~12,570 ^{14}C BP and ~12,370 ^{14}C BP with a pool of seven related dates yielding an averaged age of 12,420 ± 80 on the Unit 3 artifact and faunal-bearing stratum. A second site has been identified at the Sloth Hole site in the Aucilla River where Hemmings (1999:14–16) discovered a deeply buried artifact and faunal bearing component dating 12,300 ^{14}C BP. Both sites are located in and around deep sinkholes. The good news for future research is that both Older Dryas-age Paleoindian sites (~12,500 ^{14}C BP to ~12,300 ^{14}C BP), as well as Preboreal-age Bolen sites (~10,000 ^{14}C BP to ~9,500 ^{14}C BP), are very likely to be concentrated around former water holes (oases).

20.4.2 The Possibilities

What then are the possibilities? A number of sites have been found in and around deep karst features in Florida but are not well understood. For example, the Devils Den site (8Lv84) near Williston in North-central Florida provides an interesting example. John Goggin and his students investigated this deep sinkhole site in the late 1950s and early 1960s. In 1962, 14 fluoride tests were conducted on Pleistocene faunal remains, bone artifacts, and human remains collected from a lateral cave now about 21 m below the present water table. The fluoride test results were sent to Dr. Clayton Ray, a paleontologist then at the Florida Museum of Natural History. Three of the samples were considered to be contaminated and are not considered here. The percentage of fluoride in the remaining eleven samples is provided in Table 20.2. The fluoride dating technique is limited and used as a gauge of a site's relative age. In addition, the technique used in 1962 did not employ modern techniques such as the Ion Selective Electrode to make the determination. Nevertheless, the percentage of fluoride present in the Devil's Den samples is internally consistent and also in

Table 20.2 Devil's Den report of fluoride percentage in bone specimens from chamber 3[1]

Sample ID	*Fluoride%*	*Sample type*
F-1	1.45	Bone awl
F-2	1.24	Worked bone
F-4	1.22	Human skull fragment
F-5	1.08	Peccary radioulna
F-6	1.04	Sloth right mandibular ramus
F-7	1.64	Arctothere humerus
F-8	1.30	Arctothere humerus
F-10	1.49	Deer antler, rodent gnawed
F-11	1.79	Ondatra palatal
F-12	1.40	Neofiber skull and jaw fragments
F-14	1.42	Frog humeri

[1] Analysis of August 24, 1962 by the Black Laboratories, Inc. for Clayton Ray of the Florida Museum of Natural History, Gainesville.

line with similar values documented on Pleistocene bone from the Hiscock site in New York (Tankersley *et al*., 1998:805–811).

The paleontological remains from Devils Den indicate an interesting assemblage of upland animals occupied the area around the sinkhole in an upland, park-savanna (Martin and Webb, 1974). Deep karst features are without doubt the most prevalent in North-central Florida and many have produced Paleoindian and Early Archaic artifacts: Ichetucknee, Wakulla, Rainbow, Silver, and Silver Glen Springs and others. All of these places have multiple sites recorded in and around them.

Deep Hole (8So22) represents another deep, Little Salt or Warm Mineral Springs-like site in Southwest Florida. Little is known about this site other than isolated finds of Paleoindian and Archaic artifacts have been found near the sinkhole rim. Deep Lake in Collier County is another deep sinkhole in Southwest Florida.

The Middle Paleoindian time frame presents other interesting possibilities not only because it represents the period of transition of hunting strategies, but also because many of the lowland sites promise to yield good bone preservation. The Ryan–Harley site is not alone in this category. Sites such as the Norden site (8Gi40) in the Santa Fe River basin and the Lewis-McQuinn site (8Di112) in the Suwannee River basin have yielded extinct and extant species along with abundant lithic artifacts. The Dunnigan's Old Mill site (8Gi24), also in the Santa Fe River basin, has produced a similar mix of faunal remains; however, no diagnostic stone tools have been recovered even though non-diagnostic bone and stone artifacts are associated with the early level (Dunbar *et al*., 2006; Dunbar and Vojnovski, in press).

20.4.3 Stratigraphic Complexity

Compared to Southwestern geo-stratigraphy we should not expect the Southeast to be as straightforward. Only those sedimentary basins that were both deep enough and infilling during the time of the late glacial recession will hold sequences that can be favorably compared to Page-Ladson, but uniformity of sediment types is likely not to occur since each site resides in its own unique setting within a different river basin, lowland, or upland setting. Sites in Florida that formed in shallower areas within lowland and/or wetland basins are likely to contain stratigraphic profiles that only reflect part of the story, in stratigraphic levels separated by erosional or non-depositional hiatuses. There are no equivalents to early Younger Dryas age black mats in the Southeast United States as there are in the southwest and there should not be given the differences in climatic history.

There is no substitute for undertaking controlled excavations on underwater sites. Even though the extraction of cores from Pleistocene sequences is informative, the establishment of a site's event stratigraphy cannot be accomplished without the control of formal archaeological excavation bracketed by radiometric dating. To do otherwise is too uncontrolled and too coarse-grained for accurate determination.

20.5 Conclusions

Mason (1962) was first to recognize that the largest concentration of Paleoindian artifacts in the United States occurs in the Southeast. However, the general absence of organic preservation in Southeastern late Pleistocene sites has worked against understanding both chronological depth and comparison of data sets with adjoining regions such as the Southwestern US. As a result, the Southeastern archaeological literature is dominated by Paleoindian stone tool analyses (see for example Goodyear, 1974, 1983; Daniel and Wisenbaker, 1987; Ellis and Lothrop, 1989; Callahan, 1996) that provide little opportunity to comprehensively test existing hypothesis, revise them, or to established new ones. Southeastern sites located in wetland, inundated, and karst settings are now beginning to broaden our understanding of Paleoindians of the Southeast.

The first advances towards the understanding the evolution of climate during the late Pleistocene were derived from palynological investigations of sediment cores derived from Southeastern lakes and other wet site settings containing organic preservation (Watts, 1969; Delcourt and Delcourt, 1977; Watts and Hansen, 1994). These cores not only provide a pollen record, but also provide the organic samples necessary for radiocarbon dating. Palynological studies derived from coring provide a general view of botanical change through time. The palynological study conducted by Hanson (Chapter 6) and Newsom (Chapter 7) at the Page-Ladson site provides a fine-grained view of botanical change by employing the use of samples collected from controlled excavation. Thus, the simultaneous increase of charcoal and artifacts in both the Early Paleoindian I (Chapter 15 at 12,425 ± 32 ^{14}C BP $n = 7$) and Bolen (Chapter 18 at 9,959 ± 38 ^{14}C BP $n = 4$) components at the Page-Ladson site is in agreement with the other data indicating the water table was substantially below present during those times. There is direct and indirect evidence that human activity took place on and directly adjacent to the central sinkhole floor at the Page-Ladson site during these intervals.

As I discussed in Chapter 14, Kathryn Hoppe's research related to mammoth migration patterns in the Southeastern and Southwestern US (Hoppe *et al.*, 1999; Hoppe, 2004; Hoppe and Koch, Chapter 13) supports the notion of an extended, continuing, and purposeful Clovis procurement strategy. It does not support the concepts of rapid overkill (Martin, 1967) or general foraging that primarily excluded the procurement of megafauna (Meltzer and Smith, 1986; Meltzer, 1988).

Perhaps the most important implication of Hoppe's findings relates to Paleoindian procurement strategy. If mammoths did not undertake long-range migrations similar to African elephants, then the notion that Paleoindians followed migratory herds of mammoths over long distances is also not true. Therefore, a hypothesis for this procurement strategy might be as follows:

Among the stimuli leading to Paleoindian migrations was a factor that developed after one or more primary procurement targets, for example, mammoth, mastodon, and horse, were depleted from the range or territory being exploited. The impetus for this type migration was not instantaneous and took time to develop. Paleoindians did not follow herd animals; they identified unexploited resource-rich areas and migrated to them. They moved to new ranges populated by a full or nearly full array of vital resources. Resources that included preferred target animals of various sizes including megafauna, because some species of megafauna represented a vital resource to Paleoindians. This strategy provides an alternative for the need to adapt to a diminished selection of in place resources. It is also a strategy that could be practiced as long as megafauna resources were available in unexploited or replenished nearby ranges and human population pressures (such as territorial competition) did not restrict human movement into a territory. This hypothesis also allows for the possibility that Paleoindians, in this instance Clovis, originated from an earlier center of population, and eventually migrated from that center thereby leaving along the way a distinctive techno-environmental repertoire of material culture. In all likelihood the epicenter of Clovis dispersal began in the Southeast United States.

Recently, archaeological sites such as the inundated and wetland sites of the Aucilla and Wacissa River basins (Fig. 20.1), including the keystone site Page-Ladson, and sites located in karst features such as Dust Cave in Alabama (Fig. 6.1), have begun to broaden our understanding of Paleoindian life ways in the Southeastern US. These sites provide enhanced evidence because organic specimens, primarily bone, are preserved. Inundated environments, like that in the Page-Ladson sinkhole, provide outstanding preservation of botanical and occasionally soft tissue remains.

The Page-Ladson site provides evidence of episodes of global climatic shifts, on par with the world-class status given to the palynological site at Lake Tulane in South Florida (Grimm *et al.*, 1993; Watts and Hanson, 1994; Watts *et al.*, 1996). The site has also yielded evidence of human utilization from ~12,400 ^{14}C BP to ~9,500 ^{14}C BP. Other Paleoindian sites in the Aucilla-Wacissa basins have produced significant contributions to our understanding of Paleoindian life ways. For example, the first direct evidence of Paleoindian big game hunting in Florida at the Alexon Kill site (8Je570) (Webb *et al.*, 1984); the first Middle Paleoindian camp site with preserved faunal remains, and therefore subsistence evidence, at the Ryan–Harley site

(8Je1004) (Dunbar *et al.*, in press); and a Clovis site that has yielded the single largest concentration of carved ivory artifacts in North America at Sloth Hole (8Je121) (Hemmings, 1999).

Utilization of the chronostratigraphic–geoclimatic approach first employed by Southwestern archaeologists provided the methodology to develop a regional evaluation for the Southeast. The addition of the INTIMATE Group guidelines (Lowe *et al.*, 2001) to this methodological approach allowed the Southeastern chronostratigraphy and geoclimatic data to be understood within the context of late Pleistocene global climate change. Findings at the Page-Ladson site determined that the Southeastern regional data do fit within the global context of climate change, but the regional change between the Southeast and Southwest differed greatly. Within this framework of time, stratigraphy, and environment came the opportunity to develop the human resource matrix presented above. This matrix is a preliminary model that will be elaborated as more sites are investigated via multidisciplinary means and are thus developed: thereby refining our knowledge of paleoenvironment, ancient peoples, and their shifting cultural development.

References

Anderson, D. G. 1996. Models of Paleoindian and Early Archaic Settlement in the Lower Southeast. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 29–57. University of Alabama Press, Tuscaloosa, AL.

Callahan, E. 1996. *The Basics of Biface Knapping in the Eastern Fluted Point Tradition a Manual for Flintknappers and Lithic Analysts*. 3rd edition. Piltdown Productions, Lynchburg, VA.

Daniel, I. R., and M. Wisenbaker. 1987. *Harney Flats: A Florida Paleo-indian Site*. Baywood Publishing Co., Farmingdale, NY.

Delcourt, P. A., and H. R. Delcourt. 1977. The Tunica Hills, Louisiana–Mississippi: Late Glacial Locality for Spruce and Deciduous Forest Species. *Quaternary Research*, 7:218–237.

Dunbar, J. S. 1981. The Effect of Geohydrology and Natural Resource Availability on Site Utilization at the Fowler Bridge Mastodon Site (8Hi383c/Uw) in Hillsborough County, Florida. *Report of Phase II Underwater Archaeological Testing at the Fowler Bridge Mastodon Site (8Hi393c/Uw) Hillsborough County, Florida*, editors J. Palmer, J. S. Dunbar, and D. H. Clayton, pp. 63–106. The Department of State, Tallahassee, FL.

Dunbar, J. S., and C. A. Hemmings. 2004. Florida Paleoindian Points and Knives. *New Perspectives on the First Americans*, editors B. T. Lepper, and R. Bonnichsen, pp. 65–72. Center for the Study of the First Americans, Texas A&M University Press, College Station, TX.

Dunbar, J. S., C. A. Hemmings, P. K. Vojnovski, S. D. Webb, and W. Stanton. 2006. The Ryan/Harley Site 8Je1004: A Suwannee Point Site in The Wacissa River, North Florida. *Paleoamerican Prehistory: Colonization Models, Biological Populations, and Human Adaptations*. College Station, TX, Center for the Study of the First Americans, Texas A & M University.

Dunbar, J. S., and S. D. Webb. 1996. Bone and Ivory Tools from Submerged Paleoindian Sites in Florida. *The Paleoindian and Early Archaic Southeast*, editors D. G. Anderson, and K. E. Sassaman, pp. 331–353. University of Alabama Press, Tuscaloosa, AL.

Ellis, C. J., and J. C. Lothrop. 1989. *Eastern Paleoindian Lithic Resource Use*. Westview Press, Boulder, CO.

Fanning, A. F., and A. J. Weaver. 1997. Temporal-Geographical Meltwater Influences on the North Atlantic Conveyor: Implications for the Younger Dryas. *Paleoceanography*, 12 (2):307–320.

Feranec, R. S., and B. J. MacFadden. 2000. Evolution of the Grazing Niche in Pleistocene Mammals from Florida: Evidence from Stable Isotopes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 162:155–169.

Goodyear, A. C. 1974. The Brand Site: A Techno-functional Study of a Dalton Site in Northeast Arkansas. *Publications on Archeology: Research Series*; No. 7, pp. 113–118. Arkansas Archeological Survey, Fayetteville, AK.

——. 1983. A Hypothesis for the Use of Crytocrystalline Raw Materials Among Paleoindian Groups of North America. *Eastern Paleoindian Lithic Resource Use*, editors C. J. Ellis, and J. C. Lothrop, pp. 1–9. Westview Press, Boulder, San Francisco, CA.

Grimm, E. C., G. L. Jacobson, W. A. Watts, B. C. S. Hansen, and K. A. Maasch. 1993. A 50,000-year Record of Climate Oscillations from Florida and Its Temporal Correlation with the Heinrich Events. *Science*, 261 (5118):198–200.

Haynes, C. V. 1971. Time, Environment, and Early Man. *Arctic Anthropology*, 8 (2):3–14.

——. 1982. Were Clovis Progenitors in Beringia. *Paleoecology of Beringia*, editors D. Hopkins, J. Matthews, C. Schweger, and S. Young. Academic Press, New York, NY.

——. 1984. Stratigraphy and Late Pleistocene Extinction in the United States. *Quaternary Extinctions: A Prehistoric Revolution*, editor P. M. Martin, and R. G. Klein, pp. 345–353. University of Arizona Press, Tucson, AZ.

——. 1991. Geoarchaeological and Paleohydrological Evidence for a Clovis-Age Drought in North America and its Bearing on Extinction. *Quaternary Research*, 35:438–450.

Haynes, C. V., D. J. Stanford, M. Jordy, J. Dickenson, J. L. Montgomery, P. H. Shelley, I. Rovner, and G. A. Agogino. 1999. A Clovis Well at the Type Site 11,500 B.C.: The Oldest Prehistoric Well in America. *Geoarchaeology*, 14 (5):455–470.

Heine, K. 1994. The Late-Glacial Moraine Sequences in Mexico: Is There Evidence for the Younger Dryas Event? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 112:113–123.

Hemmings, C. A. 1999. *The Paleoindian and Early Archaic Tools of Sloth Hole (8Je121): An Inundated Site in the Lower Aucilla River, Jefferson County, Florida.* Masters Thesis, Department of Anthropology, University of Florida, Gainesville, FL.

——. 2004. *The Organic Clovis: A Single Continent-Wide Cultural Adaptation*. University of Florida, Department of Anthropology, University of Florida, Gainesville, FL.

Hemmings, C. A., J. S. Dunbar, and S. D. Webb. 2004. Florida's Early-Paleoindian Bone and Ivory Tools. *New Perspectives on the First Americans*, editors B. A. Bradley, and R. Bonnichsen, pp. 87–92. Center for the Study of the First Americans, Texas A&M University Press, College Station, TX.

Holliday, V. T. 1997. *Paleoindian Geoarchaeology of the Southern High Plains.* University of Texas Press, Austin, TX.

——. 2000a. Folsom Drought and Episodic Drying on the Southern High Plains From 10,900–10,200 14C Yr B.P. *Quaternary Research*, 53:1–12.

Hoppe, K. A. 2004. Late Pleistocene Mammoth Herd Structure, Migration Patterns, and Clovis Hunting Strategies Inferred from Isotopic Analyses of Multiple Death Assemblages. *Paleobiology*, 30 (1):129–145.

Hoppe, K. A., P. L. Koch, R. W. Carlson, and S. D. Webb. 1999. Tracking Mammoths and Mastodons: Reconstruction of Migratory Behavior Using Strontium Isotope Ratios. *Geology*, 27 (5):439–442.

Huckleberry, G., C. Beck, G. T. Jones, A. Holmes, M. Cannon, S. Livingston, and J. M. Broughton. 2001. Terminal Pleistocene–Early Holocene Environmental Change at the Sunshine Locality, North-Central Nevada, USA. *Quaternary Research*, 55:303–312.

Humphrey, J. D., and C. R. Ferring. 1994. Stable Isotopic Evidence for Latest Pleistocene and Holocene Climatic Change in North-Central Texas. *Quaternary Research*, 41 (2):200–213.

Koch, P. L., K. A. Hoppe, and S. D. Webb. 1998. The Isotopic Ecology of Late Pleistocene Mammals in North America Part 1. Florida. *Chemical Geology*, 152 (1–2):119–138.

Lamprey, H. F. 1964. Estimation of the Large Mammal Densities, Biomass and Energy Exchange in the Tarangire Game Reserve and the Masai Steppe in Tanzania. *Journal of East African Wildlife*, 2:1–46.

Leyden, B. W., M Brenner, D. A. Hodell, and J. H. Curtis. 1994. Orbital and Internal Forcing of Climate on the Yucatan Peninsula for the Past Ca. 36 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 109:193–210.

Lowe, J. J., W. Z. Hoek, and the INTIMATE Group. 2001. Inter-regional Correlation of Plaeoclimate Records for the Last Glacial–Interglacial Transition: A Protocol for Improved Precision Recommended by the INTIMATE Project Group. *Quaternary Science Reviews*, 20:1175–1187.

Manabe, S., and R. J. Stouffer. 1997. Coupled Ocean-Atmosphere Model Response to Freshwater Input: Comparison to Younger Dryas Event. *Paleoceanography*, 12 (2):321–336.

Martin, P. S. 1967. Prehistoric Overkill. *Pleistocene Extinctions: The Search for a Cause*, editors P. S. Martin, and H. E. Wright, pp. 75–120. Yale University Press, New Haven, CN.

Martin, R. A., and S. D. Webb. 1974. Late Pleistocene Mammals from the Devil's Den Fauna, Levy County. *Pleistocene Mammals of Florida*, editor S. D. Webb, pp. 114–148. The University Presses of Florida, Gainesville, FL.

Mason, R. J. 1962. The Paleo-Indian Tradition in Eastern North America. *Current Anthropology*, 3 (3):227–246.

Meltzer, D. J. 1988. Late Pleistocene Human Adaptations in Eastern North America. *Journal of World Prehistory*, 2 (1):1–51.

Meltzer, D. J., and B. D. Smith 1986. Paleoindian and Early Archaic Subsistence Strategies in Eastern North America. *Foraging, Collecting, and Harvesting: Archaic Period Subsistence and Settlement in the Eastern Woodlands*. Center for Archaeological Investigations Occasional Paper No. 6:3–31.

Neill, W. T. 1964. The Association of Suwannee Points and Extinct Animals in Florida. *Florida Anthropologist*, 17:17–32.

Polyak, V. J., J. Rasmussen, and Y. Asmerom. 2004. Prolonged Wet Period in the Southwest United States Through the Younger Dryas. *Geology*, 32 (1):5–8.

Rosenau, J. C., G. L. Faulkner, C. W. Hendry Jr., and R. W. Hull. 1977. Springs of Florida. *Bulletin No. 31 Revised.* Florida Geological Survey, Tallahassee, FL.

Tankersley, K. B., K. D. Schlecht, and R. S. Laub. 1998. Fluoride Dating of Mastodon Bone from an Early Paleoindian Spring Site. *Journal of Archaeological Science*, 25 (8):805–811.

Vojnovski, P. K., and J. S. Dunbar. In press. Early Floridians and Late Mega-Mammals: Some Technological and Dietary Evidence from Four North Florida Paleoindian Sites. *Foragers of the Terminal Pleistocene*, editors R. B. Walker, and B. N. Driskell. University of Nebraska Press, Lincoln, NE.

Waller, B. I. 1970. Some Occurrences of Paleo-Indian Projectile Points in Florida Waters *Florida Anthropologist* 23 (4):129–134.

Watts, W. A. 1969. A Pollen Diagram From Mud Lake, Marion County, North-Central Florida. *Geological Society of America Bulletin*, 80:631–642.

Watts, W. A., and B. C. S. Hansen. 1994. Pre-Holocene and Holocene Pollen Records of Vegetation History from the Florida Peninsula and Their Climatic Implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 109:163–176.

Watts, W., E. C. Grimm, and T. C. Hussey. 1996. Mid-Holocene Forest History of Florida and the Coastal Plain of Georgia and South Carolina. *Archaeology of the Mid-Holocene Southeast*, editors K. E. Sassaman, and D. G. Anderson, pp. 28–40. University Press of Florida, Gainesville, FL.

Webb, S. D., and C. A. Hemmings. 2001. Ivory and Bone Tools from Late Pleistocene Deposits in the Aucilla and Wacissa River, North-Central Florida. *Enduring Records: The Environmental and Cultural Heritage of Wetlands*, editor B. A. Purdy, pp. 1–8. Oxbow Books, Oxford, England, UK.

Webb, S. D., J. T. Milanich, R. Alexon, and J. S. Dunbar. 1984. A *Bison antiquus* Kill Site, Wacissa River, Jefferson County, Florida. *American Antiquity*, 49:384–392.

Western, D. 1975. Water Availability and its Influence on the Structure and Dynamics of a Savannah Large Mammal Community. *Journal of East African Wildlife*, 13:265–286.

Chapter 21

Conclusions

S. DAVID WEBB
Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, USA.

21.1 Introduction

In attempting to summarize the work of two dozen scholars and more than a hundred volunteers over a period exceeding two decades, the best strategy must be to simplify these final thoughts. I will offer a selected set of conclusions in what I hope will be a broad overview. The only danger in this light approach is that I must surely pass over many of the most critical details. For that reason, of course, the serious reader must return to the substance of the preceding chapters.

I shall marshal these concluding statements in much the same manner as the book is organized. Thus the order of topics will move from methodology to geological background, to the sequence of ancient vegetation and environments seen by two eminent paleobotanists. Then we come to the two multidisciplinary sets of contributions featuring first the Late Pleistocene and secondly the Early Holocene. At the very end I will predict some of the major directions in which this work will lead, and suggest some of the next challenges that will surely reward future researchers who choose to continue this unfinished work.

21.2 Methodological Conclusions

Initially, organizational aspects of the Aucilla River Prehistory Project (ARPP) consumed most of the efforts of the founding group. An important component of the

S. David Webb (ed.), First Floridians and Last Mastodons: The Page-Ladson Site in the Aucilla River, 545–551

methodology and conceptualization of goals originated with amateur SCUBA divers. They brought to the ARPP more field experience and underwater manpower than the small cadre of professional personnel that the State of Florida could muster. This early pattern of professional and amateur collaboration gave a sound basis for ARPP's growth and popular support during the succeeding decades.

The success of underwater exploration during ARPP's early field seasons was generally proportional to the clarity of the water. When we were in an exploration mode, as was typical in our early years, summer rains brought devastating loads of dark tannic water. We learned to compromise between the greater comfort and personnel availability of summer months and the clearer visibility of the cooler spring and fall months. After the fourth year, excavations at the Page-Ladson site had become ARPP's primary objective, both because of its long, nearly continuous stratigraphy and because of its productivity of fossils and artifacts. With a fixed locus of well-mapped bottom topography, water conditions became less crucial, although ARPP still utilized clearwater seasons to extend exploration of diverse sites.

As grants and private funds increased, ARPP was able to improve the diversity and sophistication of its equipment. Likewise each season saw innovations and improvements as more experienced crews continued to develop better procedures. The constant goal, increasingly realized, was to conduct SCUBA excavations, even in poor visibility, with the same precision as sound archaeological excavations on the land. A major step forward was acquisition of an excellent system for underwater videography, providing faithful site data and authentic procedural records. ARPP was then able to invite collaborators in such specialized disciplines as palynology and soil chemistry to study the evidence retrieved from the bottom.

The motto of ARPP, faithfully recited for each new group of participants, was: "We steadfastly seek the three S's". These were "Safety first; then science; and thirdly 'smelling the roses' ". ARPP proudly concludes that these goals were met by more than a hundred participants over a period of two decades.

21.3 Geological Conclusions

Two outstanding features of the lower Aucilla River region are its lowland karst geomorphology and the rich outflowing of the Floridian Aquifer that sustains its many springs, rivers, and swamps. The success of the ARPP depends directly on this region's long history of eroding and filling numerous vertical sinkholes. Especially during the Pleistocene Period eustatic sealevel cycles strongly affected Florida's Gulf Coastal Lowlands.

The most fortuitous feature of the sinkhole that makes up the Page-Ladson site is that it experienced nearly continuous deposition during the latest Pleistocene and earliest Holocene. And because its sediments consist mostly of fine-grained organic sediments, it yields a nearly continuous string of credible carbon dates. Nearly 8000 years of prehistory are recorded in some detail within several vertical sections that span over 8 m, a rate averaging about 1 mm per year.

This stack of strata with nearly 50 carbon dates scattered through it provides the possibility of correlating local depositional history and inferred local climatic history with North Atlantic and even global pleniglacial climatic episodes. Surely some of these preliminary findings will be modified, but the Page-Ladson site provides one of the fullest such records in Florida. At this site two of the richest records, in terms of fauna, flora, and artifacts, occur in Unit 3 at 12,600 ^{14}C BP and at the upper surface of Unit 5 at 10,000 ^{14}C BP. Both represent relatively arid episodes and both can now be correlated with extreme climatic cooling episodes in the eastern Gulf of Mexico. Known as Meltwater Pulses 1A and 1B, respectively, these episodes featured vast amounts of meltwater (estimated at six times historical volumes) being diverted down the Mississippi River because the St. Lawrence Seaway and Hudson Bay drainages were blocked by parts of the Laurentide ice sheets.

21.4 Paleobotanical Conclusions

Two botanical approaches give a more regional palynological perspective and, from the same strata, a local macrobotanical view of the vegetation surrounding Page-Ladson sinkhole. Mesic hardwoods with swamp cypress at water's edge appear much like the present pristine vegetation in the area. During the Meltwater Pulses 1A and 1B, however, ragweed, grasses, and other indicators of more arid conditions with more open landscapes appeared. The macroscopic samples include wood, seeds, bark, leaves, and fruit rinds. The microscopic samples also yield quantitative estimates of fine charcoal abundance in two size fractions, a pioneering approach with implications about climate and human environmental impact. A third, most intriguing paleobotanical contribution emerged fortuitously when the ARPP team recognized that a major component of Late Pleistocene Unit 3 consisted of digesta of *Mammut americanum*, the American Mastodon. These digesta record a very rich menu, including the oldest known evidence of gourds (*Cucurbita pepo*).

21.5 Late Pleistocene Conclusions

Unit 3 in the Page-Ladson stratigraphic sequence records a particularly critical sample of fauna, flora and human cultural evidence in a well-dated context. Such associated records are extremely rare in eastern North America. The paucity of strong faunal and cultural associations, mainly by default, has given some credence to the idea that Paleoindians in the east were less committed as large-game hunters than in the west. Thus, one of the most important conclusions drawn from the megafaunal and Paleoindian association at Page-Ladson is that the first Floridians were hunters of megafauna. And, quite possibly, as a further inference, we now suspect that such associations would be far more common if there were more sites in eastern North America with better bone preservation (Anderson and Sassaman, 1996). The essential data from Page-Ladson are restored in a scene developed by the National Geographic Magazine, and reprinted here with kind permission. The date of Unit 3, as calibrated, is between 14,000 and 15,000 years ago.

Other studies of the Late Pleistocene treat both the molluscan fauna and the vertebrate fauna, each of which includes distinct terrestrial and aquatic components. The butchered tusk of an American Mastodon is considered in two chapters, one to establish its context and identity, and another extraordinarily penetrating investigation of its life history based on dentinal growth patterns and stable isotopes. The volumes of digesta of this same species are detailed, shedding vast new light on its browsing diet. The digesta also preserve steroids and epithelial cells of *Mammut*. Strontium isotopic studies shows that *Mammut* migrated to granitic terrain, returning to Florida in summer or early fall, as suggested by the ripe grapes and other fruits in their digesta. Carbon isotopic studies of seven megafaunal species illuminate the feeding ecology of each and also help clarify the discussion of why so many large herbivores vanished toward the end of the Pleistocene.

21.6 Early Holocene Conclusions

The richest single stratum in the Page-Ladson turned out to be the upper surface of stratigraphic Unit 5, excavated within the west bank of the Aucilla River in Test F and Test C. At that time, about 10,000 ^{14}C BP, the water in the Page-Ladson sinkhole had ceased to rise. Over a period of a century or two the upper margin of the sinkhole was occasionally occupied by a band of people recognized by their characteristic lithic tools as the Bolen culture. The loss of megafauna, including *Bison* in Florida, perhaps a millenium earlier, gives no evidence of having diminished the success and population levels of prehistoric humans. Indeed, to judge from the local record, they appear to have broadened their range of adaptations and to have augmented the density of their populations. The shift to corner- and side-notched spear points may reflect a change in hunting patterns with emphasis on *Odocoileus virginianus* (white-tailed deer). They left dimple stones of unknown use. For the first time in the Florida record there are adzes of various sizes and wedges, presumably associated with the abundance of worked wood pieces including a large, partly hewn cypress log. Pollen analyses revealed a very high incidence of charcoal. One of the two hearths on the "Bolen surface" contained a large piece of charcoal. Besides the many bones of aquatic fishes and turtles, there were charred remains of a box turtle. A partial deer cranium probably served as a cup or ladle with a carefully trimmed antler as its handle.

The Bolen people frequented the margins of the Page-Ladson sinkhole during an interval of increased aridity and disturbance of the surrounding landscape. This time coincides with voluminous flooding of glacial meltwater down the Mississippi River system and into the western Gulf of Mexico. This is the second such episode, and is known as Meltwater Pulse 1B. The apparent concentration of human activities around the Page-Ladson sinkhole, both in the time of early Paleoindians and in the time of the Bolen culture, tends to support the "Oasis Hypothesis" at least during times of increased aridity.

Subsequently the water table rose gently, depositing Unit 6. Its lowest member is a thin, shelly silt deposit rich in siliceous forms of life. Fortunately this deposit helped preserve and illuminate the material on the Bolen Surface. People continued to live near the Page-Ladson sinkhole, as indicated by a few later lithic tools, and intriguingly, by vertical wooden stakes, representing some architectural feature, driven into the underlying sediments of Unit 6L and the upper part of Unit 5.

Thereafter, the regular accumulation of sediments in the Page-Ladson site ceased. The Aucilla River began to flow. It began to erode surface limestone ridges between sinkholes, and it also undermined limestone land bridges, as evidenced by their collapsed remnants in the mid-Holocene river deposits. Even today the river has not completed its maturation to a continuous surface flow. Half-Mile Rise, where the Page-Ladson site exists, is an excellent example of a stretch of the river that rises and then sinks again. The Aucilla River's immature stage of development helps explain why the ancient sinkhole sediments that constitute the Page-Ladson site have only partly eroded.

21.7 Future Research Potential

The title of this book champions the status of the Page-Ladson site as the best evidence in eastern North America of interaction between early Paleoindians and extinct megafauna. This site is one of the best-dated late Quaternary stratigraphic sections in the southeast, and ranges from a very early Paleoindian level near the bottom, up through an early Archaic level near the top.

In this book we have endeavored primarily to place on record the wealth of new data from diverse disciplines that this 20-year project has yielded. We have largely avoided entering the fray surrounding some of the broader issues such as the peopling of the Americas and the extinction of the megafauna. We do not wish to imply that the foregoing data are irrelevant to, nor that we are indifferent to such grand concerns. It is only a comment on the scope of this book.

With regard to Late Pleistocene interactions of early Paleoindians with extinct megafauna, we offer the Page-Ladson evidence as a strong indication that such interactions were far more extensive in eastern North America than many scholars have been willing to concede. The paucity of evidence in the east has allowed some to postulate a fundamentally different mode of subsistence than in the west. Yet, the present studies, documenting major proboscidean hunting and ivory tools, bring the east more nearly into line with the west, and suggest that the principle distinction of the Paleoindian record in eastern North America has been the near absence of adequate bone preservation.

We also suggest a more optimistic prospectus concerning the diversity of taxa utilized by Paleoindian hunters not only in eastern, but also in western North America.

One frequently reads in the summary literature that only *Mammuthus* was killed, and very rarely (twice, by some recent accounts) *Mammut*. This hard line must surely give way to a more comprehensive understanding of the broad menu that Paleoindians sometimes provided themselves. In the west, for example, it is unreasonable for skeptics to insist that the evidence for occasional utilization of *Camelops* should resemble the massive wasting of a western *Bison* herd. In several Aucilla River sites, including Page-Ladson, gentle underwater preservation conserves details and associations that implicate Paleoindians as butcherers of many large mammals and also giant tortoises.

This is not a plea for lowering the standards of evidence. Much more work is needed at favorable sites, especially undisturbed wet sites. As in any scientific enterprise, replicate studies will either strengthen or weaken the kind of findings presented above. We also note that many older studies of probable associations between Paleoindians and megafauna have been cast aside prematurely rather than probed more deeply.

A related study, still in its infancy, concerns the methods of Paleoindian hunting in the New World. In general we suspect that the efficacy of Paleoindian hunting methods has been underestimated. The first requirement in order to delve more deeply into this subject is to excavate more extensively in favorable sites. Fluted points must be followed into some broader contexts including non-lithic technology and bones or other evidence of prey handling. The diversity of ivory tools, including atlatl hooks of ivory and bone, in Florida wet sites adds another dimension to the classic Clovis toolkit. It leads back perhaps to the richer diversity of hunting sites and cave art of Paleolithic people in Eurasia.

Future studies of Paleoindian hunting may also emulate Eurasian work by considering hunting strategies as fully as they consider hunting tools. It is quite clear that Paleoindians adapted to their particular quarry, season, and environment. In arctic and high temperate latitudes of North America they clearly concentrated at times on wooly mammoth. At other times in northeastern United States they keyed on migrating caribou. Elsewhere they learned to hunt *Mammuthus columbi* or *Mammut americanum*. The southward migration of *Mammut* into Florida during the summer surely entered into the planning of those early Paleoindians who butchered them for their ivory, their meat, and who knows how many other valuable resources. If *Canis familiaris* entered the New World with *Homo sapiens* then clearly one must consider added dimensions of tracking and ambushing techniques. Fire hunting is another strategic possibility, especially in arid settings or even in the southeastern United States during arid climatic intervals. With much effort and some serendipity, large-scale analyses of more Late Pleistocene hunting sites will illuminate some of these issues.

And finally the new evidence of early Paleoindian culture in association with *Mammut* and other megafauna some 14,000 years ago in north Florida warrants serious consideration as scholars seek a new paradigm of the "Peopling of the Americas". If the first Americans came from Asia via some northern route, then these dates, approximately a millenium earlier than the classic Clovis sites in the southwest, suggest that immigrants may have turned east before they turned west. They evidently butchered *Mammut americanum* in eastern woodlands before they butchered *Mammuthus columbi* in the southwest. If, on the other hand, the first Americans crossed the north Atlantic as emigrants from Solutrean sources in western Europe then Florida's ivory industry and atlatl practice will become more directly relevant in transatlantic comparisons (Bradley and Stanford, 2004).

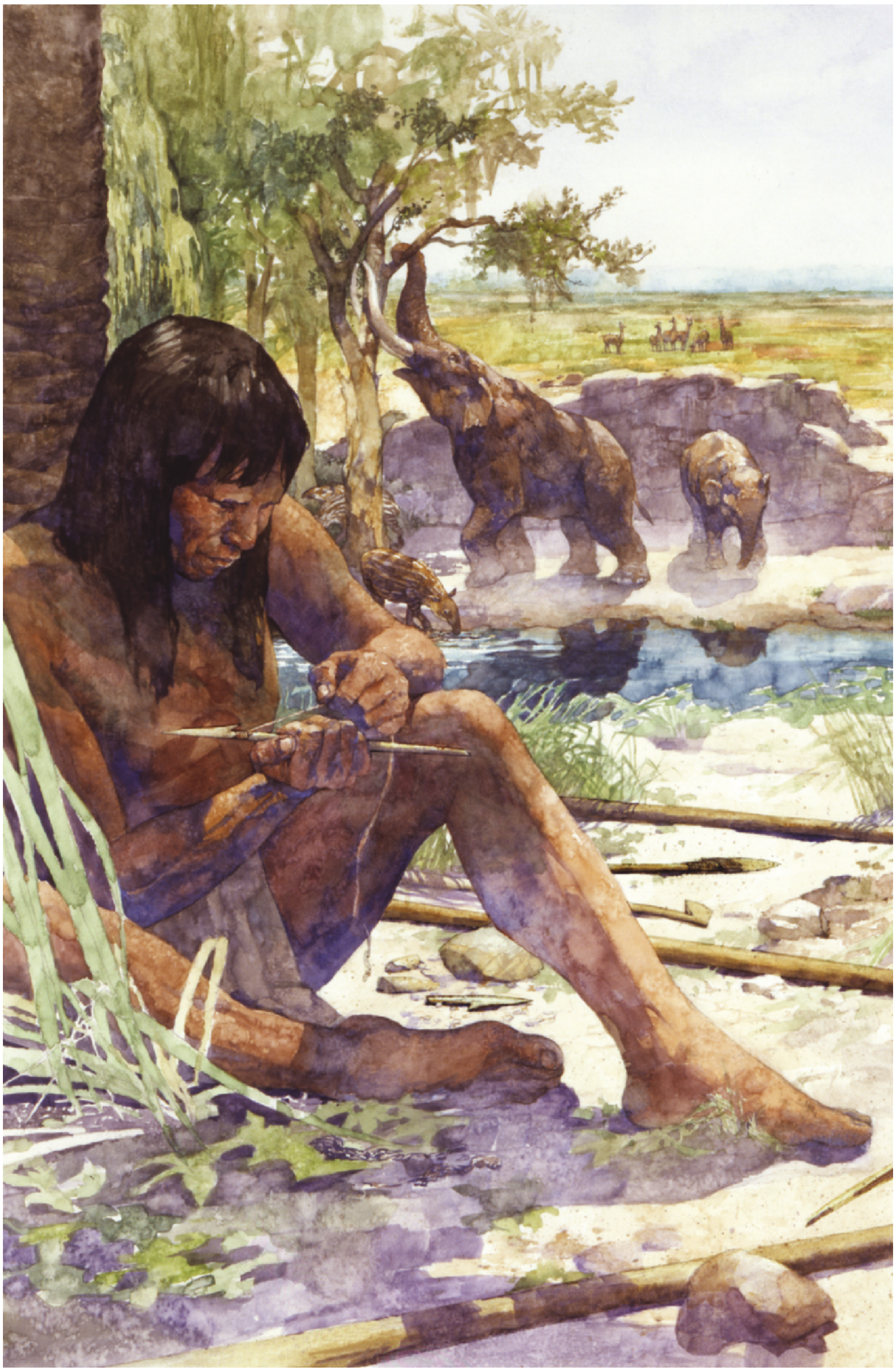
In a dark hole in the bottom of a landlocked stretch of swampy river, a small group of professional and amateur SCUBA excavators developed the Page-Ladson site. Most of our findings were wholly unexpected. Some discoveries were not well enough understood at first, our first hearth, for example. We turned our frustration into success simply by returning to the field with clearer plans, improved methods, and better equipment each year for two decades. We conclude that such fundamental efforts have helped improve and rationalize our concepts of how the First Floridians interacted with *Mammut* and other megafauna within the changing environments of the Late Pleistocene and how they recovered to a new mode of life in the early Holocene. We are pleased to offer this contribution to illuminating the first third of human prehistory in Florida and its associated environmental changes.

References

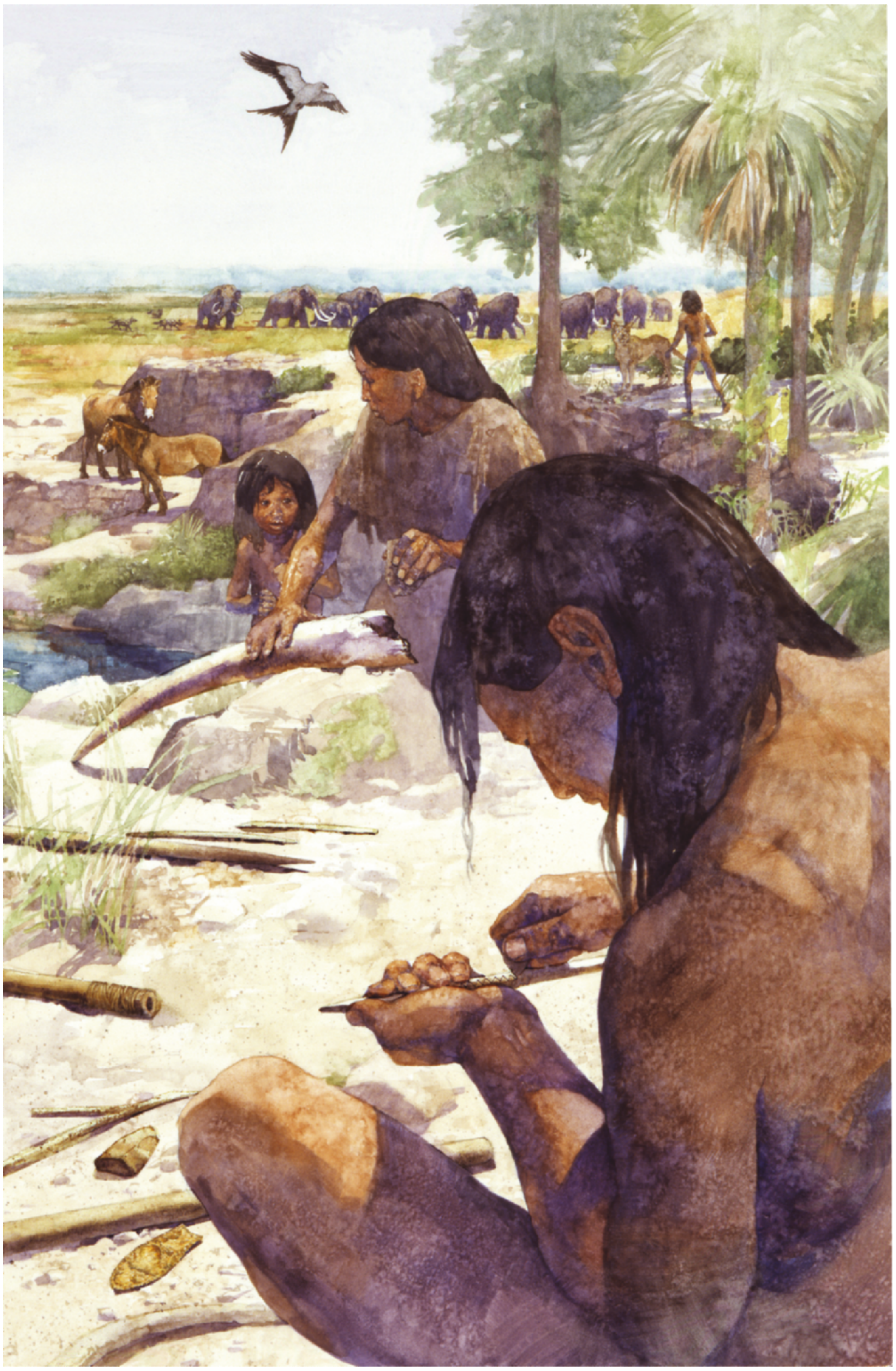
Anderson, D. G. and K. E. Sassaman (editors). 1996. *The Paleoindian and Early Archaic Southeast*. University of Alabama Press, Tuscaloosa, Alabama.

Bradley, B. and D. Stanford. 2004. The North Atlantic Ice-Edge Corridor: A Possible Paleolithic Route to the New World, *World Archaeology* 36:459–478.

Appendix: Color Version of Figures



Paleoindians around sinkhole, photograph by National Geographic Society.



Paleoindians around sinkhole, photograph by National Geographic Society.

Figure 1.1

Figure 1.2

Figure 1.3

Figure 1.4

Figure 1.6

Figure 1.7

Figure 1.8

Figure 1.9

Figure 1.10

Figure 1.11

Figure 1.12

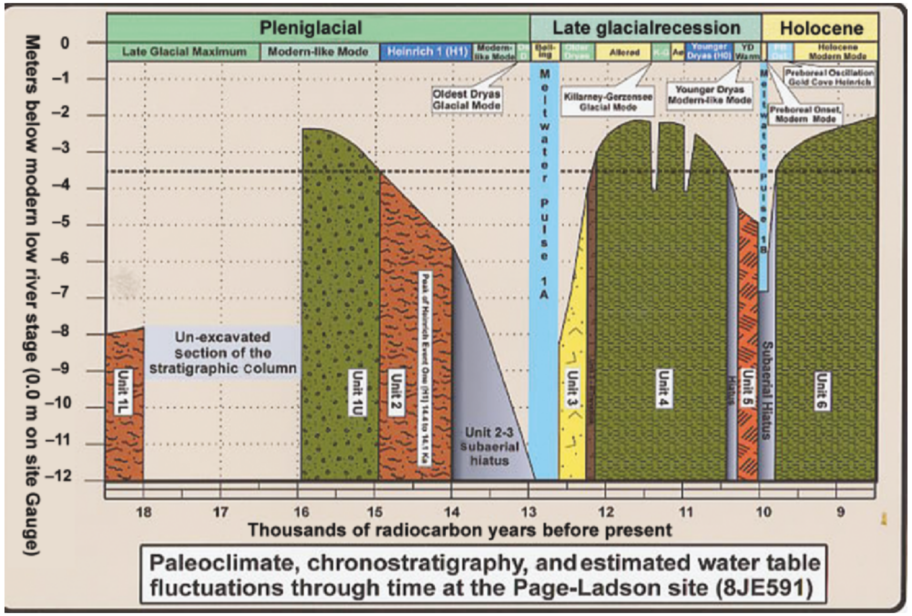

Paleoclimate, chronostratigraphy, and estimated water table fluctuations through time at the Page-Ladson site (8JE591)

Figure 5.1

Figure 8.1

Figure 8.2

Figure 8.3

Figure 8.4

Figure 10.1

Figure 10.5a

Figure 10.5b

Figure 10.5c

Figure 10.5d

Figure 10.6a

Figure 10.6b

Figure 10.7a

Figure 10.7b

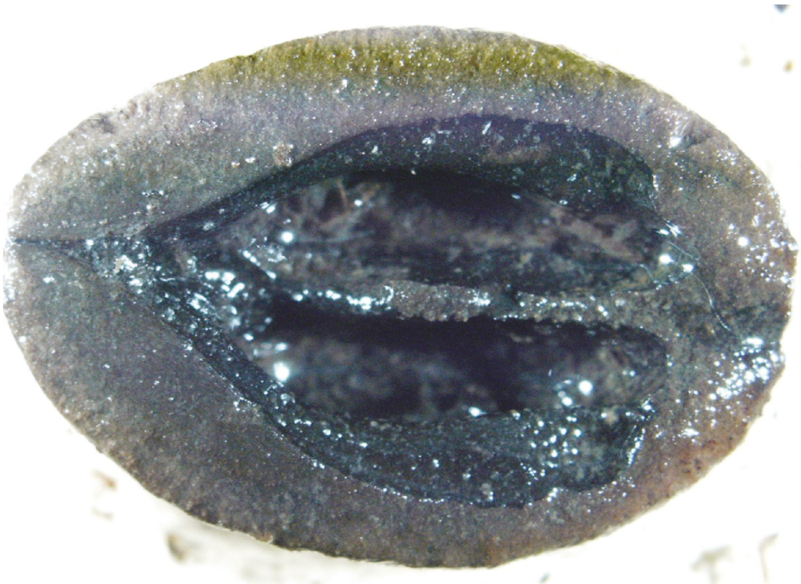


Figure 10.9

Figure 10.10c

Figure 10.11

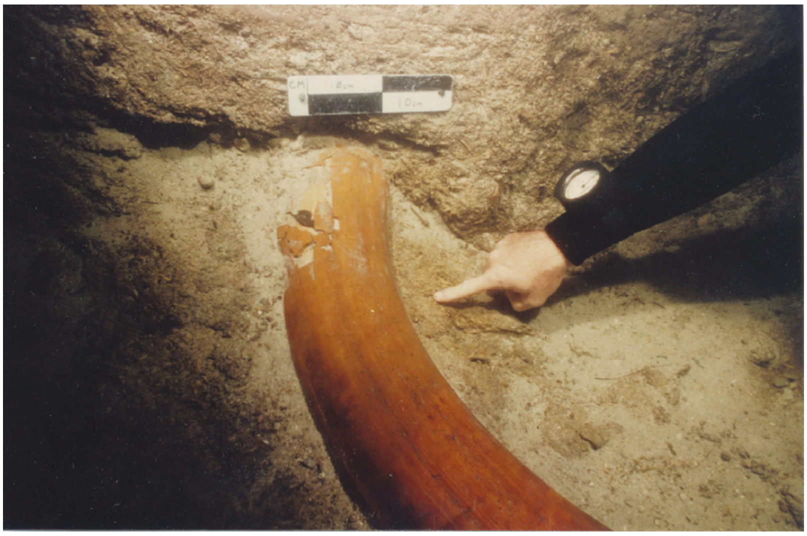


Figure 11.1

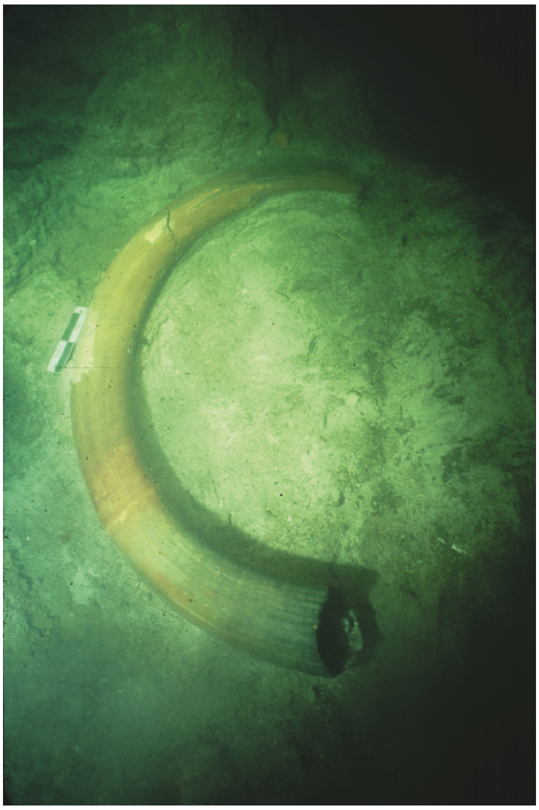


Figure 11.2

Figure 11.3

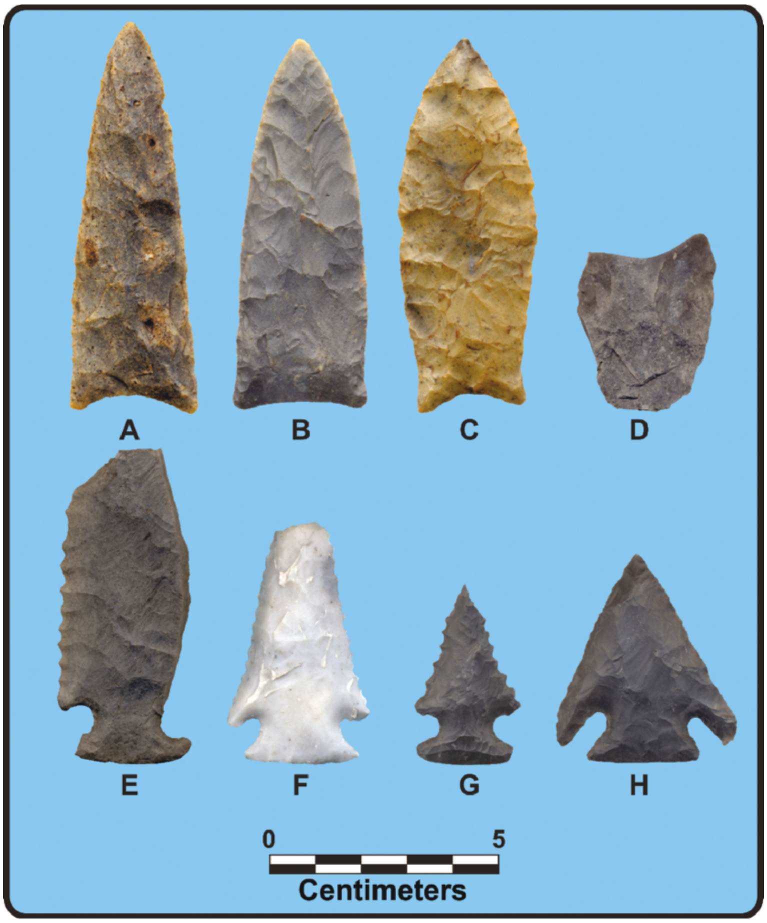


Figure 14.1

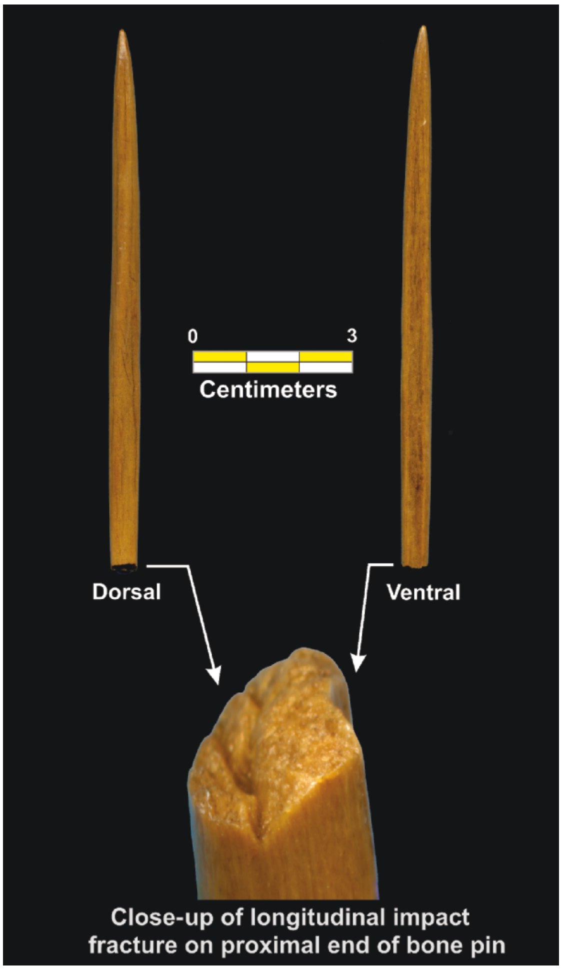

0
3
Centimeters
Dorsal
Ventral
Close-up of longitudinal impact fracture on proximal end of bone pin

Figure 18.5


cm
1 2 3 4 5
inch
one
two
Florida Bureau of Archaeological Research
cm
1 2 3 4 5
inch
one
two
Florida Bureau of Archaeological Research

Figure 18.6

Index

Page numbers followed by f and t indicate figures and tables, respectively.