Manuals in Archaeological Method, Theory and Technique

Elizabeth J. Reitz
Myra Shackley

Environmental Archaeology

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Environmental Archaeology

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For the anonymous, but real, ecology student who could not define an amphibian even though his assignment was on the global decline in frog populations, and dedicated to family, friends, and colleagues, who made this work possible.

Preface

The stimulus for this work is the influential role that Myra Shackley's 1981 publication, *Environmental Archaeology*, has had on the field. This small volume continues to linger on the shelves of many environmental archaeologists, treasured as a simple source where one can obtain a brief summary of the biotic and abiotic components of archaeological sites. Since 1981, significant publications have described materials, methods, and interpretations in environmental archaeology. Yet the 1981 volume is the only one that surveys the soils, sediments, and biological materials fundamental to this field without presuming the reader is trained in the earth and biological sciences. The complaints of field staff, environmental archaeologists, and resource managers that none seem to understand the needs of the others can be traced, in part, to the unfilled gap created when the 1981 edition went out of print. Yet biological and earth scientists, anthropologists, and field staff attracted to the historical record of human–environmental interactions are more numerous and, in some cases, more vocal in their need to access this record and to be able to critically evaluate it. The stimulus for this volume is to update the information in the 1981 volume for a younger generation of environmental archaeologists and for new audiences that have emerged over the decades.

Facilitated in part by the 1981 volume's impact on the field, the number of practitioners in environmental archaeology and its role in archaeology has grown. Sadly, it is still too often the case that an excavator turns to environmental archaeology to justify the excavation and make the final report look more impressive. A corollary to this is the tendency to rely on environmental archaeology in inverse proportion to the age of the site, working on the assumption that sites occupied by people with written records have so much documentary information that there is little to be learned from environmental archaeology. Others argue that the relationships between people and their environments are less critical in complex societies so that environmental evidence does not require examination.

These attitudes and assumptions are far from valid. One cannot interpret human behavior without considering its environmental context or understand Holocene environments without reference to people. The causes and consequences of these

relationships are critical to addressing fundamental aspects of life, both in the past and today.

Environmental archaeology is an interdisciplinary field with skilled researchers producing technical data that provide historic depth for the human role in environments, the impact of the environment on human society, environmental change and stasis, and the history of specific sediments, organisms, and ecosystems. Students and professionals in archaeology, wildlife and heritage conservation management and policy, and others use these data. Some either do not use archaeological data or do so inappropriately, because there are few ways for nonspecialists to gain entry into the literature. For biotic and abiotic data from archaeological sites to contribute to debates about the causes, frequency, duration, and consequences of environmental change and stasis, more people should be familiar with site formation processes, field methods, biogeochemical materials, laboratory techniques, and analytical procedures that define the strengths and weaknesses of such data.

Many scholars who produce environmental data from archaeological sites are unfamiliar with the limitations imposed by archaeological contexts. They may be soil scientists, art historians, chemists, geologists, plant biologists, geneticists, palaeontologists, veterinarians, lawyers, microbiologists, agricultural historians, mycologists, taxonomists, ecologists, human biologists, climatologists, forest resource managers, or epidemiologists, among others. Each discipline has its own theories, methods, and intellectual histories that engage practitioners of those disciplines. Some of these are pertinent to the archaeological arena and others are not. These researchers bring perspectives and knowledge that enhance archaeological field work and subsequent interpretations. In some cases, however, researchers prepare technically accurate and competent publications whose meanings elude people untrained in that discipline and ignore the promise and pitfalls of the archaeological context.

This volume cannot resolve all of the impediments to communication among these diverse groups. Instead, it focuses on gaps the senior author has found among her own students: ecologists who think that only people of European descent adversely impact the environment, anthropologists whose studies of human ecology are long on theory and short on facts, and archaeologists who confound ecology with ceramics. Very few of them know what pollen rain or incremental growth structures are or why they should know about them. In the following pages, we endeavor to answer questions such as: If the sample is too small, why can't we just get more samples? Why does it take longer to identify fish bones than it does potsherds? Why can't we collect all organic samples using the same sampling strategies? Why is a description of the present-day environment inadequate as evidence for the resources people used in the past?

This volume is designed as a general introduction to site formation processes, field methods, taxonomy, anatomy, morphology, laboratory procedures, and analytical procedures for each of the primary systematic data classes. Further reading is encouraged through references to literature representing the global expanse of environmental archaeology, primarily focused on the Holocene. Many of the methods applied to Holocene studies were developed for, and are still applied to, geological and archaeological sites of much greater antiquity. The choice to emphasize the

Holocene was made to keep the focus on anatomically and behaviorally modern people (*Homo sapiens sapiens*) and to control the tendency for this volume to grow into several volumes. The emphasis is on biological remains because, though there are many excellent treatments of soils and sediments, very few writers have attempted to compile a summary of the organismal part of the archaeological record.

One of the appeals of the 1981 publication was its brevity. This edition remains true to the introductory format, though it has grown beyond the slim volume that stimulated this effort. Yet much is left out. It is not possible to cover all of the topics encompassed under the umbrella of environmental archaeology, even briefly. Our focus is on sediments, soils, and, especially, organisms because of their potential to inform debates on environments, cultures, heritage management, and species conservation. We acknowledge the difficulty of being brief without being trivial and hope we have struck the right balance.

Updating the 1981 work has required faithful attention to our objective: to provide fundamental information to: (1) people unfamiliar with archaeology; and (2) people unfamiliar with the biogeochemical foundation of environmental archaeology. Not all of these are students; many are professionals. The need for this volume is compounded by the sad fact that many students no longer are trained in organismal biology and know little about soils, chemistry, genetics, and physics. We offer this volume with these two audiences in mind. It is not our intention to provide training in the disciplines involved or to offer thorough treatments of the complex topics reviewed here. Our wish is to be useful to professionals in other fields, students, archaeologists, and others who wish to know more about environmental data from archaeological sites without necessarily becoming expert in each topic. Our aim is to present a comprehensive but concise survey of organic materials, primarily, that are basic to environmental archaeology in a form that will be suitable for beginning professionals yet remain accessible to nonprofessionals. At the same time, we hope that casual readers will find the treatment readable and the topics timely and interesting.

Georgia, USA — Elizabeth J. Reitz
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Contents

List of Figures

List of Tables

Chapter 1
Introduction to Environmental Archaeology

The human past cannot be understood without integrating the full range of evidence contained within archaeological sites and recognizing that cultural systems are inextricably linked to their environments. This realization stimulates systematic applications of scientific methods to support broad interpretations of long-term changes in both human behaviors and the environments within which they occur. Insights into cultures and environments contribute to studies of the **Holocene** epoch (beginning ca. 10000 BP or 8000 BC) as well as to our present and future lives. Climate, weather, and geology are basic to soil fertility, vegetation, and the economic potential of landscapes. Studies of these and related phenomena emphasize different aspects of relationships among individuals, cultural institutions, and environments. Human behavior and archaeological sites must be interpreted within such broad contexts. In this chapter, some perspectives that inform models of environmental change and stasis and human–environmental relationships are presented, along with commonly used ecological concepts and a summary of environmental archaeology's diverse research interests.

What Is Environmental Archaeology?

Archaeology is about human life in the past. From an archaeological perspective, people left an imperfect record of their lives as modified sediments and soils containing other bits of inorganic and organic debris. Separately the ingredients of this record yield partial insights into a location, its history, and the people who lived there at any given moment in time. To learn all that we can about the past, relationships among this record, people, cultural institutions, and **ecosystems** (organisms and physical components that interact; Odum 1994:4) must be examined.

Environmental archaeologists examine these relationships guided by theories and practices drawn from biological, chemical, physical, and social sciences. This eclectic field emphasizes systemic relationships among peoples

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and their environments. Some definitions stress the properties, distribution, and effects of **biogeochemical** (biological, geological, and chemical) and **hydrological** (water-related) phenomena; others stress cultural ones. Shackley (1985:14) writes that: "Environmental archaeology is concerned both with the reconstruction of these past environments, and with elucidating the role and significance of human communities within them. We need to understand the nature of the relationship between man [sic] and the land in the past, together with the intrinsic bias imparted by the fragmentary nature of the archaeological record and the processes of change, both natural and human in origin, which the record may reflect." Butzer (1982:6) writes "…the primary goal of environmental archaeology should be to define the characteristics and processes of the biophysical environment that provide a matrix for and interact with socioeconomic systems, as reflected, for example, in subsistence activities and settlement patterns."

More recent definitions stress the complexity of these relationships. Branch et al. (2005:8) define the field as "…the study of the environment and its relationship with people through time…" Evans (2003:1) defines it as "…the study of past human environments, traditionally from archaeological excavations, sections and boreholes but increasingly from written sources, and the relationships between humans and those environments." Wilkinson and Stevens (2003:15) write that environmental archaeology is "…the study of the landscapes that were inhabited by past human populations and the economies they constructed, on the basis of preserved biological remains and geological phenomena."

The derivation of the word "ecology" as "the management of the household" highlights relationships among environments and economies (Odum and Barrett 2005:2). **Palaeoenvironmental studies** may be defined as "…the study of past floras, faunas, and geomorphology associated with past people…" and **palaeoeconomic studies** as "…that of diet, trade, building materials and the like…" (Wilkinson and Stevens 2003:15–16). Palaeoenvironmental studies include stasis and change in the histories, functions, and structures of communities, **biogeography** (spatial distribution of organisms), climate, and land-use patterns, among other phenomena. The term "palaeoeconomy" in reference to what might be thought of as the human side of this dichotomy appears too narrow when we consider the complex roles of organisms in ecosystems and human affairs. Interpreted narrowly, economic institutions are associated with acquisition, production, distribution, consumption, ownership, and inheritance. Although economic processes are vital to human life, cultures are much more complex than this and environmental archaeologists explore all cultural institutions, not just those that are, strictly speaking, economic.

Nonetheless, a dichotomy between environment on the one hand and culture on the other is a basic one. It reflects different perspectives on the scope of archaeology, environmental archaeology, and the traditions that inform broad, multi-faceted research agendas.

History, Humanity, or Science?

These diverse definitions reflect a long-standing identity crisis within archaeology. Is it a history of who, what, where, when, and why? Is its role primarily to refute, confirm, or elaborate upon textual evidence? Is it a discipline from the humanities focused on artistic, ideological, and similar achievements? Is it a science seeking universal laws governing human behavior in evolving populations and communities within a changing biogeochemical sphere? What is science? Is it defined as the application of the scientific method to research? Or can it be defined topically? Analysis of stable isotopes might be considered a scientific application whereas interpreting the symbolism of flowers left on an altar might be considered humanistic and, if linked to a written tradition, historical. How would a study of starch grains embedded in the altar be classified?

Environmental archaeology is best served by merging the perspectives of these and other fields. One of the theories that unifies studies of the archaeological record is that of **uniformitarianism**. This theory, which emerged from the thinking of Scottish geologist James Hutton in the late eighteenth century, proposes that biogeochemical and other processes operating today also operated in the past and produced the same effects. Drawing on this theory, environmental archaeologists use **proxies** (indirect records of phenomena) to assess sources of raw materials, verify dates of manufacture, and consider the location of the materials and their identity, as well as their temporal and behavioral affiliation (**context**). They locate battlefields, document the rise and fall of urban centers, and track migration patterns. They study iconography, ritual expression, and cultural history. But the strength of environmental archaeology is the application of biological, chemical, and physical theories and practices to questions about the human past, especially about relationships among peoples and environments. Thus, environmental archaeology is a science with important anthropological, historical, and humanistic components.

Archaeology shares three interests with other sciences. One interest explores relationships between **function** (purpose) and **structure** (organization, form). Another examines **heritable traits** (genetics; i.e., nature) and **learned patterns of behavior** (culture; i.e., nurture). The third interest considers the causes, processes, and consequences of change and stasis through time and space. These are related concepts, but often one assumes ascendancy over the others as research paradigms change. Many archaeological studies in the mid-twentieth century focused on functional aspects of learned behavior. By the end of the twentieth century, the focus was on structural aspects of human behavior while advances in archaeogenetics made heritable traits more accessible to study. At the same time, resource management policies and advances in geochemistry revived interest in documenting climatic and other environmental changes during the Holocene. By the early twenty-first century, theories about broad cultural transformations had waned and those involving gender, cognition, genetics, and environmental change had increased.

This characterization is confounded by differences between European and American traditions in archaeology. Broadly speaking, archaeology in Europe has been distinct from social anthropology. In the American tradition, archaeology was one of four anthropological subfields focused on different aspects of human behavior. Archaeologists trained in the European tradition might study a specific classical site, trace the origins of historically known groups of people, or document the history of domestic plants and animals. Archaeologists in the American tradition might seek evidence of human biological, linguistic, and social behavior through time and space: the anthropology of the past. Many sites studied in the European tradition were associated with human evolution or historical events; many of the sites studied in the American tradition were occupied before European-sponsored voyages of exploration and expansion. Some of the research conducted in the European tradition could draw from archives to elaborate upon the archaeological record while many sites studied in the American tradition were "prehistoric," occupied before European-style histories were written. These distinctions are less significant now, though they linger in the older literature.

Theory or Practice?

Some argue that theory is absent or underdeveloped in work that appears focused on empirical details and the methods used to derive them. This dichotomy gives the false impression that there may be a theory without a method to test it or a method without an underlying theory. Many of the practices developed by environmental archaeologists are experimental and test alternative theories about the biogeochemical world, human behavior, and archaeological sites (e.g., Albarella 2001; Branch et al. 2005; Evans 2003; O'Connor and Evans 2005; Wilkinson and Stevens 2003). These theoretical paradigms are the foundation of environmental archaeology. For example, theories about the rates, causes, and consequences of genetic mutations and of the impact of decomposition on stable isotopes support rich fields of research with results that inform archaeological practices and interpretations.

Among the most fundamental theories is that there is a relationship between people and environments; changes in one sphere may be accompanied by changes in the other. Some still consider the Holocene to be climatically stable and others attempt to distinguish between pristine, natural, Holocene environments that do not include humans and those that do (Barton et al. 2004; Odum 1994:17). Environmental archaeologists repeatedly demonstrate that these two hypotheses are untenable, proposing instead that human influence extends to even remote parts of the planet (e.g., Hong et al. 1996; Renberg et al. 1994), that the Holocene experienced environmental change early and often (e.g., Andrus et al. 2002; Buckland et al. 2011; Huffman 2008; Morwood et al. 2008), and that people were responsible for some, but not all, of those changes (e.g., Bloch et al. 2010; Innes and Blackford 2003; Stinchcomb et al. 2011; Summerhayes et al. 2010; Tipping et al. 2008).

A great deal of research tests theories about this relationship in the history, structure, and function of cultures and specific cultural institutions. Under what

circumstances and via what processes do changes occur, or is stasis maintained; what does this evidence look like in the archaeological record; and why? Among the most fundamental theories are those concerning **anthropogenic** (human-related) and **non-anthropogenic** (unrelated to human behavior) influences on environmental phenomena, and both the processes involved and the outcomes. Another group of theories endeavors to predict or explain the role of environments in the formation and maintenance of cultural institutions and the trajectories of cultural histories.

Artifact or Ecofact?

Some archaeological specimens are termed **ecofacts** (e.g., Binford 1964) to distinguish between objects made by people, such as buildings or tools, and the raw materials out of which these are made, such as clay and wood. Others use it to refer to any biological or geological evidence, presuming that it is something made by nature rather than by people. These distinctions give a false perspective on the human role in forming archaeological sites. So-called "unmodified" ecofacts were selected by people, transported to the archaeological site, modified by processing, redistribution, and ritual practices, discarded, perhaps several times, and finally sank beneath the surface until excavated. Should residues of tannins used to dye textiles and leather goods, or glues, fats, resins, and shellac used in paintings, be considered ecofacts or artifacts? These materials are very much the product of human behavior.

This may be a difficult concept for people not trained in anthropology to understand, particularly those whose primary interests are environmental history and resource management. Materials from archaeological sites do provide biogeochemical and hydrological information, but it is not unmodified evidence; most materials recovered from archaeological sites are the result of human activities, even if inadvertent. To separate anthropogenic from non-anthropogenic phenomena, it is critical to appreciate the *artifactual* nature, the cultural context, of all archaeological remains. This concept can be extended beyond the archaeological site to regional and even global scales (e.g., Hong et al. 1994).

The term "cultural filter" encapsulates this relationship (Reed 1963:210). The **cultural filter** encompasses choices made by people as they select resources to use or ignore; decide where to live and when; schedule resource use in terms of daily, seasonal, and annual cycles; develop technologies to acquire and process resources; and distribute, store, use, and dispose of them. The filtering aspect of these choices is particularly manifest in procurement methods. Technologies, **residential patterns** (e.g., mobility, sedentism), and schedules take advantage of the habitats, aggregation, abundance, shape, size, and other aspects of preferred and avoided resources. Preferred resources have specific properties appropriate for their intended uses and may be present at the site out of proportion to their local abundance. People balance the time and energy required to obtain resources against risks and benefits so as to achieve an acceptable return for effort. In addition, adverse circumstances may motivate people to make use of exceptional resources that are not part of the

preferred or even acceptable list of resources, such as foods consumed during famines or building materials used after a storm. Such behaviors underlie cultural identity and are intrinsically interesting, but they obscure more routine relationships among the resource base, people, and archaeological deposits.

Foci of Environmental Archaeology

Environmental archaeology is the study of processes and outcomes of dynamic human behaviors in dynamic ecosystems. The primary foci are: (1) geological and biological discoveries derived from archaeological materials; (2) **synchronic** (contemporaneous) and **diachronic** (chronological) interpretations of the structure and function of environments and cultures, as well as of environmental and human histories; and (3) advancements in knowledge about the materials studied and the methods used to study them. The objective is to define and explain fluid relationships between people and the world in which they live so as to understand the currents of human life through time and space and their impacts on the planet. The focus should not be exclusively on either environmental or cultural contexts, though at a specific site the evidence may fall largely into one or the other of these categories.

Theories in Environmental Archaeology

The application of biological, chemical, and physical analysis to archaeology began as early as the 1700s, in some cases long before (Albarella 2001; Branch et al. 2005:4–8; Brothwell 1990; Butzer 1971:3–11, 1975; Evans 2003:1–20; Herz and Garrison 1998:5–6; O'Connor and Evans 2005:1–8; Rapp and Hill 1998:4–17; Reitz and Wing 2008:15–30; Wilkinson and Stevens 2003:18–23). Many current theories and practices in environmental archaeology trace their roots to the nineteenth century when questions focused on the origins, antiquity, and evolution of organisms. These drew upon stratigraphic affiliations and associations of extinct animals with human-made objects. Perceptions about environments, especially aspects associated with climates, were fundamental to these early theories. Due to this historical association, environmental archaeology shares research traditions with anthropology, biology, ecology, geology, and palaeontology. The diverse theories and interpretations in environmental archaeology reflect shifts in research interests in these fields as well as within archaeology.

Theories about relationships among environments, cultural institutions, and human populations are broadly classified as environmental determinism, environmental possibilism, cultural ecology, human ecology, and historical ecology (Balée 2006; Evans 2003:1–5; Harris 1968; O'Connor and Evans 2005:1–8; Winterhalder and Smith 1992). The ascendency of one theory or another influences the degree to

which biological materials are emphasized in archaeology. Not all environmental archaeologists operate under these paradigms, particularly if their primary training is outside archaeology, but many are impacted by them indirectly because they influence the willingness of project directors and funding agencies to include environmental archaeology among the project's goals. The primary differences among these theories are the importance attributed to the internal dynamics of cultures, historical trajectories, and non-cultural **biotic** (organic; e.g., fungi, plants, animals) and **abiotic** (inorganic; e.g., climate, sediments, soils) factors as facilitative or causal stimuli for cultural change.

Environmental determinism and possibilism are theories that no longer are widely accepted, though their influences are seen in the older literature (Ellen 1982:1–51). **Environmental determinists** argue that environmental characteristics determine human behavior; culture is a passive rather than an active agent; and cultural phenomena are explained by the environments in which they are found (e.g., Ratzel 1896). Cultures are viewed by **environmental possibilists** largely as products of their histories with environments playing a minor role (e.g., Kroeber 1939).

A different perspective on the human/environmental relationship is provided by ecological theories. From the perspective of **cultural ecology**, cultures and environments are defined in terms of each other, with environments playing active, reciprocal roles in human affairs rather than determining or passive ones (Ellen 1982:52–65). Steward (1955:30) argues that resource use is more directly related to environments than are other cultural phenomena; thus, characteristics associated with subsistence and economics, especially technological ones, constitute the cultural core. Kinship, political, and belief systems are secondary features. **Human ecologists** expand upon cultural ecology using ecological concepts to interpret and predict interactions between people and their environments (Bates and Lees 1996; Butzer 1990; Ellen 1982:66). This perspective emphasizes holistic, evolutionary, and systemic models to conceptualize cultural behavior (Ellen 1982:73–79). Ecological concepts such as populations, communities, niches, evolutionary ecology, and systems theory are important in human ecology (Clarke 1972:30; Winterhalder and Smith 1992). **Historical ecology** provides the temporal perspective of changing landscapes to such studies (Balée 2006; Winterhalder 1994). Many of these theories are associated with New Archaeology or processual archaeology, which emphasizes scientific rigor, site formation processes, quantification, experimentation, and anthropological interpretations.

Anthropologists recognize that environments and human perceptions of environments are different. Defined from the perspective of human behavior, environments have both non-cultural and cultural components. Symbolic, cognitive, and structural analyses interpret human perceptions of environments by drawing upon perspectives of present-day social groups. Such **post-processual** or **interpretive** studies focus on roles of environments in social lives of human communities, cultural relationships, native meanings, and behavioral strategies (e.g., O'Day et al. 2004). Underlying some of these interpretations are hypotheses that attribute insignificant or unimportant roles to non-cultural environments.

Ecological Concepts

Ecological concepts and analogies are essential to environmental archaeology. It is important to distinguish between environments and ecology (Dincauze 2000:3; Wilkinson and Stevens 2003:46). **Environments** are the biological, chemical, and physical elements in which organisms live; **ecology** is the "…branch of science dealing with the interactions and relationships between organisms and the environment…" (Odum and Barrett 2005:516). The behavior and distribution of organisms reflect both environments (e.g., humidity, light, nutrients, temperature, topography, water, wind) and ecosystem processes (e.g., competition, dispersal, predation, reproduction, succession). Archaeological applications may target what are, strictly speaking, environments; others focus on ecology.

Ecosystem

Fundamental to ecology is the concept of the ecosystem, which is a "…unit that includes all the organisms (the *biotic community*) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined biotic structures and cycling of materials between living and nonliving components…" (Odum and Barrett 2005:18, italics in the original; see also Odum 1994:4, 17). Theories about the relatedness of abiotic and biotic phenomena are fundamental to environmental archaeology.

Ecosystems are dynamic, but some are more resistant to disturbances generally, or to specific disturbances, than are others (Odum and Barrett 2005:70). **Resistant ecosystems** withstand disturbances and maintain their structures and functions intact. Others demonstrate **resilience**, an ability to return to their original structure and function after a disturbance. Resistant ecosystems are difficult to alter but slow to recover; resilient systems are easily altered but recover quickly.

Radiant energy from the sun is the most significant source of energy for ecosystems and the regulation of energy flow is central to their maintenance. Only a fraction of solar energy reaches the earth's surface. The energy that does reach the surface passes through a series of **trophic levels** (steps in a food chain) in a unidirectional and non-cyclic fashion, with a progressive reduction in quantity at each level, though the quality may be enhanced (Odum and Barrett 2005:79–80, 109). Energy is lost at each level, reflecting factors such as temperature, moisture, and the specific type of system (Odum and Barrett 2005:109; Odum 1994:16).

Broadly speaking, radiant energy flows from the sun to producers, which converts it to chemical energy, a form accessible to consumers (Fig. 1.1; Kormondy 1984:3, 5; Lindeman 1942; Odum and Barrett 2005:108–109). **Primary producers** are **autotrophs**, organisms that produce their own food by converting inorganic

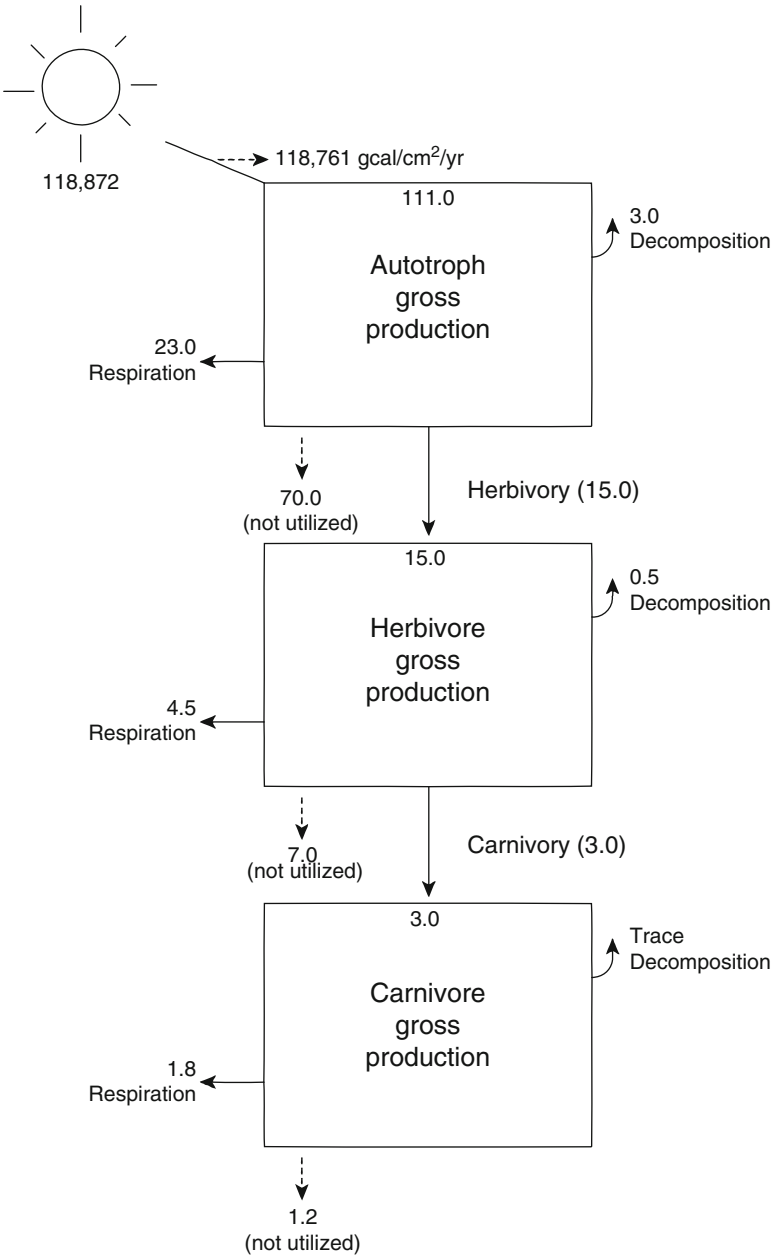

Fig. 1.1 Energy flow diagram for Cedar Bog Lake, Minnesota (USA), measured in gcal/cm^2/year. Data from Lindeman (1942) and illustrated by Kormondy (1984:32–34)

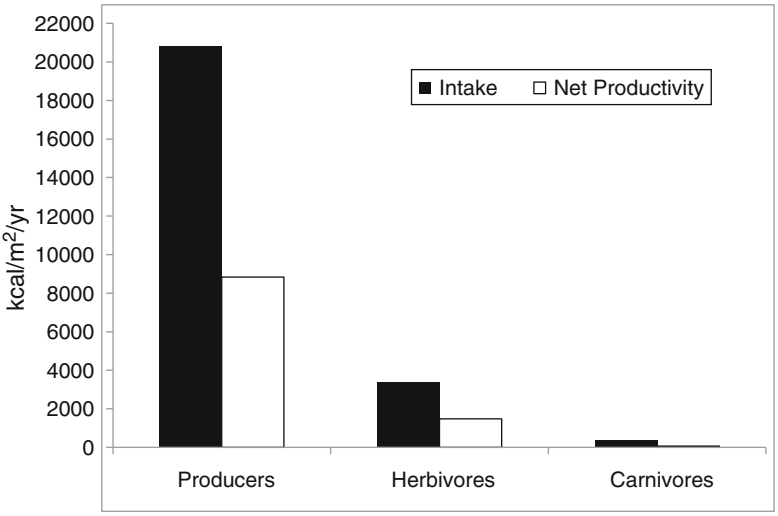

Fig. 1.2 Intake and net productivity for producers, herbivores, and carnivores at Silver Springs, Florida (USA), measured in kcal/m^2/year. Data from Odum (1957:61–62)

carbon to organic compounds, usually by photosynthesis. **Photosynthesis** is the process by which energy or inorganic substances are converted into **biomass** (living organic matter). Green plants and some other pigmented organisms (such as algae) use sunlight to convert carbon dioxide (CO_2) into sugars. Autotrophs are further divided into **photoautotrophs** (obtain energy from light) and **chemoautotrophs** (obtain energy by oxidizing inorganic substances). The resulting products, carbohydrates, are stored in the tissues of the autotrophs. Consumers are **heterotrophs** (obtain organic compounds and energy from other organisms). Heterotrophs include **primary consumers** (herbivores and omnivores that feed on autotrophs); **secondary consumers** (primary carnivores that feed on herbivores and omnivores); **tertiary consumers** (secondary carnivores that feed exclusively on other animals); and **decomposers** or detritivores. Decomposers feed on dead or decaying organic matter, breaking these down into their basic constituents and releasing nutrients so that the nutrient cycle continues (Odum and Barrett 2005:515). **Saprophytes** absorb nutrients from dead organic matter and **omnivores**, such as people, feed at multiple trophic levels.

Efficiency of energy capture between trophic levels ranges from 3 to 8% and gross productive efficiency ranges from 0.2 to 2% (Kormondy 1984:24, 32–33; Lindeman 1942). Productivity is measured in calories; a kilocalorie equals 1,000 cal. A study of a temperate-zone lake finds that autotrophs use 21% of the energy they capture on respiration and other metabolic functions, whereas herbivores use 30% and carnivores use 60% (Fig. 1.1; Kormondy 1984:31–34). Metabolic costs mean that less energy is available at the next trophic level (Fig. 1.2; Odum 1957:61–62). Approximately 80–90% of the potential energy is lost as heat at each transfer

(Odum and Barrett 2005:108). Thus, autotrophs offer far more energy than do herbivores (Kormondy 1984:32–33; Odum and Barrett 2005:122). This is one reason, among several, that predators in a **community** (an assemblage of species at a given time and place) are few and have large home ranges (Forman and Godron 1986:590; Kormondy 1984:43).

These relationships are often illustrated as pyramids, with autotrophs forming the largest mass of organisms at the bottom of a pyramid (Kormondy 1984:43; Wilson and Bossert 1971:152–153). The term **food chain** refers to the transfer of food energy from autotrophs through organisms that consume them and are in turn consumed (Odum and Barrett 2005:108). Mass diminishes toward the top of the pyramid, or the "carnivore" end of the chain. The biomass of plant material in terrestrial communities far exceeds the biomass of herbivores feeding on plant material. Likewise, herbivore biomass is greater than that of carnivores. This is not necessarily the case in aquatic communities, in which many primary producers are **phytoplankton** (minute, photosynthetic organisms, e.g., bacteria, algae [singular: bacterium, alga]) that reproduce quickly but may not form a large biomass at any one time. Phytoplankton form the base of most aquatic food chains and are fed upon by **zooplankton** (minute animals or animal-like organisms). In addition to such familiar grazing food chains, there are detritus food chains through which nonliving organic matter is decomposed and the nutrients consumed by detritivores and transferred to their predators (Odum and Barrett 2005:108). Food chains are clearly interconnected, forming what are known as **food webs**.

Energy is not the only ingredient circulating in an ecosystem. Unlike energy, nutrients circulate in biogeochemical cycles (Kormondy 1984:48–49; Odum and Barrett 2005:141). Between 30 and 40 elements are essential for life. These nutrients are divided into **macronutrients** (e.g., carbon, oxygen, hydrogen, nitrogen, phosphorus, sulfur [sulphur], chlorine, potassium, sodium, calcium, magnesium, iron, copper) and **micronutrients** (e.g., aluminum, chromium, fluorine, iodine, manganese, silicon, strontium, tin, zinc; see Table 1.1 for a list of elements and symbols). Macronutrients are required in relatively large amounts compared with micronutrients, but the classification of each nutrient as a macronutrient or micronutrient depends on the species (Kormondy 1984:49). Carbon and nitrogen cycles are particularly important in the studies of environmental archaeologists.

Population Ecology

A **population** is a group of individuals of the same species present at the same time and place (Odum and Barrett 2005:225). Populations are studied in terms of density, birth rates, death rates, age distribution, **carrying capacity** (biotic potential; the amount of biomass that can be supported by the available energy), and dispersal patterns. A species may have one suite of characteristics in the middle part of its range and a different suite at the edge of its range (Table 1.2; O'Connor and Evans 2005:24).

Table 1.1 Some elements and their symbols

Element	Symbol
Aluminum	Al
Barium	Ba
Boron	B
Cadmium	Cd
Calcium	Ca
Carbon	C
Chlorine	Cl
Chromium	Cr
Copper	Cu
Fluorine	F
Hydrogen	H
Iodine	I
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Nitrogen	N
Oxygen	O
Phosphorus	P
Potassium	K
Rubidium	Rb
Silicon	Si
Silver	Ag
Sodium	Na
Strontium	Sr
Sulfur (sulphur)	S
Tin	Sn
Zinc	Zn

Table 1.2 Differences within a species between the edge and middle of its range[a]

Edge	Middle
Low abundance	High abundance
Limited genetic diversity	High genetic diversity
Potential for inbreeding	Less potential for inbreeding
Limited response to environmental change	Flexible response to environmental change
Low variety of habitats and narrow niches	High variety of habitats and broad niches
Stenotopes	Eurytopes
r-strategists	*K*-strategists
Density-independent	Density-dependent
Physically controlled populations	Biologically controlled populations
Susceptible to local extinction	Less susceptible to local extinction

[a]Modified from O'Connor and Evans (2005:24) and used with their permission

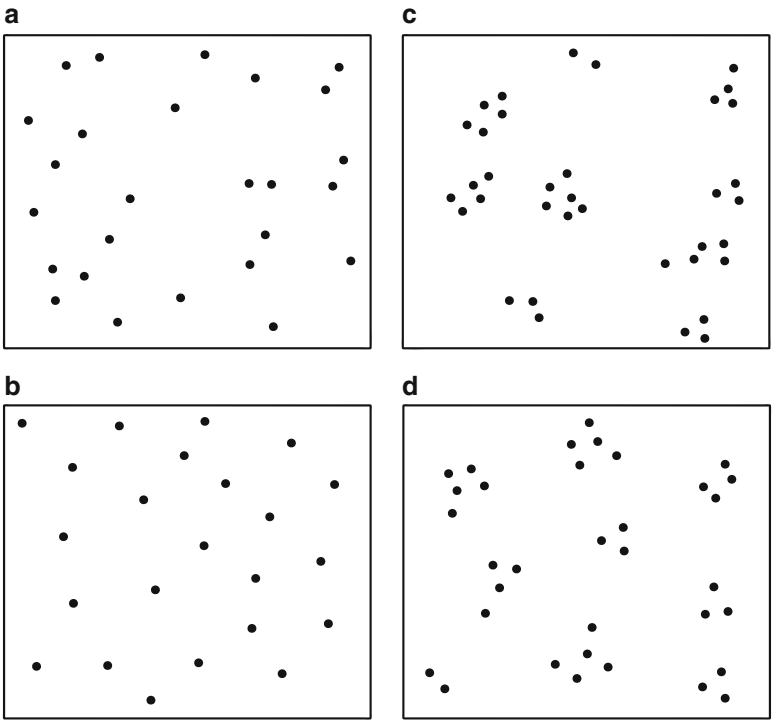

Fig. 1.3 Four basic patterns of the dispersal of individuals within a population: (**a**) random; (**b**) regular; (**c**) clumped; and (**d**) regular clumped

Population density is the size of a population within a unit of space (Odum and Barrett 2005:225), which has implications for foraging strategies because it influences the time and energy required to find and acquire a resource. There is a broad trophic level relationship with population density: the lower the trophic level, the higher the density of organisms operating in that level (Odum and Barrett 2005:226). Individual members of populations are dispersed in patterns (e.g., random, regular, clumped) that reflect the uniformity, or lack thereof, of local resources, weather patterns, opportunities for reproduction, and social attractions (Fig. 1.3; Odum and Barrett 2005:258, 260–261). Population density, however, does not reflect the size of individual organisms, which is usually calculated as biomass per hectare and has a trophic level relationship. Thus, herbivores typically comprise a larger percentage of the biomass in an ecosystem than do carnivores.

Population density is related to **natality** (birth rate), **mortality** (death rates), and age distributions. These reflect the number of individuals in a population and the age of those individuals. In animals, these may be expressed as **survivorship curves**, which represent the number of survivors in a specific age group. Survivorship curves may distinguish between species with low death rates in early age cohorts and those with high death rates in early age groups. A change in a survivorship curve may be evidence of a change in human predation or some other factors. Survivorship may

indicate whether the population density is high or low, and whether the carrying capacity is exceeded. **Mortality curves**, on the other hand, depict the age-specific probabilities of dying within a population over time.

Mechanisms for population regulation may be dependent or independent of population density (Odum and Barrett 2005:249, 255). **Density dependent** mechanisms are functions of population density, as populations increase the effects become greater. Biological factors such as predation, diseases, and competition may be density-dependent mechanisms. **Density independent** mechanisms are independent of population size. Physical factors, such as climate and earthquakes, often are density-independent mechanisms.

Two types of reproduction are classified as *r*-selection and *K*-selection, based on the *r* and *K* constants in growth equations (Odum and Barrett 2005:269). Organisms with behaviors that favor rapid population growth by quickly producing large numbers of young when population densities are below the carrying capacity are called ***r*-strategists**. These are often small-bodied organisms that mature at an early age, and live a relatively short time compared with ***K*-strategists**. *K*-strategists have traits favoring competitive abilities at population levels near the carrying capacity, mature at a later age, produce fewer young, provide them more care, have larger body sizes, and tend to have long life-spans. *K*-strategists usually are found in more stable environments than *r*-strategists. Members of a species may have different reproductive strategies if they are at the edge of the organism's range or in the middle of it (O'Connor and Evans 2005:24). Humans, with long periods of high investment into small numbers of young, are generally *K*-strategists.

Community Ecology

Communities are populations that interact with one another. They "…occur as continua, some species becoming more abundant as others decrease in importance along environmental gradients" (Ewel 1990:8). Communities each have attributes that clearly distinguish them from other communities. A terrestrial community has similar soil, temperature, and water regimes that support a characteristic association of plants, which in turn provides appropriate resources for a specific array of animals. Aquatic communities are governed by **oceanographic** (marine) or **limnological** (fresh water) factors.

Communities include **habitats** (the physical place where an organism lives) as well as **ecological niches** (the functional role of the organism). Niches combine the physical space occupied by the organism with its trophic level, reproductive behavior, and other aspects of the environment (Odum and Barrett 2005:311–312). The numbers of categories (taxa, **richness**) and abundance within each category describes the heterogeneity (**diversity**) of a system. Measures of diversity combine two independent concepts: richness and **equitability** (apportionment, the evenness or degree to which taxa are equally abundant). General patterns of species richness and diversity are characteristic of significant features of communities and landscapes such as

latitudes, climates, ecosystem productivity, habitat heterogeneity and complexity, and environmental disturbances (Odum and Barrett 2005:316–317). Diversity tends to be low in stressed communities, in communities with limited space, and at high latitudes or altitudes.

Interactions among populations take many forms, some of which are neutral and others that are positive or negative. In neutral relationships, neither population is affected by the presence of the other. In positive relationships, **symbionts** have prolonged associations with other organisms (**symbiosis**; Brusca and Brusca 2003:14–15; Odum and Barrett 2005:285–286). Some symbionts are **commensal** (one organism benefits with no adverse effect on the other). Others live in **mutualistic** relationships (both organisms benefit).

In negative relationships, one organism benefits and the other is disadvantaged through processes such as competition, predation, and parasitism. The **principle of competitive exclusion** states that two species cannot permanently occupy the same niche, one will always outcompete the other (Odum and Barrett 2005:290). Usually this is avoided by partitioning resources, for example, by feeding at slightly different locations or different times. Competitive exclusion takes many forms, but it may be expressed in resources recovered from archaeological sites as different growth patterns, shapes, sizes, and reproductive habits depending on whether the organism occupied an optimal or marginal location. In **predation** and **herbivory**, one population adversely affects the other by feeding on it. **Parasites** obtain nutrients from living hosts, the parasitic population benefits to the detriment of the host (Odum and Barrett 2005:283). If a predator or parasite is absent, prey or hosts may occupy habitats unlike those they occupy when predation or parasitism is intense. Competition, predation, and parasitism affect community structures and functions.

The association of specific organisms with habitats and niches is used to interpret many temporal and spatial aspects of the archaeological record. The limited tolerance of some species to environmental variations and the ability of others to tolerate a wide range of conditions is a particularly fundamental tool. **Stenotopic** species have narrow environmental tolerances, are characteristic of specific events or conditions in the past, and may be critical to a specific ecosystem. **Eurytopic** species exhibit broad environmental tolerances, though some otherwise eurytopic species may be less tolerant of environmental conditions, and display other differences in growth, size, shape, and behavior at the edges of their preferred range than they do in the center (O'Connor and Evans 2005:24). **Catholic** species are organisms with very wide environmental tolerances.

In archaeological applications, distinctions are made between synanthropic and background organisms. **Synanthropic** organisms live in close association with people and may be dependent on them (e.g., parasites, vermin, domestic organisms). Some are typical of anthropogenic settings (e.g., Johnston 2001). **Background** organisms become part of the archaeological record by chance rather than by the choice of either people or these other organisms (Kenward 1975). Background organic materials may be particularly abundant in or around the site or be highly mobile, such as airborne materials (e.g., insects, wind-borne seeds). Background organisms provide information about the broader landscape if their modes of transportation and deposition are understood.

Landscapes

Landscape ecology focuses on spatial and temporal heterogeneity of interacting ecosystems (Forman and Godron 1986:595; Odum and Barrett 2005:375). Landscapes incorporate multiple ecosystems of diverse sizes, subsuming multiple communities, populations, and organisms (Odum and Barrett 2005:6). Much of the research in environmental archaeology focuses on the processes of environmental stability or change at the landscape level, developing causal explanations for stasis or change, and interpreting the consequences of landscape changes for cultural institutions.

Ecologists define a **landscape** as a "heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in a similar form throughout" (Forman and Godron 1986:594). Anthropologists sometimes refine this to distinguish between "natural environments" and "cultural landscapes." The cultural landscape includes human perceptions of biogeochemical and hydrological aspects of their environments as well as interactions with neighboring human communities. This may or may not include "natural" phenomena, which are presumed to be unmodified by human activities or at least not modified to an extent that is ecologically significant (Forman and Godron 1986:596; Wilkinson and Stevens 2003:46). Sometimes "environment" is substituted for "landscape" or "ecology" may be substituted for "environment."

The archaeological record supports a series of related hypotheses that contradict distinctions between natural and cultural landscapes: (1) few Holocene settings are untouched by human behavior; (2) human perceptions of the world are relevant to every aspect of human life; and (3) people are organisms in ecosystems subject to the same selective processes and principles as other organisms. Distinctions between natural and cultural phenomena and perceptions are unsupported by available evidence. In this volume, environments encompass cultural, biogeochemical, and hydrological phenomena in the human experience and landscapes are clusters of ecosystems, regardless of whether or how people perceive them.

Major Ecosystem Types and Biomes

The forms, functions, and histories of major ecosystem types are important in the interpretations of environmental archaeologists. **Biomes** consist of large-scale geographic features such as rivers, mountains, and oceans, in combination with climates and biotic communities (Odum and Barrett 2005:412–413). Major biomes include marine, freshwater, terrestrial, and anthropogenic systems, each of which is further divided into components such as inshore waters, wetlands, and temperate grasslands. An early classification system associated climatic parameters (e.g., temperature, precipitation) and vegetation to define **life zones** (Fig. 1.4; Holdridge 1967; Whittaker 1975:167). Climatic factors influence sediments, soils, and plant communities. In addition to temperature and mean annual precipitation, other

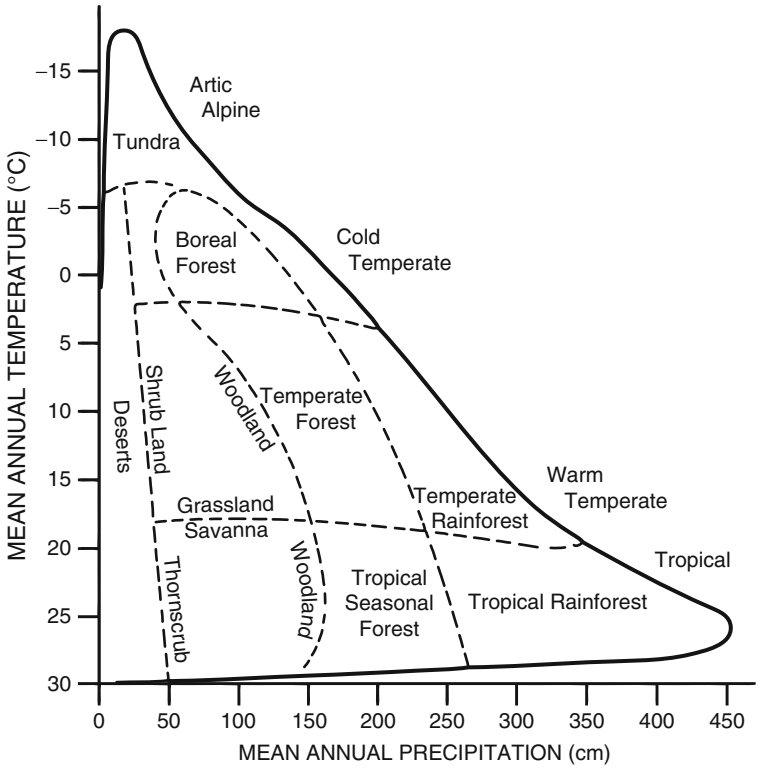

Fig. 1.4 The distribution of major terrestrial biomes with respect to mean annual temperature and mean annual precipitation. Modified from Whittaker (1975:167)

influences include the ability of soil to retain water; prevailing winds and their influence on evaporation; **topography** (physical landscape); fires; and organisms, including people.

Most ecosystem types are familiar to us, but some are not. **Ruderal** refers to plants that grow in disturbed soils, such as those associated with human settlements, waste places, rubbish, livestock, or cultivation. **Benthic** refers to the lowermost portions of aquatic settings; benthic organisms may be attached to a substrate, burrow into it, or live close to it. **Pelagic** refers to open water settings beyond the continental shelf or to deep parts of a lake (Stoermer and Smol 1999:461).

Ecological Analogy

Analyses that use archaeological specimens rely on the premise that relationships exist among the identified organisms, their environmental preferences, environmental conditions at the site, and human behavior. Furthermore, changes in one of these variables should be associated with changes in the others. These premises underlie

the use of **ecological analogy**, analogies that use contemporary observations to infer historical relationships among animals, environments, and cultures and to calibrate environmental and cultural changes.

Interpretations based on analogies should not be accepted uncritically as evidence of former environments and cultures because some of these relationships have changed over the centuries, particularly in places with long records of human modifications (e.g., Carrott and Kenward 2001). Many analogies assume that organisms have not changed their habitats and niches during the intervening centuries or millennia. This premise is unlikely to be true in every case because many phenomena (e.g., competition, predation, community transformations) alter such associations, with or without human intervention (e.g., O'Connor and Evans 2005:160–162, 209–210). Organisms previously common in a region may now be rare and taxa formerly absent from the area may now be abundant. This is particularly the case for small organisms because many are highly sensitive to subtle environmental changes so that the suite of organisms at a site may change considerably over time (e.g., Kenward 1976, 2006; Plunkett et al. 2009; Webb et al. 1998). Multi-proxy studies are important controls for ecological analogies and one must always test the hypothesis that present environmental and ecological attributes reflect earlier ones. In this sense, the concept of uniformitarianism may not strictly apply to individual organisms and the communities with which they are associated.

The Disciplines of Environmental Archaeology

The disciplines of environmental archaeology are most closely affiliated with chronometry; site prospecting; the provenance, composition, and manufacture of material culture; site formation processes; environments; resource use; human biology; and molecular, biochemical, and elemental analysis (Brothwell and Pollard 2001). The topics can be grouped into the biological, chemical, and physical sciences, though no arrangement captures the diverse interests of environmental archaeologists, the overlap among those interests, or the diverse types of information contained in organic and inorganic materials (e.g., Butzer 2009; Orton 2000:162). Although many environmental archaeologists study remains from the **Upper** or **Late Pleistocene** (ca. 127,000–10,000 years ago) and the Holocene, this division is by no means universal.

This array of perspectives, practitioners, and objectives is reflected in the names associated with each discipline (Butzer 1982:35). Most names represent historical trends in scholarship and minor variations on common themes by practitioners with different research backgrounds, theories, goals, and languages (e.g., Faegri et al. 1989:176). Generally speaking, these names emphasize either cultural interpretations (e.g., subsistence strategies) or the materials themselves (e.g., soils, fungi, vertebrates). None of the traditional definitions of the disciplines that contribute to environmental archaeology reflect the complexity of each discipline or the broad research interests they share.

Differences in project goals and archaeological materials mean that some aspects are emphasized instead of others in most applications. Environmental archaeologists trained in anthropological archaeology generally know the archaeological record is a unique one best examined by integrating cultural and noncultural perspectives, but tend to use names emphasizing cultural aspects of archaeological materials. Those trained in other disciplines may give priority to noncultural characteristics of these same materials, using names that emphasize this perspective. Thus, an anthropologist may consider the stimuli, timing, and consequences of human migration into the Pacific and Caribbean archipelagos to be associated with key cultural processes fundamental to our species' history, whereas an ecologist may consider our species to be an invasive organism associated with severe ecological damage. Such distinctions between cultural and noncultural interpretations are unhelpful to the extent that they encourage researchers to ignore the potential of merging these perspectives.

The combination of geology with archaeology is referred to as **archaeological geology**, **archaeogeology**, **geoarchaeology**, and, in some cases, **archaeometry**. The difference between archaeological geology and geoarchaeology is said to be whether geological or archaeological questions are the primary research objectives (e.g., Canti 2001). Typically, the focus of such studies is chronometry, mineral identifications, landscape systems, sediments, soils, stratification, and post-depositional disturbances. **Geophysics** and **geochemistry** provide information about where sites are located, indicate promising areas for excavation using remote sensing techniques and chemical signatures, and suggest the provenance of finds. Physical and chemical analyses of elements and isotopes illuminate diets, nutrition, life histories, husbandry strategies, and climates. **Geomorphology**, the study of the form and development of the physical environment, suggests where sites might be located and provides information about landscapes, depositional settings, and agents of deposition. **Sedimentology**, the study of sediments, and **pedology**, the study of soils, examine the characteristics and formation of these important and fundamental components of archaeological sites. **Archaeosedimentology** and **archaeopedology** specify sediments and soils from archaeological sites. Archaeometry is identified with measuring physical and chemical properties of archaeological materials to locate sites, date them, determine the composition and provenance of artifacts, and study manufacturing technologies (Waters 1992:3). Sediments, soils, elements, and stable isotopes are important attributes of ecosystems, communities, and populations and provide critical insights into interactions among peoples and environments.

Ford (1979:286, italics in the original) defines **palaeoethnobotany** as "…the analysis and interpretation of the *direct* interrelationships between humans and plants for whatever purpose as manifested in the archaeological record." Pearsall (2000:2) writes that palaeoethnobotany is an aspect of **ethnobotany**, which includes both contemporary and archaeological studies of relationships among peoples and plants, and that **archaeobotany** is a variant of palaeoethnobotany. Others contend that the focus of archaeobotany is on the plants themselves, excluding cultural interpretations (Popper and Hastorf 1988). Palaeoethnobotany tend to focus on plant macrofossils

(e.g., seeds, wood). Two related studies are those of **pollen** and **spores** (microscopic reproductive cells; **palynology**) and **phytoliths** (silica deposits that form in plant tissue). **Paleobotanists** often focus on the evolution of plants over a timescale that extends beyond the Holocene; but in practice the distinction between palaeobotany and archaeobotany may be less the time period considered and more whether the focus is on plant evolution or on relationships among people and plants.

Zooarchaeology and **archaeozoology** refer to the analysis of animal remains from archaeological sites, sharing an intellectual history with palaeontology. This link is most closely demonstrated by **taphonomy**, which considers the processes associated with the formation of both palaeontological and archaeological sites. Although originally proposed for studies of animal remains, in practice such studies are not restricted to zoological studies, as will be seen in Chap. 2. The primary materials studied by zooarchaeologists are crab exoskeletons, mollusc valves, and vertebrate skeletal and dental remains. Hair, skin, feathers, egg shells, and other animal remains are studied by zooarchaeologists. Some animals, such as insects, intestinal parasites, earthworms, and very small molluscs, may be studied by palynologists, pedologists, or sedimentologists because they have access to chemicals, fume hoods, and high-powered microscopes sometimes needed to examine these organisms.

In the tradition of American archaeology, **bioarchaeology** refers to studies of human remains (Larsen 1997:3). Bioarchaeology once was an alternate name for zooarchaeology (Clark 1972), as was **osteoarchaeology** (Reed 1963). In some cases, bioarchaeology refers to all organisms except people, sometimes as part of a dichotomy that distinguishes between earth and biological sciences (e.g., Butzer 2009; Derevenski 2001; Wilkinson and Stevens 2003:17, 23). Humans must meet the same requirement to successfully recruit the next generation that confronts all organisms. It is difficult to envision how the dynamics of environments or cultures can be investigated without reference to the evidence for success or failure that is recorded in human remains. Nor should this rich source of environmental information be ignored, given the extent to which changes to Earth during the Holocene are products of human behavior. It is impossible to do so in some cases. The study of human remains has grown beyond the perspectives of what once was known as physical anthropology, enhancing the insights human remains offer to environmental and cultural histories, functions, and structures. This is particularly true of evidence for physiological stresses, pathogens, disease ecology, diets, biomechanical and activity patterns, injuries and violence, and population histories that elaborate upon aspects of demography such as age and sex (Schutkowski 2001). Isotopic, elemental, organic residue, and genetic analyses of human remains link biogeochemical, cultural, and hydrological systems by transcending disciplinary boundaries among human biology, nonhuman biology, geology, chemistry, and physics.

The prefix "ethno" may be used to links studies of organisms from archaeological sites with **ethnography** (description and analysis of contemporary cultures at a given place) and **ethnology** (comparative study of contemporary cultures; e.g., Ellen 1982:206–211). Studies of contemporary peoples distinguish between the perspectives of the observer (e.g., the researcher) and those of the observed (e.g., the contemporary population). Folk classifications of environmental phenomena are

particularly informative of perceived relationships. Fields such as ethnotaxonomy and ethnopharmacology explore classification systems, vernacular nomenclature, and ways in which resources are used today. Through such studies we learn of relationships among peoples and their environments that may be invisible in the archaeological record, such as the use of materials as drugs, cosmetics, tools, or building products, age- and gender-based divisions of labor, and belief systems that dictate appropriate schedules for the use or avoidance of specific fishing or harvesting practices. In the archaeological setting, we see some of the consequences of such choices, but may not know what the choices were. This terminology may be applied to archaeological phenomena, such as ethnobotany (e.g., Pearsall 2000:2) and ethnozoology (e.g., Cleland 1966), as a way to emphasize that a particular study is an ethnography of human behavior and cultural institutions, albeit of those in the past.

Ethnographic observations are extended to the archaeological past through **ethnographic analogy** (using studies of living populations to interpret the past) and are elaborated upon through **experimental archaeology** (controlled studies designed to explore or reproduce patterns found in the archaeological record; e.g., Davidson and Carter 1998). **Ethnoarchaeology** (observations of contemporary site formation processes) and **ethnohistory** (use of documentary records and oral histories) are additional important tools used to interpret the archaeological record. Analogy and experimentation broaden our perceptions of social, spatial, and temporal factors involved in the formation of archaeological deposits. Like ecological analogies, however, they must be used with caution and interpretations verified through additional tests and multiple proxies (O'Connor and Evans 2005:214–220).

Units of Analysis

These disciplinary names do not do justice to the range of theories, methods, materials, and interpretations encompassed within environmental archaeology. They are overwhelmed by advances that enable the study of organisms that are neither plants nor animals (e.g., algae, fungi, formerly classified as plants) and analysis of stable isotopes, organic residues, and genetic materials. Increasingly, disciplinary boundaries are crossed for practical reasons. For example, site formation processes may be examined by ethnographers, human biologists, geochemists, or soil scientists. Many times, access to reference materials, reference standards, and equipment determines where and by whom the research is done. Some people question whether environmental archaeologists are truly archaeologists when so many are not employed in departments of anthropology or archaeology and much of the research does not fit "traditional" categories or require the practitioner to engage in field work. These distinctions may be largely semantic, but they are sources of tension between project directors and consulting researchers who operate under different assumptions about their goals and how to achieve them.

Environmental archaeology's strength lies in melding theories, methods, and perspectives that grew out of traditional disciplines to study the human past and relationships among peoples, environments, and ecosystems. On the principle that the field is best served by ignoring, overcoming, or dissolving these distinctions, this volume is arranged in terms of the materials studied rather than by research traditions that claim the right to study them.

The need to integrate rather than segregate these units of analysis is embedded in Kenward and Hall's (1997:665) discussion of indicator groups and taxa. **Indicator** or **ecological groups** are combinations of organisms defined taxonomically or by some other common element (e.g., habitat, seasonal preference). Kenward and Hall (1997:665, italics in the original) define an **indicator taxon** as "…*one which reliably carries the implication of the occurrence of some event*, *activity*, *or ecological condition in the past*" and an indicator group as "…*a natural grouping of organisms selected because it includes a range of stenotopic species which together encompass a wide spectrum of ecological conditions or human activities relevant to the aims of the study being carried out*." Indicator taxa, single species typical of, perhaps even restricted to, specific niches may not be as useful as indicator groups for studying environments or human behavior. Associations of organisms with similar requirements may indicate the presence of a particular habitat or use of particular collection strategy. Organisms with strong preferences for specific combinations of temperature, moisture, shade, and soil in such settings as woods, grasslands, salt marshes, dung, streams, or anthropogenic habitats are more informative than are eurytopic organisms with broad tolerances, at least in parts of their range (e.g., Atkinson et al. 1986; Schelvis 1990).

Although indicator taxa and groups are useful for specific studies, Kenward and Hall (1997) advocate a third unit of analysis. This is an **indicator package**, which they define as "…*a collection of recordable data of any kind which*, *when occurring together*, *can be accepted as evidence of some past state or activity*" (Kenward and Hall 1997:665, italics in the original). A synthesis of biotic, abiotic, and cultural data pertaining to archaeological deposits is an objective of all archaeological research, albeit difficult and seldom achieved. The first step toward this objective, however, is to ensure that a wide range of evidence is included in the research project through thoughtful field work and multi-proxy studies.

The Goals of Environmental Archaeology

Each contribution made by environmental archaeology emphasizes different aspects of four related goals. The first goal is to document and explain systemic relationships among humans and their abiotic and biotic environments. The second goal is to document the spatial distributions of phenomena, such as land forms, biological communities (biogeography, **zoogeography**, **phytogeography**), people, and social institutions at a given point in time. The third goal is to gain insights into changes in these phenomena and to define relationships among environmental changes and human

behavior through time. The fourth goal is to test theories about the phenomena being studied and the methods used to study them so as to improve upon those methods and the interpretations derived from them. For organizational purposes, these overlapping goals are summarized here in three sections: (1) environmental change and stasis; (2) human–environmental interactions; and (3) materials and methods.

Environmental Change and Stasis

The objective of studies focused on environmental change and stasis is to use the long-term and global perspectives of archaeology to clarify the causes, processes, and consequences of environmental dynamics. Reconstructing abiotic and biotic aspects of environments and documenting change and stasis require us to distinguish between broad environmental changes and related, or unrelated, ecological and cultural processes (e.g., Barker 2001). Of particular interest are the causal roles people may play in these changes, and their responses to them. The consequences of this interplay often are evaluated in terms of short-term adaptations, long-term sustainability, and systemic resistance or resilience.

Reconstructing environments and documenting environmental change require us to compare characteristics found in the archaeological past with those prevailing today, defining environmental characteristics prevailing when the site was occupied, and documenting changes that might have occurred before or after that occupation. The premise is that most organisms are faithful to specific environments and their most common responses to novel or adverse conditions is to alter their growth habits or relocate, if they can. Environmental tolerances are not the only factors governing reproduction, growth, or biogeography; environmental tolerances of specific organisms, in fact, may be very broad or based on characteristics other than those that define climates or other environmental features (e.g., Preece 2001; Robinson 2001; Yalden 2001). Indicator packages that form distinctive, multi-spectrum units may offer more reliable temporal and spatial evidence than a single indicator taxon. Symbiotic and background organisms provide indirect evidence for environments through their association with anthropogenic habitats such as pastures, gardens, structures, stored goods, and refuse.

Peoples are, in part, responsible for some environmental changes because their activities destroy, modify, and create aspects of the environments in which people and other organisms live (e.g., Sandor 1992). People intentionally and unintentionally impact specific organisms by transporting them beyond their "natural" historical ranges (biogeographical expansion), extirpating them from those former ranges, driving them into extinction, or constructing habitats in which they flourish (e.g., Masseti et al. 2010). The archaeological record contains evidence for deforestation, reforestation, grassland or forest management, altered drainage patterns, erosion, siltation, construction projects, pollution, fire regimes, productivity, land use, soil formation, and mechanical stresses. Some of these phenomena are associated with human activities; others, such as weather patterns and atmospheric conditions, may not be.

Many of these changes coincide with plant and animal husbandry, but not all. Guilizzoni et al. (2002) and Szeroczyńska (2002) demonstrate the importance of both climate change and early farming on productivity and nutrients in lake ecosystems. Stinchcomb et al. (2011) show the extent to which land use related to maize (*Zea mays*) cultivation beginning in the Medieval Climate Anomaly (AD 1000–1300), amplified by the wetter, stormier conditions of the Little Ice Age (AD 1450–1530), played a role in floodplain sedimentation between AD 1100 and 1600 in eastern North America. Although people may have played little or no role in some changes, their responses are part of their culture's history and context.

Because archaeological evidence is largely the product of human behavior, anthropogenic causes should be considered and eliminated before concluding that environmental changes are due to nonanthropogenic causes. Many nonanthropogenic phenomena are associated with environmental change, such as isostatic uplift, tectonic movement, volcanic eruptions, floods, storms, plant successions and other ecosystem processes, coastal remodeling, and climatic cycles. Some of these produce archaeological signatures similar to those produced by anthropogenic causes. In other cases, anthropogenic and nonanthropogenic factors combine into a complex feedback system that intensifies both cultural and environmental responses (e.g., Wilkinson 2005). Deforestation associated with fields or timber harvesting might lead to mud slides and infestations of weeds and other pests, for example. Separating changes stimulated by the internal dynamics of a cultural system (e.g., new political leadership) from those influenced by nonanthropogenic environmental change (e.g., a storm or an extreme weather pattern) is particularly challenging (e.g., Büntgen et al. 2011).

Human–Environmental Interactions

Investigating human–environmental interactions uses contemporary observations of populations and community dynamics applied by ecological analogy to archaeological materials. The archaeological context, however, is, by definition, primarily a cultural one. Although environments have intrinsic characteristics, people confer upon them additional meanings. Many, perhaps most, human behaviors are based on anthropogenic perceptions and cultural criteria rather than on environmental and ecological realities. Although people must have nutritional and reproductive opportunities adequate to recruit the next generation, even the most casual survey of the archaeological literature demonstrates that people by and large met this challenge. People could interact with their environments in ways that might not have been the most efficient, sustainable, or logical from an ecological perspective, but which nonetheless prevailed in the cultural sphere at that time and place, even if such behavior led to environmental degradation and cultural extinction.

Environmental archaeologists also study **exchange systems** (e.g., reciprocity, redistribution, trade, markets, inheritance); trace migrations and colonization; reconstruct residential patterns; elaborate upon household behaviors; examine

institutions of social control; document the processes and consequences of urbanization or state formation; and consider conceptual landscapes (Charles and Halstead 2001). Resource management is linked to political complexity, social stratification, storage facilities, residential patterns, and formalized trade networks (e.g., Builth 2006).

Among the most basic and dynamic interactions are those involved in converting raw materials into goods and services (e.g., foods, raw materials, status) to foster our biological selves and our social environments. Organizing the acquisition, distribution, ownership, and inheritance of such materials is among the roles of economic, political, and belief systems. A primary function of cultural institutions is to facilitate the ways by which people obtain goods and services while ensuring that the costs required to find, catch, transport, process, distribute, and otherwise use them do not exceed their biological and social benefits. The criteria upon which choices are based derive from cultural interactions and judgments. Documenting which resources were used; how, when, where, by whom; the reasons for these choices; and the consequences of decisions related to acquisition, production, distribution, ownership, and inheritance is among the objectives of environmental archaeology.

Organic and inorganic materials provide goods and services beyond foods and beverages, such as fabrics, transportation, shelter, social symbols, tools, ornaments, and labor. Some are used as poisons, euphoriants, psychedelics, stimulants, and medicines. Others are used as adhesives, disinfectants, sealants, mordants, dyes, perfumes, incenses, and waterproofing agents. Many products have multiple uses, such as oils used in tanning, for light, and for warmth. Some organisms, usually domestic ones, provide dung used as plaster and other building materials, as fertilizer and fuel, or for other purposes. Some are exotic ornamentations, visual displays of a kin group, household, or individual's social affiliations, rights, duties, and authority (e.g., Masseti et al. 2010).

Subsistence strategies include decisions about where, when, and how to procure a resource and what to do with it once acquired. This can be generalized to include all economic activities that produce, distribute, and consume resources for whatever purpose. Distinguishing among nutrition, menus, diet, and cuisine is a useful way to consider foods and beverages (Reitz and Wing 2008:251). **Nutrition** is a measure of the physiological adequacy of a diet measured in terms of basic chemical requirements. Although plants and animals have fundamental chemical requirements, these can be met in many ways. **Menus** are lists of food items available, whether or not they are used (Armelagos 1994). **Diets** consist of foods and beverages actually selected from this menu. Some of these may be famine foods rarely consumed by anyone in the community and others may be highly desirable, but rare foods that only a few members of the community are able to enjoy. The quality, quantity, and composition of an individual's diet reflects season and location, in addition to the age, sex, and status of the individual (Dennell 1979). It is unwise to presume that our own dietary choices are shared by other cultural groups. Reinhard et al. (2006), for example, find evidence in **coprolites** (desiccated feces) that small prey animals may be eaten whole, a habit that affects subsequent analysis,

such as that of genetic material (Reinhard et al. 2008). Many different choices are made about how foods are procured, distributed, prepared, and served. These choices present culturally distinctive foodways or cuisines. **Cuisines** define the combinations of foods; the manner of preparation; the style of cooking; the social rules governing when, how, and by whom they are prepared and eaten; and the circumstances under which they are eaten (Farb and Armelagos 1980:228–229). These choices distinguish cultures from one another and serve important biological and social functions though they may not be readily observed in archaeological data.

Economic models emphasize the complexity of human responses and the diverse strategies used to manage costs, risks, and outcomes. Risk may be managed by physical storage of a surplus, social storage of a surplus through exchange systems and social obligations, resource ranking, ownership of valued resource locations, and labor organization. Long-term strategies must provide a good return for effort with minimal risk while meeting such objectives as satisfying social expectations and supporting social norms. Some decisions are based on the social value of the raw material or the final product. Nutrition-related strategies encompass which resources to use, the manner of their acquisition, preparation, the style of cooking, the social rules governing when, how, by whom they are prepared and eaten, and the circumstances under which they are eaten. Conscious and unconscious decisions are based on such criteria. Many behaviors are intangible, though ethnology, ethnography, ethnohistory, ethnoarchaeology, and experimental archaeology may elaborate upon the archaeological evidence.

Spatial associations, ubiquity, richness, and diversity may indicate which habitats or resources were most frequently used and distinguish between strategies that focused on a few resources (i.e., specialized) and those that used a wide variety of resources (i.e., generalist, diffuse). These strategies have related components that are important aspects of human behavior, such as diets, residential patterns, technologies, social networks, storage systems, population size and density, agricultural origins, gender and ethnic stratification, labor management, and the structure of exchange systems. Residential patterns relate to population size, population density, and the degree of sedentism that can be supported by a resource base and economy. The daily, seasonal, and annual availability of resources are important factors that people incorporate into their activities, especially into residential patterns, technologies, labor organization, and distribution systems.

Once an organism, or other resource useful to people, enters the human sphere, portions are distributed throughout the community. Patterns of resource distribution within a site or region and the presence or absence of other organisms or types of materials may be evidence of processing methods, special use areas, and exchange systems. Some modifications are associated with processing raw materials into foods and beverages, and others with the production of other products (e.g., textiles, watercraft, offerings). Processing techniques may correlate with the distance between where the resource is acquired and where it is used; domestication; and social organization (e.g., kinship, rank, norms, roles). Exchanges in raw materials or finished products over long distances may be direct; through intermediaries, some of whom may be specialists; or as tribute and taxes.

In addition to asking where, when, and how resources and resource areas were used, we must ask why they were used. Many patterns appear to be designed to manage risk and are linked to political institutions, social structures, social norms and roles (e.g., gender, identity), and belief systems (e.g., Halstead and O'Shea 1989; Miracle and Milner 2002). Such institutions are influential in the decision-making process as people endeavor to maintain familiar cultural systems. Jochim (1976, 1981), for example, postulates that large, mobile, scarce animals will be highly valued regardless of their nutritional content, just as big game is today. This concept can be extended to other resources, such as caviar, household furnishings, and beauty treatments. A human population can support energetic extravagances if basic requirements are met regularly through more efficient, more reliable, and less costly mechanisms. High cost or risk to acquire, process, and distribute an item may, therefore, correlate with prestige, authority, or wealth. In a culturally diverse community, this might correspond with ethnicity. Status and social hierarchy may be suggested by associations of specific forms of acquisition, processing, distribution, and disposal with monumental architecture, other public works, palaces, ceremonial precincts, and burials, or by evidence of communal eating or ritual feasting. Such interpretations are strengthened by architectural style, defensive structures, inner sanctums, artistic motifs, and similar architectural or artistic elements.

Causes and consequences of transitions from one mode of life to another, such as from pastoralism to farming or from rural to urban life, are of particular interest. An objective of this research is to consider whether transitions were stimulated by population movements (migration, immigration, colonization), diffusion of ideas or materials, or internal social dynamics and independent invention. Changes in the relative frequencies of one resource compared with others may mark alterations in patterns of acquisition, production, and consumption, perhaps even of the genetic or social identity of a site's occupants. These may have little to do with local conditions, but may be evidence of environmental changes elsewhere.

It is likely that our species has manipulated resources for most of our history (e.g., Summerhayes et al. 2010). Human–environmental interactions can be thought of in terms of a continuum that extends from hypothetical systems in which all biological resources are "wild," that is, untended and certainly not domesticated, to those in which all such resources are domesticated. Transitions along this continuum altered human life, environments, and ecosystems. These transitions were not unidirectional, irreversible, inevitable, or universal. Even today people rarely rely exclusively on domestic resources. Studying the causes and consequences of such transitions is an objective of environmental archaeology. Why did these transitions occur? Where were specific organisms domesticated? Why was such a limited suite of organisms domesticated? What were the biological processes and consequences of domestication for the domesticated organisms? What were the biological and cultural stimuli and consequences for people and their institutions? Many of the products that we associate with domestic plants and animals are **secondary products** that emerged during domestication. Wool, blood, dairy products, and some plant products are the results of domestication, not the stimuli for it. Widespread use of dung for fertilizer, fuel, and plaster may be a consequence of domestication.

Domestication itself is a series of interactions among peoples and domesticated organisms (Branch et al. 2005:7; Vrydaghs and Denham 2007). It is generally thought to be broadly associated with population increase, environmental change, or cultural dynamics, especially those involving political and economic institutions; but it is likely the process was multi-faceted and regionally distinctive (e.g., Conolly et al. 2011). To what extent were domestic plants and animals originally commensal organisms, organisms habituated to human manipulation by initially minor management behaviors (e.g., protecting, weeding, maintaining water sources, burning grasslands, providing supplemental nutrition), or organisms whose reproduction was purposely managed to encourage favored traits? The impact of tending, taming, transplanting, cultivating, and controlling specific plants and animals on environments and human lives was, and continues to be, great. Domestication may be associated with surpluses, storage, artistic displays, public works, novel ceramic traditions, increased labor demands, changes in residential patterns, changes in population size and density, complex ceremonial behaviors, and increases in social and political complexity. Domesticated organisms often occupy social roles well beyond their nutritional or other overtly economic value (e.g., Morey 2006).

Much research focuses on finding early locations and dates for domestication, defining the origins of domestic organisms, identifying wild progenitors, establishing processes and sequences leading to domestication, tracing the diffusion of the concept and the organisms, and assessing associated environmental and cultural conditions. At one time this research was based on theoretical concepts such as: only sedentary peoples had domestic food sources, all domestic resources derived from single origins; domestic foods supplanted wild ones; and surplus management. Many of these concepts derive from an early focus on the history of agriculture in southwest Asia and Europe (see Harris 2007 for definitions of agriculture and related terms). Clearly such concepts need to be rethought to incorporate more diverse combinations of resources at all levels of economic and political complexity in other parts of the world (Kennett et al. 2010; Kuijt and Finlayson 2009; Kusaka et al. 2011; Williams 2006; Zheng et al. 2009). Delineating the routes followed by some early domestic plants and animals from hypothetical centers of domestication to other locations documents processes of diffusion, trade, migration, political influence, and colonization.

Attitudes, ideology, ritual, and symbolism, so obvious today, are difficult to observe or interpret without ethnographic guidance (e.g., Lentz et al. 2008; Marr et al. 2004, 2007). Many organisms have specific associations with rites of passage when individuals or groups transition from one state to another by birth, puberty, marriage, death, and burial. Cultural values define organisms as preferred foods, nonfoods, famine foods, funeral offerings, feasting foods, sacrificial offerings, and social markers. Belief systems prohibit or encourage the use of organic materials for specific purposes, at specific times, in specific places, by certain people. Pets and floral tributes convey messages through color, behavior, habitat, specific portions, and intangible attributes (e.g., Sillasoo 2009). These attributes and their cultural significance may not be objectively evident in the organisms themselves (e.g., the color "pink" with female infants and the color "blue" with male infants in the United States). Some organisms accompany people as marks of status, food for the dead,

sacrifices, or as religious symbols; others are buried or enshrined on their own (e.g., Morey 2006). First-fruit ceremonies, harvest festivals, and fertility rituals continue to be important even in today's urbanized societies so detached from rural areas of production. Specific plants and animals are associated with hot or cold properties necessary to restore the body to its proper balance; figure prominently in ritual calendars and creation stories; or are linked with powerful phenomena such as storms, disease, famine, drought, warfare, or special skills. Taboos are difficult to verify in the archaeological record because materials that are sacred, powerful, or fearful may either be absent in the archaeological record because of avoidance behavior, or abundant because of the benefits conferred by association with the object. Although in some instances cannibalism might be a subsistence strategy, for both energetic and social reasons, it is more often a ritual act than a dietary one. Gifts or sacrifices (including those of people) to deities or their earthly representatives is another way in which resources are used. Merging taxonomic identification, iconography, art, and geochemistry provides evidence for some of these roles.

Residential patterns, trash disposal, storage, air and water quality, hygiene, sanitation, and water management have consequences for the living conditions and health of people and the resources upon which they rely (e.g., Ortner 2001). Hunting fruit bats and flying foxes (*Pteropus* spp.) in Indonesian Borneo today is not only a concern for conservation biologists as declines in bat populations affect pollination, seed dispersal, and other ecosystem processes, but also for disease ecologists who observe the risk of disease transmission from bats to domestic animals and hunters (Harrison et al. 2011). Routine aspects of daily life and work habits of both people and domestic animals modify their skeletal and dental remains. Husbandry techniques, such as stalling or supplemental feeding, affect the health and living conditions of livestock, with consequences for human health. Plant growth habits reflect management strategies, such as irrigation, weeding, coppicing, and selective harvest. Some diseases are associated with genetic affinities, sedentism, high population densities, close contact between people and domestic animals, or specific types of resources. Many aspects of human behavior enhance health (e.g., medicines) or encourage poor health (dietary restrictions, warfare, slavery, poisons).

Materials and Methods

The methods used to recover and study sediments, soils, and organisms have their own unique problems and promises. Many are experimental and test alternative theories about the biogeochemical world, hydrology, human behavior, and the ways archaeological sites reflect these phenomena. Stratigraphy and other aspects of context, site formation processes, and recovery methods are important links between the archaeological past and interpretations. Such connections need to be factored into interpretations. Data from a full range of temporal and spatial scales are needed to move beyond limited descriptions of specific excavation units to interpretations of environmental and cultural variability over time and space.

Many activities introduce organisms into the archaeological record, making it important to determine which materials represent human behavior and which do not. Our own cultural standards are not adequate criteria upon which to base this distinction. In some cuisines, guinea pigs (*Cavia porcellus*), dogs (*Canis familiaris*), and horses (*Equus caballus*) are relished; in others they are considered unclean, inedible, or too sacred to eat (e.g., Simoons 1967). Perhaps the most compelling evidence in favor of an economic role is the presence of specific organisms in feces and the digestive system or as residues on tools (e.g., Fullagar et al. 2006; Sobolik 2008). Symbiotic and background organisms may not directly reflect human choices, but they provide knowledge about the site's function, appearance, and history. Structures, waste areas, and refuse pits offer ideal habitats to organisms attracted to the built environment. Cave floors and the floors of buildings that once had high-pitched, thatched roofs may contain the remains of many background or symbiotic organisms intermingled with debris more directly related to human activities. The very archaeological matrix itself is altered by both anthropogenic and nonanthropogenic activities. Some organisms, such as earthworms, are active site formation agents.

Environmental archaeologists often explore the boundaries between **primary data** (objective, replicable observations) and **secondary data** (derivative, inferential data leading to revised hypotheses), the methods used to obtain both, and their reliability (e.g., Clason 1972). Primary data are obtained through a variety of methods and manipulated to derive secondary data. Not all of the observations needed for a thorough study are available for all specimens and additional data may be required by some research designs. Success in obtaining adequate data is dependent upon sampling designs and sample size. The choice of which method to use is related to the research question and the materials being studied. A single method is unlikely to serve all analytical needs and some methods are so flawed that they no longer are used. Each method has limitations, confounded by the fact that the phenomena being studied are individually and in combination varied, complex, and related in ways that are poorly understood.

It is largely to overcome weaknesses of specific materials and methods that environmental archaeologists strongly advocate regional, interdisciplinary, and multiproxy collaborations. Methods build upon each other and interpretations should be verified with data obtained from as many perspectives as possible. The study of diverse proxies enables conclusions drawn from one proxy to be tested against those drawn from others, and the weakness of one proxy to be overcome through the strengths of other proxies (e.g., Dimbleby and Evans 1974). It is important to validate interpretations by additional observations, as well as to conduct controlled experiments with the methods and materials themselves.

Goals of This Volume

Although environmental archaeology often is more closely identified with the earth sciences than with the biological sciences, the emphasis here is on biological remains. The primary goal of this volume is to help readers become informed users

of the historical record offered by organic materials recovered from archaeological sites and the sedimentary matrix in which those materials are preserved. Readers need to be familiar with general anthropological and ecological perspectives (this chapter), site formation processes (Chap. 2), archaeological research designs and field techniques (Chap. 3), and materials studied by environmental archaeologists (Chaps. 4–13). The final chapter (Chap. 14) summarizes contributions made by environmental archaeologists.

As increasingly sophisticated studies of biological materials are developed, environmental archaeology becomes less accessible to the broader archaeological community. Researchers whose interests are history, art, ritual, language development, gender roles, or trade networks (to name a few) find it difficult to keep up with, understand, or be interested in the fundamentals upon which environmental archaeologists rely. This was a stimulus for the earlier version of this volume published in 1981: to help nonspecialists understand what environmental archaeologists do and why.

Since the 1981 volume was published, environmental archaeology has become even more specialized and complex, with the gap between environmental archaeologists and the broader field of archaeology widening. Some argue, both within environmental archaeology and within archaeology, that a dichotomy now separates environmental archaeology from the broader pursuits of archaeology (Albarella 2001:7; Wilkinson and Stevens 2003:12). Some worry that environmental archaeology is marginalized; others insist that it is archaeology that has gone astray. A goal of this new volume is to offer a bridge over this gap by providing answers to some of the most basic questions, highlighting intriguing applications, and indicating limitations embedded within some of the more common materials and methods.

The 1981 volume included detailed descriptions of field and methodological procedures. Over the years, chemicals and equipment have emerged that have changed many of these procedures and we anticipate further developments (e.g., Goldberg and Macphail 2006; Larsen 1997; Pearsall 2000; Pollard and Heron 2008; Reitz and Wing 2008; Traverse 2008; Weiner 2010). Thus, laboratory methods occupy a smaller place in this volume to make room for information that may be more useful to people who do not expect to be environmental archaeologists. The volume is not intended to be an instructional manual on how to prepare and study wood, for example, but it is intended to enable the reader to know what wood is, be familiar with basic collecting and handling procedures, understand strengths and weaknesses involved in interpreting wood, and find references where more information is available.

Recognizing that many readers have little background in this subject, the chapters begin with descriptions of the taxonomy, anatomy, and morphology of the materials under review. Much more information is available in standard textbooks such as Campbell et al. (2008) and Krogh (2009). Readers may find it helpful to add to their libraries one of the many reference books available, such as *The Penguin Dictionary of Biology* (Thain and Hickman 2004).

A more specific goal is to provide sufficient background in the biological sciences to enable archaeologists and nonarchaeologists to know when a study might be useful, help nonarchaeologists understand archaeological contexts, and for all to

become aware of the needs of the others prior to field work, during excavation, and subsequently. All parties need to be familiar with topics and biases that arise when environmental sciences are applied to archaeological materials in order to know how environmental and archaeological data can and cannot be used.

We are committed to the idea that the method follows the question; one starts with a research question and identifies the most suitable method. The reader might not know that from this volume, however. A review of research questions is largely confined to this chapter and Chap. 14. This is so for several reasons. Environmental archaeology is an interdisciplinary field; with slight differences in emphasis, the same research questions could be repeated in each of the intervening chapters. To avoid this repetition, most chapters end with examples of applications that demonstrate contributions environmental archaeologists make to studies of the relationships among peoples and their environments. These applications offer broad geographical, temporal, and theoretical coverage. By demonstrating that studies in environmental archaeology rely upon multiple proxies, they transcend the organismal focus of much of this volume. These diverse proxies provide distinct perspectives on research, emphasizing the point that studies relying on single lines of evidence may lead to erroneous interpretations (Peacock and Seltzer 2008).

Colleagues will notice that many classic studies are not referenced here. This is a deliberate attempt to highlight studies that use current methods, represent trends in the field, and are accessible through reliable electronic outlets. Sadly, many of the foundational studies in environmental archaeology are not readily accessible. Some are becoming more widely available as individuals and laboratories post classic and current works on line, but this is limited and it is unclear who will maintain these electronic archives in the future. In addition, several survey volumes give particular emphasis to principles, theories, and interpretations developed in these important early works (e.g., Albarella 2001; Branch et al. 2005; Dincauze 2000; Evans 2003; O'Connor and Evans 2005; Wilkinson and Stevens 2003). There is no need to replicate these excellent surveys, though there is a need to supplement them with more fundamental information about the soils, sediments, and organisms upon which they are based. The studies highlighted in this volume build upon the classic studies, the primary literature, and theoretical interests embodied in these works. We hope that this volume will stimulate readers to seek out important early sources as they explore more deeply into this exciting field.

A Note on Chronology

The authors whose work is cited in this volume used the dates and notations prevailing at the time of their publication. Because establishing chronologies is not a goal of this volume, we use the dates as published by those authors. Radiometric clocks, such as those used in radiocarbon dating, have greatly improved the precision with which the age of a site, local and regional chronologies, and specific events can be dated. When Libby introduced radiocarbon dating in 1949, he surmised that the

concentration of radioactive carbon (^{14}C) in the atmosphere was constant through time, a premise that proved to be incorrect; thus radiocarbon dates generally are converted into calibrated dates. Other improvements in radiocarbon dating, as well as different ways of converting radiometric data into other formats, have led to several styles in characterizing dates (Kipfer 2000:5, 60, 78). One of the most common is BC/AD, referring to before Christ or after Christ (*anno Domini*) using the Christian calendar. BP indicates the date is before present, conventionally understood to be before AD 1950. BP dates are sometimes referred to as "years ago." The format "cal BC/AD" indicates that the date is calibrated, as does "cal BP." Sometimes dates are presented as bc/ad/bp (lower case), indicating uncalibrated radiocarbon dates, and BC/AD/BP (upper case), indicating calibrated radiocarbon dates. BCE/CE indicates dates before or after Common, Christian, or Current Era.

Summary

Environmental archaeology provides unique perspectives on human relationships with environments and ecosystems in the past and offers insights into the future. As evidence grows for a human role in environmental and ecosystem changes, the historical record of previous conditions contained within archaeological sites and of human responsibility for and responses to subsequent changes is of practical importance. Although this is by no means the only reason to be interested in environmental archaeology, it is a compelling one and makes the reissue of this volume timely. With this knowledge in hand, we hope that a broad audience will be able to evaluate and use environmental data from archaeological sites and that environmental archaeology will be incorporated into anthropological, biological, ecological, and geological theory in a more useful and accurate manner. For those who find the biological emphasis in this volume tedious, we urge them to recognize that environments, ecosystems, and cultures are not simple and none can be understood without the others.

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Chapter 2
The Processes by Which Archaeological Sites Form

Which of the materials recovered from archaeological sites represent human behavior and which do not? How were these materials altered over time? Are the materials representative of those present in the environment when the site formed? Which represent local communities and which are from distant locations? What were the processes by which the archaeological assemblage formed? These are just a few of the questions asked during an archaeological study, and the answers define many of the relationships among environments and cultures embedded in the archaeological record.

Archaeological sites are products of multiple processes that could produce similar results (**equifinality**), many of which are difficult to isolate. Archaeological sites form through interrelated cultural and noncultural processes, broadly termed **site formation processes**. Foremost among these processes are the choices people make about which resources to use and how. Resources often are used out of proportion to their abundance in the environment as people selectively extract resources for specific purposes. Further, materials recovered from sites are but a small fraction of what was originally used. Resources circulate within the human sphere and then are discarded, where further changes occur. The primary outcomes are inaccurate representation of materials compared with their original availability and use compounded by changes in the materials themselves, in the relationships of materials and contexts to each other, and the addition of other materials. These processes mix materials from one event with those from other events, or cause them to vanish altogether. Ecological analogies, experimental archaeology, and ethnoarchaeology all refine interpretations of the processes involved in the formation of archaeological sites.

Many environmental interpretations rely on distinguishing among the sources of organic materials recovered from archaeological sites. These materials may be **autochthonous** (endogenous, originating at the point of deposition, local) or **allochthonous** (exogenous, originating elsewhere). These do not necessarily have sharp boundaries between them. Kenward (1976), for example, divides allochthonous materials into **circumjacent** (originating within a few meters of the deposit), **local**

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(from the general area), and **regional** (from a wider area). Distinguishing among these sources requires identifying what happened to materials as they became part of the record; assessing the extent to which remains have been added, modified, or lost; identifying the individual agents or processes involved and their effects; and distinguishing among formation processes of environmental and cultural significance.

From Life Assemblage to Study Assemblage

The processes involved as the archaeological assemblage forms and while materials remain within the archaeological context can be considered **first-order changes**. First-order changes are reviewed in this chapter. Archaeologists have no control over them, but must accommodate them in excavation strategies and subsequent analyses. First-order changes have a profound influence on the archaeological record and its interpretation. **Second-order changes**, those associated with excavation and study, are considered in Chap. 3. Both chapters elaborate on first- and second-order changes from the perspective of organic materials; those affecting sediments and soils are reviewed in Chap. 5.

Archaeological materials pass through several stages from the time they enter the human sphere until they are studied (Fig. 2.1; Lyman 1994:17–31; Reitz and Wing 2008:119). Information about human behavior and environments is modified before, during, and after discard; during excavation; and through analysis and publication. The life assemblage of a region is large compared with what is used by people. The death assemblage is larger than the deposited assemblage, which in turn is larger than archaeological assemblages, such as the faunal assemblage in Fig. 2.1. The deposited assemblage represents choices about resources to use or avoid and how to dispose of them, decisions that differ through time and space. Other organisms may join the mixture without direct human intervention. The surviving deposit reflects autochthonous and allochthonous organisms, cultural decisions, and the ability of different materials to endure conditions encountered in the process of deposition. Second-order changes begin as field staff decides where and how to excavate and environmental archaeologists choose where to collect samples and which ones to study with what methods, resulting in the archaeological and, finally, the studied sample assemblage. These stages influence the potential of archaeological materials for reliable analysis.

In this chapter, we begin with the transformation of the living community into the archaeological assemblage, followed by a review of archaeological site types, the impact site type may have on environmental data, and abiotic and biotic processes significant to environmental archaeology. All materials found in an archaeological context are influenced by these processes (e.g., Andrus and Crowe 2002; Dobberstein et al. 2009; Gernaey et al. 2001; Gifford-Gonzalez et al. 1999; Hedges and van Klinken 1995; Hunt and Rushworth 2005; Kenward 2006; Lieverse et al. 2006; Lyman 1994; Noshiro et al. 2009; Shahack-Gross 2011; Stein 1992, 2008).

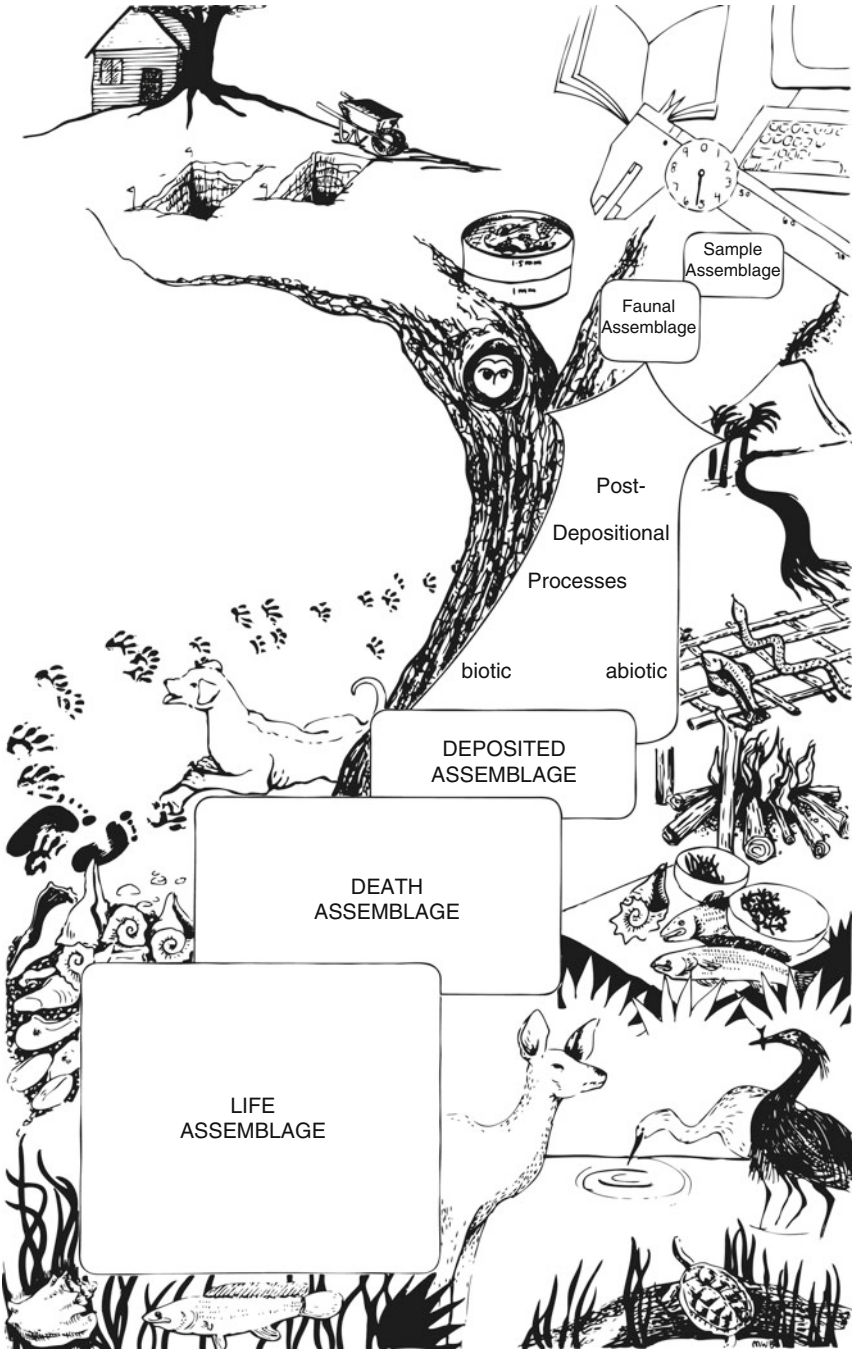

Fig. 2.1 The possible pathway of animal remains from life assemblage to sample assemblage. Drawn by Molly Wing-Berman. From Reitz and Wing (2008:119) and used by courtesy of Cambridge University Press

Site Formation Processes

Efremov (1940:85), a vertebrate palaeontologist, defines **taphonomy** as "…the study of the transition (in all its details) of animal remains from the biosphere into the lithosphere…." He broadly separates these events into those that occur between death and burial (**biostratinomy**) and those that occur after burial (**diagenesis**). These concepts are commonly used in environmental archaeology for both organic and inorganic materials, but the distinction between pre- and post-burial, originally proposed for palaeontological sites, is hard to maintain for archaeological materials, where the path from living being to archaeological specimen involves many complex human behaviors. In practice, "taphonomy" may refer to both noncultural and cultural influences or be combined into the broader category: site formation processes. Site formation processes are active at many temporal, spatial, and functional scales. They encompass the full time frame of transformation and all the agencies involved, some of which are unique to the human sphere. O'Connor and Evans (2005:69) extend taphonomy to include excavation, publication, and curation of materials. Applying taphonomic concepts to archived materials, sadly, is appropriate, though we refer to excavation and post-excavation processes as second-order changes in the next chapter.

Efremov (1940) identifies several challenges to interpreting a palaeontological assemblage. First, the extent to which an assemblage reflects the original living community (**biocoenosis**) is largely unknown. Second, the death community (**thanatocoenosis**) reflects the number of species in the original life community, the rapidity with which they died, the length of time their remains accumulated, and the existence of conditions favorable or unfavorable to preservation. Third, excavated collections are accidental accumulations of remains and likely poor reflections of the original life or death communities. These challenges apply to some extent to all archaeological deposits and materials.

Related geological and biological processes need to be considered to resolve these problems. One group of processes, biostratinomy, encompasses the disorganization and attrition that occurs between death and discard. This might include such noncultural processes as chemical or mechanical damage and scavenging in addition to human behaviors such as harvesting, transporting, processing, and exchanging materials. Diagenesis occurs after discard and includes postdepositional biological, chemical, and physical processes that lead to disorganization, dissolution, contamination, and (occasionally) preservation. Diagenetic processes depend on the chemistry of sediments and soils, temperature and humidity cycles, and mixing of materials by biological agents (**bioturbation**). Studies of biostratinomy and diagenesis are enhanced by familiarity with contemporary processes, the focus of ethnographic observations and experimental archaeology.

Cultural Site Formation Processes

Site formation processes are intrinsic to archaeological sites. Schiffer (1976:27–28, 1983) defines a **systemic context** (S), the living community of people and other

organisms in which materials originate, and an **archaeological context** (A), the one into which these materials are deposited. In the systemic context objects are in use within the cultural system and in the archaeological context they no longer are in use. In the terminology of taphonomy, many events in the systemic context are associated with biostratinomy and those in the archaeological context are subsumed under diagenesis. Materials that survive to be excavated pass through both contexts. **C-transforms** are cultural processes and **n-transforms** are noncultural ones, both of which move materials among contexts, sometimes more than once (Schiffer 1976:14–15).

Four processes describe the direction of transformations as materials move between systemic and archaeological contexts. **S–A processes** transfer materials from systemic to archaeological contexts through discard, burial, loss, or abandonment (Schiffer 1976:28, 30–34). In **A–S processes**, scavengers, reuse, looters, erosion, tree-falls, and burrowing organisms, among other agents, transform materials from the archaeological context back into the systemic context (Schiffer 1976:29, 34–36). Items returned to the systemic context eventually may reenter the archaeological context. **A–A processes** are those in which materials move within the archaeological context, perhaps through plowing, channelization, or bioturbation, but remain buried (Schiffer 1976:29, 36–37). **S–S processes** keep materials in the systemic context for an extended period, perhaps because they are valued social symbols, because they are costly to replace, or for their sentimental value (Schiffer 1976:29, 37–41). Such items may enter the archaeological context after many years of use or display. It is not uncommon, especially in areas where building materials are scarce, to find that dressed stones and wooden lintels were removed from older structures and reused in later ones, a process that continues today. The consequence of these four processes is that materials may not be recovered from the archaeological time or place in which they were originally made, used, or discarded.

Archaeologists distinguish among primary refuse, secondary refuse, and de facto refuse (Orton 2000:59; Schiffer 1976:30). **Primary refuse**, such as fuel wood in a hearth or animal waste on a slaughter house floor, is discarded and subsequently recovered from the location of use. **Secondary refuse** is deposited at locations other than where it was used. Secondary refuse is found in pits or structures intended for deposition (trash pits, latrines) or in those originally intended for other purposes (e.g., wells, moats) and later filled with debris. Rubble fill inside dressed-stone walls, around the base of a foundation, or supporting a modern roadway may be secondary refuse. Secondary refuse is removed from its original behavioral context. **De facto refuse** consists of usable items that are abandoned; they enter the archaeological context where they were used, perhaps because they were hidden or lost. Caches of seeds in storage pits or jars are de facto refuse. These types of refuse represent different temporal scales. Primary deposits are created over a slightly longer period of time and include materials that accumulated after debris was last cleared from that location (if it was cleared). Secondary deposits contain a mixture of materials that accumulated from multiple events someplace else over shorter or longer periods. Deposits of de facto refuse are often small, representing specific, brief activities.

Burials of people and other materials (either as grave goods or by themselves) are difficult to classify in these terms. This is particularly the case where "burial" involves exposure, perhaps followed by additional rituals and subsequent interment or cremation. In some cases the deceased individual is revisited over the years, the surviving portions of the skeleton rewrapped in some fashion, and provided additional offerings. Or the remains of an earlier burial are displaced when a new body is added to the grave. All of these steps, and others, mix the original burial with materials from subsequent events. Grave-robbing, of course, is an additional form of bioturbation.

The association of refuse and time raises the issue of **time averaging** (Lyman 2003; Stiner et al. 2001). Sites rarely offer a continuous or undisturbed record. Instead, they contain evidence of episodic events in the long and complex history of human interactions with, and modifications to, their environments. Time-averaged deposits include materials from multiple seasons, years, behaviors, and, probably, habitats. Such non-contemporaneous materials may be found in deposits that appear to represent a single, contemporaneous event. In truth, it is very difficult to recognize short-term depositional contexts in which all of the materials were, quite literally, used and discarded together at precisely the same time. Separate depositional episodes may appear continuous when, in fact, they were sporadic.

People share their lives with symbiotic, synanthropic, and background organisms. Caves, buildings, gardens, burial pits, fence rows, and other contexts are used by many organisms. These typically are harmless, but may include potentially dangerous organisms from bacteria, to poisonous plants, to large carnivores. People may consider them pests, if they are aware of them at all, and some are useful because they help control discarded refuse. Organisms such as these are not simply inadvertent inclusions, but site formation agents in their own right as well as indicators of former environmental and cultural conditions.

Types of Sites

The transformation of the life assemblage into the study assemblage begins with the choices people make among resources; their means of acquiring, using, and discarding resources; and a host of biological, chemical, and physical processes associated with different types of sites. Each site type represents different facets of human behavior, contains different evidence, and offers different opportunities for the survival of that evidence (e.g., Hudson 1993).

Archaeological sites are diverse and it is impossible to enumerate the full variety. Three major site types are linked to extracting, using, and disposing of organic materials: extraction or processing sites; residential, occupational, or monumental sites; and sacred sites. Human behavior is infinitely varied and these categories suggest distinctions among sites that do not exist in reality. Many sites do not fit into one or even several of these categories. For example, fields, gardens, trails, paths, tracks, causeways, and irrigation systems are associated with some sites. These may lie within a farmstead or city, or be far afield. They may link residential areas with ritual

sites; but not be either residential or sacred themselves. Some, such as fields and gardens, could be considered extraction sites; but they could be considered a fourth type of site: producer sites. Terraces may be producer sites, or they may be residential sites. Much of the excitement in archaeological research lies in efforts to clarify which behaviors took place at a given location, by whom, when, and why in order to define the site in such terms. Environmental archaeologists devote much of their research to these questions as well. The summary that follows is altogether too brief to capture the complexity of human behavior, and is only one way to think about the types of sites they leave for us to study. For more information about the variety of archaeological sites, the reader should consult an introductory archaeology text (e.g., Hester et al. 2009; Kelly and Thomas 2010; Orton 2000; Renfrew and Bahn 2008).

Raw materials are acquired and processed at **extraction** and **processing sites** for use elsewhere. Such sites are located near the raw material. If fields are considered extraction sites, they might be associated with water or productive soils. Although often used temporarily, some, such as fish weirs or shellfishing stations, might be revisited many times during a year or over several years. People may live at these sites briefly, to protect fields or flocks from predators, to make the best use of a short season, or to allow time for reducing some of the transportation costs by a preliminary processing of raw material to reduce unwanted bulk. The number of people involved may be small (e.g., a nut-collecting party) or large (e.g., a communal animal drive). Such sites may contain no evidence for structures or only for ephemeral ones. Some might be very casual, used by people to collect fibers for baskets or prepare a snack. Such short-term, special-use sites are often difficult to find during surveys because the material deposited is minimal, but the debris left behind (e.g., a whale or sea turtle skeleton) will likely be absent from the residential site. Debris is often specific to the activity, accumulates over a limited time frame, represents a particular segment of the annual cycle, and consists of locally available resources. Because they are indistinct, however, this part of the systemic context is largely undocumented.

Most known sites are **occupational**, **residential**, or **monumental sites**, terms that encompass many different cultural behaviors. These sites range in size from isolated farmsteads, to villages, to massive temple complexes. Some sites were occupied for a few weeks or months each year during a seasonal migratory round or intermittently for long periods of time each year by non-sedentary peoples. Others were occupied by sedentary populations, though the size of that population might fluctuate during the annual cycle or in response to social or political calendars. Some of the activities at these sites were organized spatially, distinguishing between cooking and sleeping areas, craft centers, sacred and profane areas, or public and private areas. Other activity areas include temple mounds, trash pits, men's houses, municipal structures, granaries, markets, barracks, plazas, drying racks, butchering areas, hearths, wells, fence rows, barns, ovens, stables, corrals, latrines, entry ways, and cesspits. Some activity areas may reflect lineage, occupation, gender, age, political affiliation, social status, or ethnic identity (e.g., Hastorf 1993). Many activity areas appear as a confusing array of stains left by decayed posts, but the activities in each part of the site, including open spaces, may leave different signatures in the record (e.g., Canuto et al. 2010; Shahack-Gross et al. 2004). Debris at residential

sites includes primary, secondary, and de facto refuse. Such sites are often occupied over many years and time-averaging is to be expected.

Not all monuments are sacred; and some sacred sites are very small, isolated from residential areas, and may not have imposing structures associated with them. Sacred sites include larger constructions (buildings, mounds, sacred wells) dedicated to ritual practices, as well as cemeteries, other burials, and ritual offerings. Sacred locations offer insights into social organization, symbolic life, health, activity patterns, demographic profiles, and genetic affiliations. Sometimes, it is possible to distinguish between a **primary burial**, the initial burial, and **secondary burials**, subsequent additions of other individuals or burials moved to other locations. Burials may be intact or partial, individuals or groups, inside or on top of structures, in ceramic vessels, under house floors, in remote caves, or in mounds. They may be accompanied by offerings. Offerings may be ritual sacrifices of people and other organisms buried under cornerstones, in special pits, or left at shrines (e.g., Andrushko et al. 2011). Some mortuary practices hasten decomposition (exposure), reduce the burial to ashes (cremation), or enhance preservation (mummies; e.g., McKinley and Bond 2001; Zimmerman 2001). Decomposition may be slow in caves, at high altitudes, in **bogs** (wet, spongy ground), and in ponds, where materials such as parasites, floral tributes, fibers, leather, and stomach contents may survive.

Each type of site provides evidence for specific human activities and offers different biological, chemical, and physical conditions that enhance or impede the survival of organic materials. Open-air sites are exposed to weather extremes; cave sites are more protected. The debris at extraction sites may be discarded casually and be more vulnerable to scavenging or decomposition than refuse buried in a pit at a village. To the extent that initial processing occurs at extraction sites and only the portions valued for tools, medicines, ornaments, or other purposes are transported to the residential site, both locations present modified windows on environments and human behaviors. Residential sites represent a broader array of human behaviors and environments than do extraction sites, burials, and offerings. Most of the organic material at residential sites decays eventually, but some materials may be discarded in locations that offer better potential for survival. Materials may cluster in specific sectors of a residential site, such as near a hearth or in a high-status residence. Some will be missed if only a small portion of the site is excavated. Sacred contexts represent unusual behaviors and offer special insights into cultures and environments, but materials from such locations may represent choices that are not characteristic of routine, secular life, or the local environment.

Cultural Transformations

Many first-order changes mix deposits across archaeological strata. Stratigraphy will be discussed in more detail in Chap. 3, but the concept is introduced here because factors that alter original stratigraphic associations are significant site formation processes. Most archaeological sites grow **stratigraphically**, in a sequence

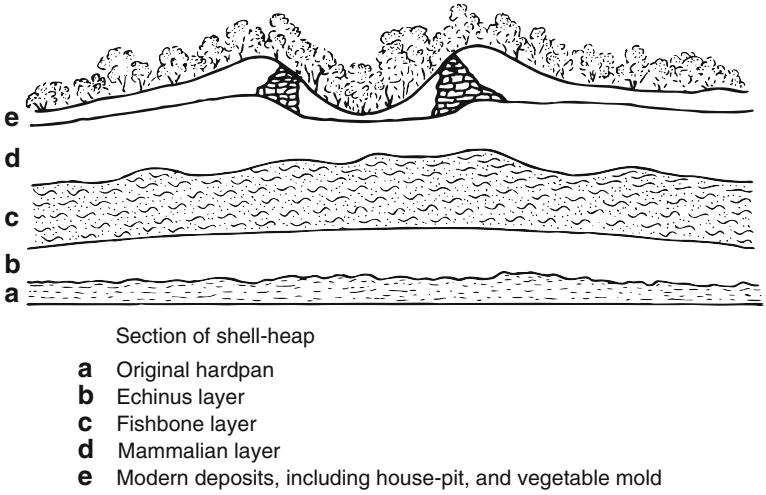

Fig. 2.2 Section of an Aleutian shell-heap with strata defined by sea urchin (*Echinus*) and vertebrate (fishbone and mammalian) layers. Modified from Dall (1877)

of layers or **strata** (singular: stratum). Based on the **Law of Superposition**, the lower strata often are older than the upper strata. Undisturbed strata represent a specific human behavior, or natural processes of sediment deposition, at a given point in time, though the stylized layer-cake in Fig. 2.2 (Dall 1877) is rare. **Single-occupation** or **single-component sites** were used once, often for a relatively brief period, and then abandoned. Sites occupied continuously or several times over centuries or millennia are termed **multicomponent** or **multi-period sites** (more than one time period is represented). Multiple occupations usually appear as superimposed, temporally distinctive strata. Sometimes, the occupational sequence not only produces vertical occupational strata, but also a linear pattern in which the site extends over some distance, perhaps along a river bank or road (**horizontal stratification**). Some multicomponent occupations produce discontinuous deposits that merge over time into what appears to be a single site. Strata may be **sterile**, meaning they lack evidence of human occupation. The following is a simplistic sequence of cultural transformations from the living, systemic context to the archaeological context.

The initial cultural transformation occurs at extraction or processing sites, which reflect resource(s) targeted, timing, location, and technology. People are highly selective and, under normal circumstances, only use resources or clear areas they consider desirable for specific purposes. Resources are acquired using an array of techniques that target plants and animals with the desired characteristics, and leaving unharvested less desirable ones (e.g., Oswalt 1976). This skews the death assemblage away from the life assemblage. Resources are avoided for a variety of reasons, some of which are related to their suitability to the intended use. In other cases, resources are avoided for ideological reasons; for example, the organism may be so

closely identified with the human community that people will not harvest it out of respect, concern for the community's prosperity, or similar beliefs. Although selectivity is an inherently interesting behavior, it begins the process by which the study assemblage diverges from the life assemblage.

Extraction sites may be near the residential site or some distance away. Resources transported a short distance may document environmental conditions near the site when it was occupied. Distant resources, or ones entering the site through trade or tribute, do not represent the local environment. Evidence for distant resources is helpful in understanding cultural systems, and provides information about regional environments, but is less useful for studying local conditions. Trade goods might be indirect evidence of local environmental changes that encouraged people to seek critical resources from more distant locations. They also may indicate environmental changes at the point of origin such that distant populations sought local trading opportunities, or they may be evidence of kinship or political alliances.

Once the resource is acquired, processing impacts its chance of entering the archaeological context. The decision to process a resource at an extraction site is based on the size or weight of the resource, the distance over which it would be transported, the type of field processing required, the number of people available for processing and transportation, and the resource's uses at the residential site. Husking and boiling nuts to extract oil reduces the costs of transporting the edible part back to the residential site, where there may then be little direct evidence that nuts were used. The meat of molluscs and sea turtles may be highly prized and frequently consumed, but if initial processing leaves heavy valves and skeletal parts on the beach, there may be very little evidence at the residential site for their use (e.g., Bird et al. 2002). Reptile and bird eggs may be eaten on the spot rather than risk the breakage or spoilage that might occur during transportation. On the other hand, some materials are useful as ornaments, construction materials, dyes, and other purposes and may be transported to the residential site at great cost in time and effort.

After materials reach the residential site, further subdivisions occur that affect what survives and is recovered. Usable parts are separated from unusable ones and resources that will be eaten are separated from those valued for other purposes. This means that edible and nonedible portions traverse different routes through the site. Areas in which food processing, cooking, secular food consumption, tool manufacture, and ritual feasting occur may be located very close to each other or widely separated. Grains might be threshed, winnowed, sieved, ground, and cooked or stored at different places within the site. Food processing and cooking methods affect what survives to be discarded and where it is discarded. The residue from these activities might be used as fodder or fuel. Accidental burning and incomplete processing are both likely to occur in some contexts. Many plants are harvested before they produce seeds, or only vegetative parts are used. Viable seeds may be safeguarded for next year's crop; others disappear altogether. Some materials are preserved for storage (e.g., salted, fermented, **parched** [heated gently]).

Reciprocity and redistribution disperses resources within and beyond the site with some expectation that similar resources may be returned at some point in the future. In **reciprocity**, goods and services are given with no immediate expectation

of return or overt attempt to assess value. Materials are routinely exchanged at naming ceremonies, funerals, and other important ritual occasions. One need only think of the obligations of wedding gifts to understand the combined informality and formality associated with reciprocal obligations. **Redistribution** is an exchange system found in societies with social inequality where elites accumulate resources, store them, and later redistribute them. The obligation may be to redistribute all of these goods, but some may be retained to benefit a high official, kin group, religious hierarchy, or state. Communal feasts, such as the potlatch of the Pacific Northwest coast (Canada; USA), are ceremonial forms of redistribution. Redistribution may be a mechanism for managing extremes in resource availability (Brumfiel and Earle 1987), as a form of social storage.

A variety of other behaviors may influence the archaeological evidence, from the largest animal bones to stable isotopes and other chemical elements, and organic molecules. Plant and animal husbandry strategies are significant site formation processes (e.g., Jones et al. 2010). The location and management of arable fields, fallowing, tillage, crop and pasture rotations, manuring, sowing, harvesting, balances between livestock and plant husbandry, and supplemental feeding of livestock (what, when, where) can all affect archaeological deposits. Livestock and crop management decisions, such as whether fields are fertilized or irrigated, trees pruned, herds foddered, crops stored, or animals sheltered during the winter, all influence the record. Sources of irrigation and drinking water are important. Substances ingested throughout life leave evidence in sediments and organic materials. The length of time infants are breast-fed influences human biogeochemistry. A particularly important variable is the movement of people during their lives, either through their own volition or by force, to be buried someplace other than where they were born.

Feasting, sacrifices, and other ritual behaviors are important site formation processes (e.g., Munro and Grosman 2010). Feasting deposits may contain organisms that are distinctive compared with non-sacred deposits or the organisms may be present in unusually large quantities. They may be rare, large, or have special attributes, or be costly to acquire in terms of time, effort, or risk. Some refuse is sacred and discarded in special areas, with unusual care, or with rare objects. Human remains often receive special care, but some bodies or body parts are just discarded; perhaps they were considered "not human" because they violated social norms, were from the wrong social group, or were too young to be accorded full honors.

Through such cultural transformations, organic materials are altered, eventually leaving the systemic context and entering the archaeological one. The more primary processing that takes place at a site, the more waste products will be discarded there. Common areas at a village may have lost most of the material discarded within them because such areas were swept or trampled, but a great deal of debris may collect in low-traffic areas. Refuse from food, fodder, and craft by-products is lost along paths, accumulates next to buildings, is discarded into creeks, or is thrown into abandoned structures or piles that become large accumulations of trash (**middens**). Sedentary populations in urban centers sometimes take a more organized approach to sanitation and trash disposal, discarding refuse into pits, burning it, feeding it to

livestock, or using it as fertilizer, but the air and water quality of densely occupied communities may be poor. Architectural features such as floors and burial mounds may protect underlying sediments, leaving them as records of preconstruction conditions. In addition to being careless about trash, people may be casual about where they dispose of human waste. **Palaeofeces** (human or animal feces), including coprolites, are found in latrines and similar contexts, but a surprising number are found on house floors and middens (e.g., Bathurst 2005; Reinhard 2008). Walters (1985) describes materials at a modern Aboriginal camp in Australia as being in a constant state of flux.

Archaeological Transformations

Archaeological transformations continue the process by which the living community becomes the study assemblage. There are two types of transformations: abiotic and biotic. **Abiotic transformations** include physical and chemical processes. **Biotic transformations** are associated with organisms. Many abiotic conditions facilitate or discourage biotic transformations (e.g., French 2003:13–19; Grupe 2001; Jones and Colledge 2001). These two types of transformations are not exclusive; most archaeological materials are subjected to both.

Abiotic Transformations

Abiotic transformations are associated with chemical conditions, temperature, humidity, and physical or mechanical forces (e.g., wind, water, ash falls). Soils are formed and changed by abiotic processes, as well as by biotic ones (e.g., Stein 2008). They move organic materials from life, death, and discard locations, alter them in a variety of ways, promote the preservation of some, and cause the destruction of others. Fluctuations in the water table and dissolved minerals in the deposit replace organic constituents of materials with inorganic ones, leading eventually to fossilization. As discussed below, few, if any, archaeological materials are true fossils.

Base status is an important aspect of the depositional environment. **Base status** refers to whether the soil is acidic (pH < 6.5), neutral (pH 6.5–7.5), or alkaline (pH > 7.5; Goldberg and Macphail 2006:32). The **pH** level (*p*otential of *H*ydrogen, measured as the concentration of hydrogen ions) is termed "high" in alkaline deposits and "low" in acidic ones. The types of organisms present and the preservation potential of organic materials differ depending on whether conditions are acidic, neutral, alkaline, or waterlogged (Table 2.1; Battarbee 1986; Goldberg and Macphail 2006:47, 61). Base status, combined with moisture, influences biological activity and preservation (Goldberg and Macphail 2006:61, 65).

The ideal pH for preserving bone mineral (**hydroxyapatite** or **carbonate hydroxylapatite**) of vertebrates is reached at about 7.6–8.1, depending on ambient

Table 2.1 Soil characteristics and preservation of organic remains in humus[a]

Conditions	Parent material	Humus form	Soil organisms	Preservation potential	Comments
Acid pH <3.5–6.5	Quartz sand; schist	Mor and Moder	Mites, non-burrowing segmented worms, fungi	Pollen, macrobotanical material, phytoliths, diatoms	Raw humus with few microorganisms. Surface litter (mor) and insect mull. Bone is lost
Neutral pH 6.5–7.5	Loams	Mull	Springtails, terrestrial slugs, burrowing earthworms, bacteria	Bone, molluscs, phytoliths, diatoms, some macrobotanical material	Pollen is oxidized; large-scale mixing by meso- and macro-fauna, charcoal can become fragmented
Alkaline pH>7.5	Shell, sand, chalk, salt, lake sediments	Mull	As above but biotic activity becomes restricted	Molluscs, bone, phytoliths (except for pH>8)	Pollen is oxidized; salt, carbonate, and gypsum crusts on pottery and other artifacts; large-scale mixing by meso- and macro-fauna, and fracture by secondary crystal growth
Waterlogged	Peat, estuarine sediments	Peat	None	Pollen, molluscs, diatoms, most organic materials, including insects, skin, leather	Soft-tissue "pickling" (e.g., bog bodies)

[a]Mor, moder, and mull are found in the upper levels of soil (humus). Mull is leaf litter with high biological activity, moder forms where products of decomposition accumulate and has moderate biological activity, and mor is raw humus or duff with low biological activity. Peat is an accumulation of dead organic matter in waterlogged contexts. Modified from Goldberg and Macphail (2006:47)

temperatures and the specific chemical environment (Berna et al. 2004; Linse 1992). Bone mineral is increasingly soluble as alkalinity increases (pH > 8) or acidity increases (pH < 7; Gordon and Buikstra 1981; Linse 1992). Some archaeological deposits consist largely of mollusc valves. Calcium carbonate in these valves forms a matrix that neutralizes hydrogen ions in the soil, and may create a shell "umbrella" that sheds water. In this way, mollusc shells "buffer" the pH while protecting fragile organic materials from mechanical damage, producing conditions associated with outstanding preservation of vertebrate skeletal and dental materials in deposits containing large quantities of shell (Weiner 2010:77).

Alkaline conditions that enhance preservation of vertebrate remains usually are poor for preserving plant remains, most of which survive best in acidic conditions unless they are transformed in some way (e.g., Braadbaart et al. 2009). Plants generally are poorly preserved because of the properties of the materials and the ways people use them; many plant remains are eaten or otherwise destroyed by processing and use. **Diatoms** (plant-like protists), pollen, and phytoliths have better prospects in some otherwise unfavorable contexts due to their chemical composition, density, and surface characteristics. High pollen frequencies may occur in acidic contexts where pH values are lower than 5 (Dimbleby 1957). Phytoliths tend to be poorly preserved in contexts saturated with carbonates (e.g., shell-bearing deposits) and alkaline contexts with a very high pH (9 or above). Phytoliths are particularly vulnerable when high carbonates and alkalinity are combined with high temperatures and rainfall (Piperno 2006:22).

Chemical weathering refers to the decay and alteration of minerals in inorganic and organic materials. It includes hydrolysis, oxidation/reduction, and solution (Goldberg and Macphail 2006:64). Oxidation potential (**Eh**) is closely related to pH and influences the preservation of pollen, which is susceptible to oxidation (Pearsall 2000:260–261). High Eh and neutral or alkaline pH levels are particularly harmful for pollen (Faegri et al. 1989:148).

Mineralization by replacement, impregnation, or coating may occur where other forms of preservation are less common (e.g., McCobb et al. 2001, 2003). The preservation of plant remains through precipitation of metal corrosion products is of special interest because such materials may be recovered from contexts otherwise unsuitable for plant preservation (Green 1979; Keepax 1975). In some cases, even surface ornamentations of seeds are preserved by replacement or impregnation. The degree of preservation is variable, reflecting durability, organic input, rate of burial, decay rate, and hydrologic properties (e.g., McCobb et al. 2001). Seeds and fruits are replaced or impregnated by a variety of minerals, including potash, gypsum, calcium carbonate, and calcium phosphate (Helbaek 1969, 1970; McCobb et al. 2001; Nicholson 2001). Phosphate-mineralized seeds and fruits may be common in fecal deposits. Some plant materials are mineralized in the digestive system and others undergo this process after being discarded (e.g., Green 1979; McCobb et al. 2003). This may preserve otherwise easily decayed soft parts; but some plant parts are more susceptible to mineralization than are others. Oats (*Avena*) are most commonly mineralized, but other cereals, such as wheat (*Triticum*) and barley (*Hordeum*), also may be mineralized, as well as seeds from legumes (Leguminosae [Fabaceae]),

plums (*Prunus*), crab apples (*Malus sylvestris*), grapes (*Vitis)*, figs *(Ficus*), and blackberries (*Rubus*).

Technically, a **fossil** is a specimen whose physical and chemical attributes have changed because organic components are altered by solution, reprecipitation, or replacement (Allaby and Allaby 2003:215–216; Gifford and Foster 1989:8; Herz and Garrison 1998:71). This happens at various rates, very recent specimens can be at least partially fossilized, and some very old ones may be only slightly fossilized, depending on the depositional environment. Much of the taphonomic literature grew out of research on materials deposited before the Holocene at sites not associated with anatomically modern people (*Homo sapiens sapiens*). To palaeontologists, anything younger than ca. 6,000–10,000 years old is not a fossil and these materials are referred to as "**subfossils**." Others argue that all biological remains from sites of any age are fossils, even if they have no obvious chemical or physical changes. Insects, pollen, and waterlogged plant remains are frequently referred to as fossils whether or not they show evidence of mineral alteration. "Subfossil" implies that the specimen is partially fossilized, as some archaeological materials are.

Random use of these terms to refer to anything that is buried, albeit widespread, confuses simple discard with an important taphonomic process, i.e., fossilization. Fossilized materials recovered from Holocene-aged sites are interpreted very differently from unfossilized materials at those sites. Mineralization, recrystallization, petrifaction, and casts may preclude many of the analyses reviewed in this volume. It is important to be clear about which specimens are fossils or casts and which are not, recognizing that most organic materials recovered from archaeological sites have experienced some changes in their physical and chemical attributes.

Temperature and moisture influence organic preservation, the formation of soils, and survival potential of archaeological materials, including archaeological proteins (Coles 1987:13; Gernaey et al. 2001; Holliday 2004:266). Alternating wet and dry cycles change pH, calcium carbonate, organic matter, and phosphate values of sediments. Organic materials exposed to harsh weather and extreme fluctuations are less likely to survive than are materials where temperature and moisture are stable. Fluctuations in temperature and moisture promote shrinkage and expansion of organic materials, causing them to lose integrity. Alternating cycles of heat and cold, ultimately relating to levels of radiation received from the sun (**insolation**), fracture inorganic and organic surfaces. The resulting fissures may be further enlarged by frost action as water enters through them, freezes, and expands. The loss of integrity this generates provides microorganisms access to the interior tissues, leading to further destruction (Grupe 2001). Materials deposited in calm waters or bogs; permanently dry deserts, caves, or crypts; permanently frozen conditions; locations with stable, though extreme, temperatures (e.g., high altitudes); or locations offering immediate burial, escape some of the damage from temperature and moisture cycles to the extent that microbial activity is retarded.

Physical weathering is closely related to temperature and moisture cycles (Goldberg and Macphail 2006:64–65). Water and wind can erode away entire sites. Sunlight, wind, and water degrade organic matter, increasing its vulnerability to microorganisms and mechanical forces. Wind dries the surface of organic materials

and scours it with suspended particles. Exposed vertebrate skeletal materials crack and flake until the outer layer fragments, exposing the specimen's inner surfaces to further weathering (Behrensmeyer 1978). Scouring provides water and microorganisms access to the interior of the material, promoting additional loss of structural integrity. Flowing water and water-borne particles wash materials downstream, realign them, and scour them. This may happen as water flows across, or percolates through, the site. Such **fluvial transport** may mix cultural with noncultural deposits. The accumulating wind- and water-born sediments add weight to archaeological strata, which may fracture underlying materials. These actions affect materials exposed on the surface of the ground for even a brief amount of time and continue after burial.

Gravity, seismic activity, volcanism, and glaciation are sources of additional mechanical damage. Mud slides, soil creep, slumping, and sheet wash erode some surfaces and augment others. Seismic activity and volcanism can enhance or limit the preservation of soils and organic materials. Lava and volcanic ashes (**tephra**) may blanket a region, sealing older deposits beneath recent ones, diminishing lakes, and enlarging islands. Moving ice and ice-borne materials erode surfaces over which they pass.

The amount of oxygen in a deposit is another abiotic variable. **Anoxic** conditions are **reducing** environments (low in oxygen) and **oxic** ones are **oxidizing** (oxygen-rich) environments. Many decomposing organisms are aerobic and require oxic conditions to sustain them. **Aerobic decomposers** require oxygen; they often are highly active and cause rapid decay. Their impact on archaeological materials contrasts with that of **anaerobic decomposers**, which require little or no oxygen (Stoermer and Smol 1999:452). Anaerobic organisms are lethargic, perform the work of decomposition slowly, and may contribute to environments with a low Eh potential, enhancing pollen preservation.

Preservation of organic material is particularly good in permanently wet contexts because these are anoxic; the decomposing organisms in them act slowly. Bogs, wells, latrines, and similar damp conditions may yield rich organic deposits. Anoxic environments are enlightening because they contain organic materials rarely, if ever, found in the more typical oxic deposits that experience fluctuations in temperature, moisture, and are subject to weathering (e.g., Plunkett et al. 2009). Such deposits must remain damp and anoxic; if they dry out aerobic decomposers become more active. Fluctuating water tables typically lead to pollen destruction.

Paradoxically, preservation of organic remains in water-saturated sites is only matched in desiccated or cold contexts (Aufderheide et al. 2004; Corr et al. 2008). Freeze-dried tubers, such as those found in the South American Andean highlands and the Peruvian coast, show that unburned plant materials can survive even in oxic contexts if conditions are either very cold or very dry. These three otherwise dissimilar conditions (permanently wet, desiccated, or cold) combine relatively stable conditions with low levels of mechanical damage and bacterial activity.

Peat (an accumulation of dead organic matter in oxygen-poor contexts) is an excellent example of good preservation in water-saturated sites. When peats dry out or are drained, however, decomposition is hastened. Some peats are neutral or alkaline (e.g., fen peats); others are acidic (e.g., bogs of peat moss [*Sphagnum*]). Fen peats are tracts of low, marshy ground associated with upper parts of former

estuaries and freshwater lakes (Elias 1994:274). Bacterial activity increases when fen peats are drained, encouraged by the low acidity; but the high acidity of drained *Sphagnum* bogs retards most biological activity, though fungal growth may increase (Dimbleby 1978:93). Fen peats tend to contain more insect remains than do acidic peats, because of the greater diversity of insect habitats in fens (Buckland 1976; Elias 1994:22). Plants, however, may be poorly preserved. On the other hand, *Sphagnum* bogs preserve human bodies, such as that of Old Croghan Man, extremely well (Plunkett et al. 2009).

Biotic Transformations

Like abiotic transformations, biotic transformations begin in the earliest stages of site formation and continue up to and after excavation. Unless promptly buried, organic material is likely to be quickly destroyed, or at least moved, by biotic agents (Grupe 2001). Walters (1984, 1985) reports that, after 6 months, he could recover only 2% of the refuse he had discarded at a camp site in central Australia. He attributes the loss to dogs (*Canis familiaris*). Similar experiments document major losses to both dogs and pigs (*Sus scrofa*; Wheeler and Jones 1989:69–74). These losses vary according to the amount of material discarded, the condition of the material when discarded, and the abundance of scavenging organisms. Biotic transformations move surviving materials horizontally and vertically within the site, thereby confounding efforts to distinguish between autochthonous and allochthonous organisms.

Some synanthropic and symbiotic organisms feed on nutrient-rich refuse discarded by people and subsequently become part of the archaeological assemblage when they die. Some argue that gray wolves (*Canis lupus*) were camp scavengers when they first started down the path that finally led to lap-dog status. In addition to wolves, a host of vertebrates, insects, fungi, and other organisms are attracted to such deposits, some are now dependent on this association with people; for others, the human association is but one of several habitats exploited (e.g., raccoons [*Procyon lotor*]). This group of organisms is particularly problematic for environmental archaeology. It is difficult to distinguish among organisms valued by people, those considered weeds or pests, and background organisms of which people might have been unaware or that became part of the archaeological record by chance.

Animal vectors play a role in biotic transformation by regurgitating, defecating, or accumulating organic materials that subsequently are mixed with human-generated debris. Although owls and other raptors are well known for adding vertebrate remains to deposits, other birds, as well as bats, insects, and other animals add organic materials to archaeological contexts, sometimes transporting them over considerable distances (e.g., Hunt and Rushworth 2005). It may be possible to identify accumulations left by specific animal vectors because of the characteristic modifications left by each predator on the remains of its prey and characteristic accumulations of bones and teeth (Fig. 2.3; Lloveras et al. 2008:12). These vectors themselves may become part of the archaeological deposit. Although such vectors might truly be background

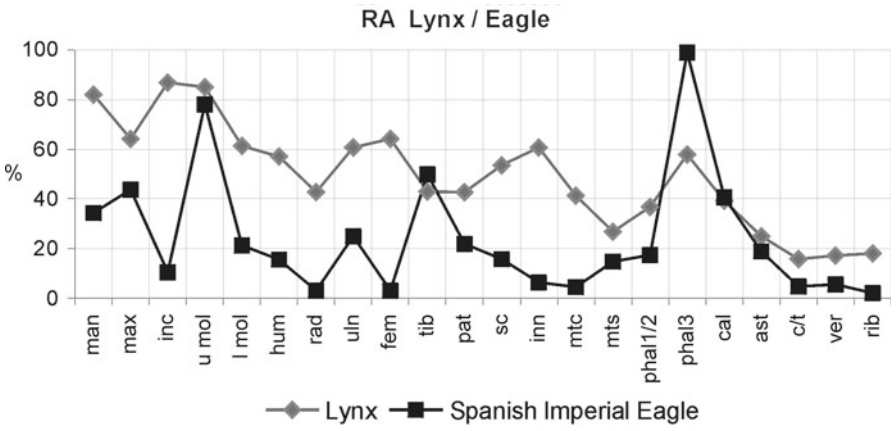

Fig. 2.3 Comparison between relative abundance (RA) of bone and teeth assemblages accumulated by Iberian lynx (*Lynx pardinus*) and Spanish Imperial eagle (*Aquila adalberti*). *man* mandible; *max* maxilla; *inc* incisor; *u mol* upper molars; *l mol* lower molars; *hum* humerus; *rad* radius; *uln* ulna; *fem* femur; *tib* tibia; *pat* patella; *sc* scapula; *inn* innominate; *mtc* metacarpus; *mts* metatarsus; *phal1/2* first and second phalanges; *phal3* third phalanges; *cal* calcaneum; *ast* astragalus; *c/t* carpal/tarsal; *ver* vertebrae; *rib* ribs. From Lloveras et al. (2008:12) and used by courtesy of the authors and Elsevier

organisms, they may also have had a cultural value as well. Bats, for example, often are interpreted as commensal organisms, but they may have been food (e.g., Harrison et al. 2011; Monson et al. 2003).

Domestic animals add to and alter accumulating refuse. Plant materials in livestock dung may be food consumed in a distant pasture (allochthonous) and subsequently deposited in the archaeological site. Fodder and bedding might be harvested at a distant location and used in byres or similar local contexts. Fodder, bedding, and dung introduce organisms from distant ecosystems into the archaeological context, where they join materials from local ecosystems and change the composition and condition of the deposited assemblage. Although this illuminates human behavior, the presence of materials originating in fodder and dung confounds efforts to reconstruct local environments and document environmental change or stasis.

Unless a deposit is anoxic, many plant materials survive only if burned. Carbonization or charring reduces plant material to a chemically inert form that is generally unattractive to scavengers. Burning must be relatively gentle (200–400°C) and/or in a reducing environment where the plant remains are smothered in ashes so that the fire is deprived of oxygen (Butzer 1982:114–117; Hillman 1981:139; Popper 1988:57). Survival is less likely if the plant material is directly exposed to hot flames. Dense, inedible materials, such as nutshells, maize (*Zea mays*) cobs, and olive (*Olea europaea*) pits, are most likely to survive carbonization. Materials used as fuel, such as wood and dung, are usually recovered in carbonized form. Edible seeds are commonly parched, but not carbonized, before consumption or storage, so carbonization during parching generally would be accidental. Non-dense plant tissues with high moisture content, such as leaves, pulpy fruits, and tubers, are often eaten fresh or boiled. They are unlikely to become carbonized and, if burned, are less likely to survive in an identifiable form.

Bioturbation refers to displacement and modification of materials within the stratigraphic sequence (even if only on the surface) by biological agents, including humans. Bioturbation may introduce "noncultural" materials and lead to the decay of organic materials. A sequence of agents may be involved, beginning with a scavenger. Dogs, for example, may remove a bone from the trash heap, gnaw through the surface (offering entry to decomposing organisms, water, and wind), and then bury it someplace else. Earthworms, insects, land snails, and other burrowing and digging animals disturb the horizontal and vertical positions of materials, as do tree-falls (e.g., Borojevic 2011). Long after the deposit has lost its appeal to larger scavengers, smaller organisms continue to alter the deposit. Roots sometimes leave evidence of their role in this process as characteristic dendritic patterns on vertebrate skeletal and dental material (Lyman 1994:376). Such actions expose organic materials to additional abiotic processes.

Trampling combines a mechanical process with bioturbation, changing the structure of materials and moving them among contexts (e.g., Eren et al. 2010). In an experimental study, Hughes and Lampert (1977) report a 30 cm thick trample zone in the occupational levels of an archaeological site. As layers accumulate, the trample zone moves upward through the stratigraphic column. Stockton (in Hughes and Lampert 1977) describes vertical displacement of material in a fairly loose, dry, sandy deposit of an Australian rock shelter. After spreading red glass fragments over a portion of the site, covering them with 5 cm of sand, and walking over the area for a day, Stockton found that 50% of the fragments moved downward as much as 16 cm and 50% moved to the surface. Mechanical damage caused by trampling gives decomposers deeper access into organic materials. Covering work areas with mats, sweeping, and clearing out accumulated dead organic matter affects organic materials, microstratigraphy, and inorganic components of the site by limiting trampling and other transformations associated with exposure (e.g., Goldberg et al. 2009).

Compounding the displacement and damage caused by trampling, people are significant earth-moving agents, engaging in numerous activities that alter their environments. They drain fields, dig holes, quarry rock, cultivate fields, build causeways, tamp down earthen floors, and bury their dead. Ploughing and construction projects, such as the house-pit in Fig. 2.2, are additional forms of bioturbation. These activities interrupt and alter stratigraphic contexts and may destroy or add organic materials. Indiscriminate, unskilled digging also is a site formation process. Unskilled excavation occurred throughout the past, as people dug for curios, bricks, dressed stones, wood, sand, or shells. It continues today.

Sediments and Soils

Site formation processes also alter the chemical and physical composition of sediments and soils (e.g., Holliday and Gartner 2007). People and their animals add gravel, sand, silt, and clay to deposits, tracking them into the site unintentionally, or transporting them as raw materials such as pigments and tools. Traditional paths used by people and livestock may become incised into the landscape, perhaps inadvertently becoming

part of local and regional hydraulic systems (Wilkinson et al. 2010). Burning grasslands and clearing forests alter drainage patterns and may lead to erosion or flooding. These and similar activities lead to soil compaction; friability; changes in soil moisture and hydrology; loss of plant and animal communities; and other landscape changes. Land-use practices change landscapes and alter soil fertility, as well as bury, remove, or displace archaeological materials (e.g., Ayala and French 2005). Additions of fibers from bedding, clothing, fodder, containers, and walls can change the characteristics of sediments, as do heat and ash from intentional and unintentional fires. Fired clay (e.g., ceramics, **daub** [clay or dung plaster]) and beaten earth in floors and walls are important components of many archaeological sites. Carbohydrate, protein, and fat residues, mollusc shells, bone mineral, urine, and fecal matter change the chemical and physical composition of sediments. These activities, as well as the decomposition of organic matter, release phosphate, calcium, nitrogen, potassium, manganese, sulfur, organic acids, carbonates, and phytoliths into the deposit. Some of these activities alter soil chemistry and further advance or retard the survival of organic evidence of environments and cultures (e.g., Weiner 2010:77).

What Might Survive?

To answer this question, we must distinguish between the typical archaeological site and those more rare contexts with outstanding preservation. The best preservation of organic remains in most archaeological sites is found where burial was rapid; the depositional environment was stable; exposure to mechanical damage, temperature, and moisture fluctuations was limited; and bioturbation was minimal. Base status is important, though the ideal pH depends on the type of material involved and other factors. Generalizing broadly, plant remains require acidic conditions and animal remains require alkaline ones. In the most common archaeological settings, most plant remains survive best if the organic component is removed by carbonization. Pollen, phytoliths, and vertebrate teeth are composed of some of the most durable materials known, however, and may have a somewhat better chance of surviving the rigors of common archaeological contexts than do other organic substances. Contexts in which decay organisms are restricted by a lack of oxygen or moisture, such as in anoxic, waterlogged, permanently dry, or permanently frozen conditions, or in which mineral replacement occurs, all favor survival of at least some additional organic remains. Although relatively less common, they are exciting when encountered because of the wealth of additional information about the past they contain.

Experimental Archaeology and Ethnoarchaeology

Many site formation processes are difficult to recognize. Laboratory tests, ethnographic observations, and experimental archaeology are useful in exploring the ways first-order changes transform the systemic context into the archaeological one

(e.g., Gifford-Gonzalez et al. 1999; Larsen 1997). Experimental archaeology and ethnoarchaeology expand our understanding of the factors that are involved in the formation of archaeological deposits, document abiotic and biotic processes that may be unfamiliar today, and test alternative explanations of patterns observed in the archaeological record.

Experimental archaeology tests supposed processes and observes the outcomes (e.g., Berna et al. 2004; Harbeck and Grupe 2009; Hjulström and Isaksson 2009; Jones et al. 2010; Margaritis and Jones 2006; Stein et al. 2003). Experiments attempt to reproduce an archaeological phenomenon, such as an oven, to verify its function and operational properties or estimate the time and other costs involved in using it or processing the potential resource (e.g., Smith et al. 2001). Some experiments assess the nutritional value of a resource, its benefits during a specific season, and the costs or consequences of obtaining, processing, and storing it. Other field and laboratory experiments test theories underlying the methods used to recover and interpret organic archaeological materials.

Ethnoarchaeology considers site formation processes and the behaviors of contemporary peoples observable today (e.g., Kent 1993). Familiarity with the cultural contexts of materials similar to those recovered from archaeological sites is critical to interpreting archaeological data. Often we have little understanding of how human behavior is linked to archaeological phenomena. Ethnographic observations broaden our horizons about human interactions with their environments and the consequences of those behaviors (e.g., Marshall 2001). They are the basis of ethnographic analogies, which use observations of modern peoples to expand our interpretive repertoire. Analogies must be used cautiously because all twenty-first century peoples are products of centuries of evolutionary history. Present-day foragers, horticulturists, or nonindustrial fishermen are not relics of previous millennia. They can, however, enlighten us about ways to interact with the environment beyond those we can envision from the perspectives of our industrialized, globalized, urban experiences. They provide insights into the ways specific activities might appear in the archaeological record (e.g., Shahack-Gross et al. 2004).

Off-Site Processes

The emphasis in this chapter is on processes associated with archaeological deposits, most of which have some affiliation with human behavior. In environmental archaeology, the processes associated with deposits less directly associated with people are of equal interest. Sediments and organic remains off-site may have little connection with people, but provide historical information about the environment before people occupied the archaeological site, while the site was occupied, and subsequently. Off-site studies provide information about sources of background organisms and overall aspects of the landscape. Many of the processes that influence organic remains on-site also affect off-site ones.

Applications

Both noncultural and cultural variables are important site formation processes, but much of the evidence that distinguishes among them is lost during field work. Lieverse et al. (2006) demonstrate the importance of field observations in their study of taphonomic factors affecting human remains buried at the Khuzhir-Nuge XIV cemetery (Lake Baikal, Siberia) between 5000 and 3700 BP (calibrated; see Katzenberg et al. 2009) (see Chap. 1 for a discussion of dates used here and elsewhere in this volume.). Extended and semi-flexed single burials, cremations, and multiple burials were found in pits covered with stone slabs or cairns. Skeletal preservation was inconsistent among the 84 individuals studied, but generally was poor. Lieverse et al. (2006) recorded as many observations as possible in the field, including data associated with five intrinsic taphonomic factors: symmetry (e.g., left or right side); completeness, fragmentation, and articulation for each element type (e.g., humerus, mandible); age at death; sex; and the archaeological age of each burial. They defined ten extrinsic, cultural taphonomic factors: depth, cremation, burial type, body position, disturbance, burial integrity, number of artifact types, grave pit size, paving stone density, and the presence of birch bark, likely used as a burial wrapping. All of the taphonomic variables considered were positively correlated with skeletal condition except element symmetry. Element type and age at death (associated with size, density, and shape of skeletal materials) were particularly important. Larger, regularly shaped skeletal elements of adolescents and young to middle-aged adults were in better condition than were irregularly shaped skeletal elements and those of infants, children, and older adults. Burials associated with birch bark were more likely to be complete and articulated than were other burial types. They conclude that cultural practices had a significant influence on natural processes of decomposition. Their study was facilitated by their ability to make critical observations in the field before the burials were removed from their context, with the inevitable loss of data that results from even the most careful excavation.

Combining taphonomic studies and ecological analogies enables researchers to refine their interpretations of human behavior and provides knowledge that can be used in developing management plans for threatened habitats and species. A report by Lloveras et al. (2008) on the dietary habits of the Iberian lynx (*Lynx pardinus*) serves this dual role. The Iberian lynx is one of the most endangered cats in the world. The study identifies signatures that distinguish among alternative sources of the large quantities of rabbits and hares (Leporidae, especially European rabbits [*Oryctolagus cuniculus*]) found in Palaeolithic sites in the Iberian Peninsula, and can be used to assess the former range of the lynx. Not only are rabbits an important food source of lynx, they are commonly used by other predators, such as the Spanish Imperial eagle (*Aquila adalberti*), as well as by people. To use the archaeological distribution of rabbits to reconstruct the former range of lynx, Lloveras et al. (2008) identify taphonomic signatures of some present-day rabbit predators to develop criteria for distinguishing between rabbit remains left by lynx and some of these other

Table 2.2 Combined total maize (*Zea mays*) yield for all experimental irrigation treatments conducted at Los Lunas, New Mexico (USA) in 1992 and 1993

Treatment	Total yield (g)
1	3,838
2	2,722
3	1,808
4	1,878
5	828
Total	11,074

Modified from Adams et al. (1999:492)

predators. The authors identify these signatures by studying rabbit remains in modern **scats** (feces) of Iberian lynx collected from the Natural Park of Doñana (Andalucia, Spain) and comparing these characteristics to scats and pellets of terrestrial carnivores, diurnal raptors, and nocturnal raptors. They report that anatomical representation, breakage, and modifications associated with digestion distinguish scats of lynx from those of other animals. In particular, highly fragmented and corroded specimens are more typical of lynx than of other predators. This study provides a method for distinguishing among rabbit predators and offers taphonomic signatures that verify the endangered lynx once was present throughout the Iberian Peninsula.

Experimental studies provide insights into some of the processes that influence characteristics upon which subsequent interpretations of organic materials may rely. One of these is the size and shape of seeds, which are influenced both by the genetic potential of the parent plant and the moisture available during plant growth. Maize was domesticated in what is now Mexico but was grown in many parts of the Americas by CE 1492. Tracing maize varieties could provide information about trade routes, patterns of human dispersals and aggregations, and changes in material culture that appear to be associated with maize cultivation. Efforts to study maize varieties are hampered, however, by the wide range of factors that influence **phenotype** (physical and physiological appearance), including **genotype** (genetic constitution), temperature, moisture, and site formation processes, in addition to human and natural selection. Adams et al. (1999) conducted controlled experiments to test the effects of moisture quantity and intervals on morphological features commonly used to study maize recovered from lowland river valleys of southern Arizona (USA). They grew a single maize cultivar, Tohono O'odham flour maize, in five test plots that received different controlled irrigation treatments and normal rainfall over a 2-year period (Table 2.2; Adams et al. 1999:492). One of these test plots (Treatment 5) was irrigated when the seeds were initially planted and thereafter received only rainfall, which is limited in this dry environment. The other plots received different amounts of water at various intervals, with Treatment 1 being the well-watered control. The authors report that total moisture, as well as the amount and timing of moisture in each treatment, influences grain morphology and yield. The effects of moisture on the morphological variability of ear, cob, and kernel characters in plots irrigated when the seeds were planted and thereafter watered only by rain are

particularly profound. Some of the effects reported could mask race-identifying characters and influence interpretations that rely upon distinguishing among maize varieties.

Summary

Some interpretations assume that the archaeological record is unbiased and complete, so that it accurately reflects previous environments, ecosystems, and cultures. In reality, however, materials enter the archaeological record along numerous pathways for many different reasons. Excavated materials may bear little resemblance to the original resource base or the ways people used, or ignored, those resources. The ways organisms became incorporated into, or excluded from, each deposit are quite different depending upon basic environmental and biological characteristics mediated by cultural institutions involved in the production, distribution, and consumption of resources. A wide range of activities affect which materials from the systemic context enter the archaeological context. Other organisms and sediments accumulate without any reference to people. Once the materials enter the archaeological context, additional abiotic and biotic processes change them further so that the studied assemblage may be very different from the deposited one. This does not mean that organic archaeological materials cannot be used to study relationships among peoples and their surroundings. It does mean that the systemic and archaeological contexts of biological materials cannot be ignored when interpreting archaeological data, nor can we assume that research designs, field methods, and laboratory procedures have no impact, a topic reviewed in the next chapter.

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Chapter 3
Research Designs and Field Methods

Unlike first-order changes, over which researchers have no control, research designs, field methods, and laboratory procedures are choices that influence the quantity and quality of material available for study. These choices alter the record of the life assemblage embodied in the death and study assemblages. Curation of materials and data are additional sources of second-order changes, as are the outlets through which new knowledge is shared with colleagues and the public. Environmental archaeologists and others at all stages of recovery and analysis should be familiar with the influence these decisions have on organic materials and their interpretations. In this chapter, research designs and field methods are reviewed. Laboratory procedures are summarized in subsequent chapters. Inevitably, even the best research designs and methods fail to capture interpretatively useful evidence for all aspects of environmental and cultural variations.

Despite lengthy discussions among professionals about the role of environmental archaeologists in the field, and struggles against the separation that specialization creates between field staff and environmental archaeologists, much of the research of the kind reviewed in this volume will continue to be done by consultants whose backgrounds may not include archaeological methods or theories. Likewise, the project director or principal investigator directing the overall project may have little training in environmental archaeology and field staff may have little or no knowledge of how samples will be used or how devastating apparently minor field decisions can be to subsequent studies. This is not to say that we approve of this situation, merely that we acknowledge that environmental archaeologists may be consultants rather than project directors. Consultants with no archaeological knowledge and field staff with no training in environmental archaeology are equally problematic.

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The Scientific Method and Research Designs

Field and laboratory procedures sample the sample. Thus, analysis relies on sampling decisions that limit the number of objects and select the number of variables studied (e.g., Orton 2000:7–8). Sample decisions should be guided by research designs that define the objectives of the field season. Some research designs guide the accumulation of data from multiple excavations over many years. Project directors and environmental archaeologists should understand long-term goals so that field and laboratory techniques are consistent beyond a single study. Inconsistent or inappropriate methods often mean that samples do not meet standards embodied in the scientific method, restrict quantification and statistical analyses, and limit the potential of organic remains to contribute to long-term research.

Sampling

Archaeological samples represent considerable investments in time, space, and funds. Because their recovery and processing is costly, the tendency is to take a "random representative sample." This generally means that only specimens that are large enough to see and that attract someone's attention are collected. Although it could be argued that experienced archaeologists are capable of making judgments such as these without bias, in reality quantified studies are hampered by informal, unsystematic, partial approaches (e.g., Orton 2000:2). Worse, subsequent researchers may not understand that "random" in this sense does not meet the statistical definition of random sampling (Orton 2000:20). They may be unaware of this bias altogether. Such biased sampling precludes quantitative analysis and may lead to incorrect interpretations.

In sampling theory, a formal random sample is representative of the sampled population because each element of the population had an equal opportunity to be included in the study, the probability of a specimen being selected is known, and the selections are independent (Orton 2000:8, 15, 20). Sampling in this sense is based on criteria such as prior knowledge, research objectives, data needed to test hypotheses, variables inherent in the materials themselves, and future applications (Orton 2000:28–29). Formal random sampling, regrettably, is rare in archaeology.

The Scientific Method

The scientific method permeates all aspects of environmental archaeology. Adherence to the scientific method is one reason environmental archaeologists appear to place more emphasis on methods than on theories. This is a false dichotomy that fails to recognize that most methods are based on complex theories about biogeochemical, hydrological, and social phenomena, though these theories may not be identified in archaeological reports.

The **scientific method** relies on theories that can be tested objectively, hypotheses that can be proved false through critical experiments and observations, and results that can be independently verified or refuted during repeated experiments and observations by other researchers using the same methods. One purpose is to prevent researchers from presuming their favorite hypothesis is valid when evidence exists that it is not. Archaeology cannot be experimental in the same sense that a physical scientist can conduct or replicate an experiment. Objective, repeatable, independent reevaluations are problematic in archaeology because the "experiment," the excavation, cannot be repeated in precisely the same way; moreover, the deposit is altered by the removal of the sample if the context is not removed in its entirety.

Most methods are essentially experiments that test theories concerning fundamental aspects of the materials under study; therefore, the strengths and weaknesses of materials and methods are important in environmental archaeology (e.g., Schmidl et al. 2007). Materials and methods must be thoroughly described, and the latter must be scientifically sound, suitable to the materials, appropriate to the research questions, and applied so as to control known sources of bias. Issues related to materials and methods must be resolved before results can be interpreted, conclusions drawn, theories reevaluated, and results accepted by skeptical peers. Scientists must be able to demonstrate that these conditions prevailed during the research insofar as possible. Scientists expect critiques of their work will begin with the methods; if the methods are weak, so are the interpretations. Some environmental archaeologists focus their research on materials and methods because they provide information about fundamental biological, chemical, and physical attributes of the materials and the ability of methods to assess those attributes. If the samples appear adequate (however crudely determined), contributions to theories about relationships among environments and cultures are possible.

To successfully integrate environmental data into archaeological projects, research designs must accommodate the constraints of the scientific method. Field work can facilitate or hamper meeting these standards. Well-conceived research designs enable project directors to control unintentional or unnecessary biases in field work, safeguarding the role of environmental archaeology within overall project goals.

Research Designs

Research designs are plans identifying research goals and the ways they will be reached. Research designs should: (1) have clear objectives, well-researched questions, and testable hypotheses; (2) draw upon available knowledge to inform decisions; (3) be clear about the contexts sampled and why; (4) include samples from as many different contexts as feasible; (5) be flexible; (6) facilitate subsequent integration of all data from the site; and (7) ensure compatibility of data during analysis and interpretation. By providing clear objectives and outcomes, research designs guide the choice of sites to excavate, where to excavate within sites, field methods, and laboratory methods.

Environmental archaeologists should be included in the development of research designs because they may identify goals that cannot be achieved or suggest alternative ways to reach goals within the context of the overall objectives. Often environmental archaeologists are consulted after field work is completed, by which time materials may have been excavated incorrectly or from locations unsuitable for the research questions. Failure to involve environmental archaeologists when developing the research design may mean that research is conducted in isolation and results have little relevance to the overall project. Environmental archaeologists may not understand, or know, the project's objectives and may thereby misdirect their research. Perhaps worse, their results may be misinterpreted or applied incorrectly.

Research is almost always conducted with a limited budget and tight schedule. When environmental archaeologists are engaged after budgets are prepared, they often encounter too much material, an overly ambitious research design, and inadequate funds. The methods of environmental archaeology take years to master, are time-consuming, and often require expensive reference materials and research facilities. Environmental archaeologists will not casually give a quick opinion that might be wrong. They are understandably reluctant to take shortcuts and may be unmoved by pleas that budgets or schedules permit nothing else.

Archaeological Excavations

Although each region has its own archaeological traditions and terminology, all traditions emphasize recovering materials carefully to maintain control over the context from which they are recovered. The following is a general description of field methods common in the United States (e.g., Hester et al. 2009; Kelly and Thomas 2010). For more information, readers should consult introductory books on field methods (e.g., Balme and Paterson 2006; Renfrew and Bahn 2008; Roskams 2001) or ask the project director for recommendations. Large projects often have field and laboratory manuals that should be followed faithfully. Reference works (e.g., Darvill 2003; Kipfer 2000, 2007) explain common archaeological terminology, but many terms are idiosyncratic and interfere with essential communications between project directors and environmental archaeologists. Project directors must take the initiative to ensure clarity because consultants may be unaware of differences in field traditions and terminology. Learning project-specific terminology is just one of the reasons environmental archaeologists should be present in the field whenever possible.

What Is a Site?

Defining what is meant by "site" is difficult (Orton 2000:67–68). Generally speaking, a site is "Any location that demonstrates past human activity, as evidenced by the presence of artifacts, features, ecofacts, or other material remains…"

(Kipfer 2000:517). This may be a petroglyph, a scatter of stone tools (**lithics**, **lithic debitage**), a farmstead, a block within a town, or an entire city. Sites generally receive names and numbers. Names may be informal, but numbers usually are listed in a register of sites maintained by a governmental or nongovernmental agency. Although each site should have a single name and number, it often is theoretically and practically difficult to define a site's temporal and spatial limits. Is a temple mound, the adjacent village, and nearby farming terraces one site or three? Although excavation often resolves such questions, site numbers may be assigned before field work begins. A single location may have multiple numbers either because the contemporaneity of portions of the site was not recognized until after the numbers were assigned or because the site is multicomponent or multiperiod and each time period was given a number. Sometimes different numbers are given to portions of sites that have different functions, though this is problematic until the function has been verified by excavation and analysis of the recovered evidence. Very large sites, especially urban complexes, may be divided into sectors, each with its own site number. Sometimes these sectors correspond to modern features such as buildings, city blocks, or construction sites.

As with field terminology, many sites and parts of sites bear unofficial designations. These may be obvious to project directors and field staff, but they are obscure to people who were not in the field. Unless field staff ensures that informal designations are clear, confusion, erroneous records, misdirected analysis, and incorrect interpretations will plague the project for decades to come.

How Are Sites Found?

The locations of many highly visible sites are well known, but other sites must be sought by combining physical surveys with historical records, maps, archaeological reports, and interviews. Many sites are buried below the modern surface with only scattered fragments of pottery (**sherds**, **potsherds**), lithics, or other debris on the modern surface. Others are covered in dense vegetation. Hidden sites, as well as unknown aspects of well-known sites, are found by means of systematic surveys designed to record all types of sites in a defined area and to assess relationships among them and between them and landscapes (David 2006; Orton 2000). Project directors try to know as much as possible about sites before excavating to avoid disturbing parts that are not germane to the research design or excavating materials they cannot study, though, in many cases, the survey will not be followed by excavation. It is advisable to involve environmental archaeologists in preliminary assessments of survey data, especially if the survey is a prelude to excavation.

Systematic reconnaissance surveys (site surveys) seek sites using an organized plan designed to determine the number, location, types, and significance of sites locally and regionally (Banning 2002; Renfrew and Bahn 2008:74–79). These surveys are based on the hypothesis that archaeological contexts will be represented on the modern ground surface because of site formation processes. In most cases only

a portion of an area is covered, which leaves some doubt as to the adequacy of the survey and the representativeness of the sites located.

Noninvasive reconnaissance involves remote sensing techniques and walking surveys (Banning 2002:44–45; David 2006; Garrison 2003; Herz and Garrison 1998). **Remote sensing** techniques, such as aerial photography and satellite imagery, often provide remarkably detailed information about locations, sizes, and shapes of sites, especially large-scale features such as roadways, fields, canals, and defensive structures (Goldberg and Macphail 2006:299–307). Other methods use geochemical and geophysical methods to measure seismic waves, electrical resistivity and conductivity, and magnetic properties to locate anomalies that might be sites and subsurface features within sites (Goldberg and Macphail 2006:312–316). **Walking** (**field-walking** or **walk-over**) **surveys** may be combined with such noninvasive techniques. In its simplest form, survey crews walk assigned routes and record the amount of area covered by artifacts observed on the surface, the types of materials present, a tentative assessment of when the site was occupied based on the materials found, and descriptions of visible phenomena such as plant communities and topography.

Limited **invasive testing** may follow or accompany noninvasive reconnaissance. In a limited **subsurface testing program** probes, soil-coring devices or similar tools are used to draw materials to the surface for examination (Banning 2002:42–43). In other cases, shovels are used, with the size of the test limited to the width of a shovel blade, hence the term **shovel tests**. These provide an opportunity to confirm or clarify knowledge obtained from other reconnaissance methods as well as to assess sediment characteristics and organic preservation before excavation begins. Subsurface tests may require additional approval from permitting authorities.

Remote sensing surveys, walking surveys, and limited subsurface testing programs are usually conducted at set intervals along straight lines (**transects**) that follow specified coordinates. Coordinates often conform to compass points, such as north–south transects and east–west transects, establishing a two-dimensional, evenly spaced **grid** across the survey area. Surveys may be tied to the **Global Positioning System** (GPS), a satellite-based network that enables field staff to specify where sites and grids are with great precision.

What Next?

Assessing locations and relationships of sites may be the only objective of the project. If the survey is a prelude or an adjunct to excavation, the survey grid, if there was one, may be refined so that location and elevations above mean sea level are known precisely. A portion of the site selected for excavation may be marked using stakes and strings, providing a visual record of **grid lines**. The vertical and horizontal lines on Fig. 3.1 designate grid lines. The purpose of the grid is to control the horizontal and vertical aspects of the excavation so that the position of everything found during excavation (e.g., material culture, stratigraphy, architecture, biological

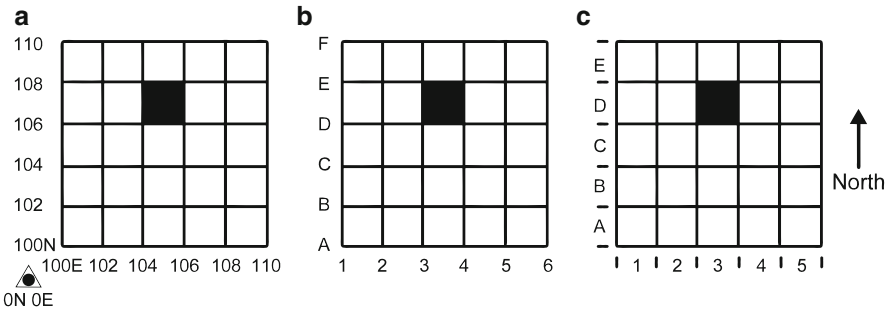

Fig. 3.1 Grid in 2 m increments established on a site; grid orientation is true north. The excavation unit shown in this figure may be designated: (**a**) by its southwest corner, e.g., unit N106E104, which is 106 m north and 104 m east of the datum point at 0N0E; (**b**) by individual grid lines labeled north and east of the datum point, e.g., unit D3; or (**c**) as an area within the grid lines, e.g., unit D3. The datum point is not shown to scale in this figure

samples) is known with reference to the grid, establishing its find location (**provenience**, **provenance**).

Grid lines define **excavation units**. These may be called **squares**, **grid squares**, or **boxes** because they generally are square in shape, though the term is often applied to combinations of squares that form rectangles or other shapes. Units are the building blocks used to begin and expand excavation. Modifications are made when intact archaeological features are visible or immovable objects such as roads or landscaping must be avoided.

Either grid lines or excavation units (and sometimes both) are identified by names, numbers, letters, or other designations (Fig. 3.1). The ways to identify these appear to be limited only by the creativity of field staff. Grid lines may be numbered in several ways or the grid squares may be numbered using either Roman or Arabic numbers, or a combination. Designations may be alphabetic, alphanumeric, or some other format. The result is the same: each unit within the grid has a unique designation, ensuring horizontal control of the provenience from which samples are recovered. These designations are perpetual and universal sources of confusion in consultants' laboratories. The more complex they are, the more frequent, pervasive, and serious lab errors will be, especially when samples are sent to consultant laboratories unaccompanied by a site map.

As we have seen in Chap. 2, site formation processes move, add, and mix archaeological materials. Field work is designed to recognize this displacement whenever possible. Human activities at a specific time and place may produce a group of items that were used together and entered the archaeological context at the same time. A goal of excavation is to confirm or disprove the premise of temporal, spatial, and functional contemporaneity or affiliation. Some contexts are relatively undisturbed. Such **sealed** or **closed contexts** are ideal for study, but they are rare and often yield samples that are very small and represent specialized behavior.

Establishing temporal contemporaneity and functional similarity can be very difficult. Consider, for example, differences between contexts whose purpose is

disposal (e.g., latrines) and those whose original functions were very different from their final use as disposal sites (e.g., moats, wells, abandoned houses). In the case of a latrine, for example, the structure and the contents of the structure are likely to be broadly contemporaneous. The latrine might have been cleaned occasionally and the length of time for deposition may be considerable, but the general period of use and the materials recovered are roughly contemporaneous and represent broadly similar behaviors: waste disposal. In the case of a house, however, material associated with the structure's construction and original purpose and the refuse discarded into it after it was abandoned represent different time periods and different functions, perhaps by very different cultural groups.

Contexts are usually recorded in three dimensions. The first two dimensions are the unit or object's horizontal distance on the two-dimensional grid. The third dimension is depth, which often correlates with time. These three dimensions are measured from a **datum point**, a reference point to which subsequent horizontal and vertical measurements refer (Fig. 3.1). The datum point ideally is located some measurable distance outside the proposed excavation area, but sometimes the excavation extends beyond the intended grid and secondary data points are required. The horizontal dimensions are measured as distance from the datum point, which is linked to latitude and longitude or GPS coordinates. A unit or object said to be at North 106/East 104 is 106 m north and 104 m east of the datum point (Fig. 3.1a). This not only controls the horizontal context of materials, but should enable future researchers to reestablish the excavation grid years later. Site maps show the location of the datum point, grid lines, excavated units, and symbols such as a north arrow and a scale (Fig. 3.2; Zierden 2001:55). In the case of Fig. 3.2, locations of a decorative garden, work yard, fence, and above ground structures are indicated in addition to the excavation units.

Depth is measured with reference to the elevation above mean sea level at the datum point. Often a survey instrument is set up at the datum point to measure depth of units and finds within the site. Ideally, the datum point is at the highest part of the site so that the entire site is visible from it, but large sites, or those with high relief or large structures, may require secondary datum points. Depth below datum refers to elevations below the plane of the survey instrument. In English, this may be abbreviated as "bd," below datum. Sometimes, depth is measured below the ground surface of the unit, abbreviated as "bs." The difference between "bd" and "bs" can be several meters, which is why the appropriate abbreviation should be recorded on every sample bag without fail. If more than one datum point is used to establish depth, this should be recorded as well. No one should assume that the depth measurement is obvious if it is not followed by "bs," "bd," or some other designation.

Excavation Basics

Excavation samples sites. Archives, surveys, subsurface tests, previous research, and research questions guide unit placement and other sampling strategies. If the objectives

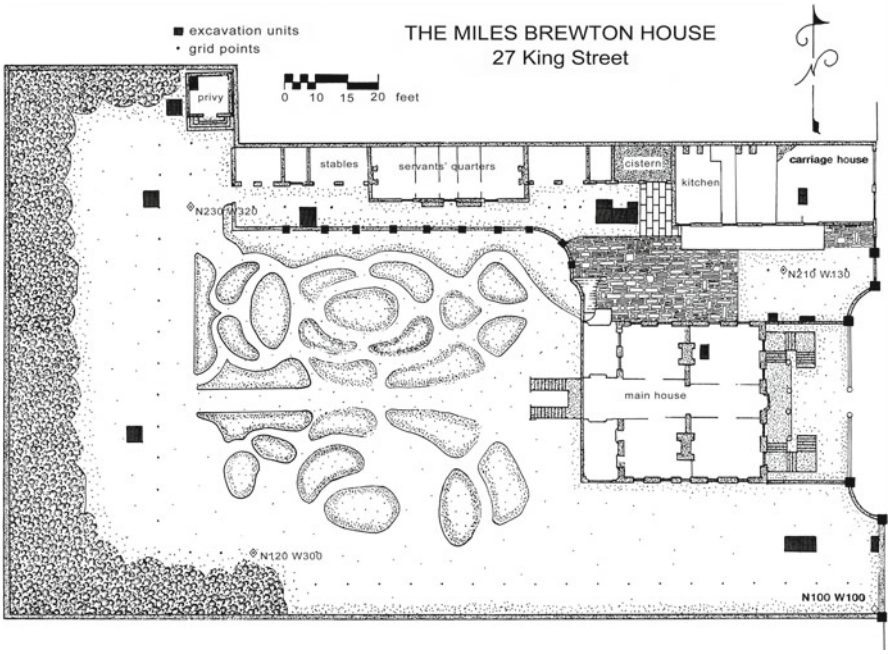

Fig. 3.2 Site map, Miles Brewton House, Charleston, SC (USA). From Zierden (2001:46) and used by courtesy of Martha A. Zierden and The Charleston Museum, Charleston, SC (USA)

pertain to spiritual life, then areas thought to be sacred compounds will be targeted. If they pertain to plant husbandry, agricultural terraces may have priority. Most projects leave portions of the site intact for future research and project directors are unlikely to disturb other portions of the site just because environmental archaeologists would like them to do so.

Each context to be sampled represents a distinct set of site formation processes and may require a different excavation approach. Plant remains from storage contexts, such as pits, may be primarily from a single species. Although this species may have been a minor crop, a cache of such remains may be an ideal source of information about that specific plant. Assemblages of plant remains recovered from threshing floors, hearths, and ovens each yield different information about how plants were processed and used. By way of contrast, sewers, trash pits, and ditches usually contain organic remains from many different activities and sources, offering generalized information about environments and cultures. Impressions on clay vessels, the contents of palaeofeces, and organic refuse in burial pits offer additional insights into which organisms or parts of organisms were used, where, by whom, and for what purposes. Insights from each of these contexts will be considerably different from those derived from the floor of a house.

Exactly which part of the site should be excavated? Often this decision is guided by the objectives of the research design, whether a general excavation of the site is

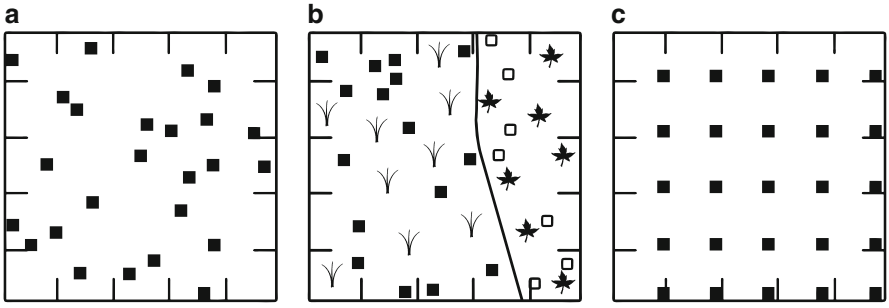

Fig. 3.3 Types of sampling: (**a**) simple random; (**b**) stratified random; and (**c**) systematic. Note that the stratified random sample strategy is designed to collect samples from within a grassy field and a smaller, wooded portion of the site

required or the work should focus on specific contexts identified by previous analysis. Many advocate controlling the unconscious bias to favor interesting or accessible contexts by using random numbers. In a simple random approach (Fig. 3.3a), units are selected using random numbers with no distinction among different contexts or zones within the site. In a stratified random strategy (Fig. 3.3b), specific contexts (e.g., plazas, terraces, wooded and grassy portions of the site) are defined, thereby dividing the site into smaller areas based on location, presumed function, or other characteristics. Within each of the broadly defined strata, units are selected for excavation using random numbers. Others excavate in a systematic fashion, perhaps excavating units at 50 m intervals along the grid (Fig. 3.3c). This use of the term "strata" should not be confused with the more customary archaeological use of the term to refer to subsurface vertical layers within the site, as described below.

Excavation nonetheless produces surprises and field staff cannot be certain about what will be found. Even the best-prepared project director may find the excavation centered on a context that is not ideal for the research plan. The excavation may encounter a sacred compound instead of a residential area, or evidence for both activities may be present in the same unit. This is why research designs need to be flexible and why project directors and environmental archaeologists must be cautious about extrapolating from a single unit to the entire site. A theory of statistical sampling is that if the sample is large enough and randomly selected, the sampled portion will represent the unsampled portion. Although this premise may be correct for a modern population census where most variables are known, most variables are not known for archaeological sites. If field staff finds an **ossuary** (charnel house) in its randomized survey, instead of a trash heap, this is not, in itself, evidence that trash was rare or absent at the site.

Field work will be constrained by protocols requiring excavation to proceed in a rigorous, controlled fashion within the grid using excavation units as primary building blocks. Excavation plans are highly variable but tend to cluster into two categories: contiguous units and individual units (Fig. 3.4). The choice of contiguous or individual units impacts the number and types of activity areas studied, the types of samples collected, and subsequent interpretations.

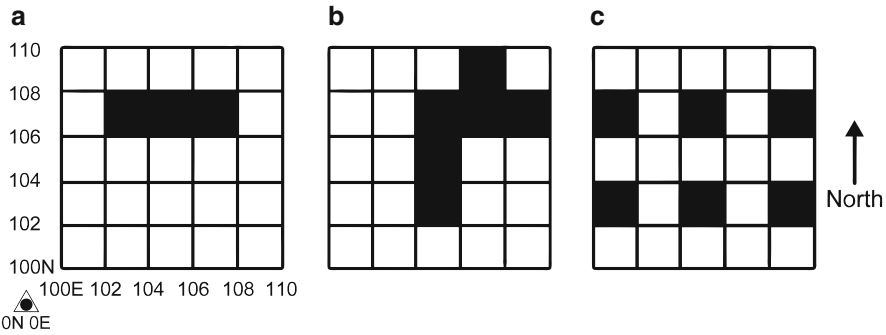

Fig. 3.4 Grid in 2 m increments with units aligned in different patterns: (**a**) contiguous units forming a trench that runs from west to east; (**b**) contiguous units forming an irregular block; and (**c**) non-contiguous, individual units set out following a systematic grid. The datum point is not shown to scale in this figure

Contiguous units consist of a series of adjacent excavation units within an area of interest, but conforming to the grid line (Fig. 3.4). Eventually, they may form a trench (Fig. 3.3a), block, or irregular pattern (Fig. 3.4b). In some cases, the units are separated from each other by a standardized portion of unexcavated earth left between adjacent units, forming **balks** or **baulks** (Fig. 3.5; Napton and Greathouse 2009:209; Renfrew and Bahn 2008:108–115). Balks may be removed between units or left in place. They may be over a meter wide or only a few centimeters wide. Balks enable field staff to maintain a visual, below-ground record of the site and often are the preferred source of organic samples. This pattern is known as a **box-grid** or **box-excavation** because of the appearance of the excavation as a series of boxes (units) with walls (balks) between them (Roskams 2001:14). Contiguous units may recover a great deal of information from a specific part of the site but budgets, schedules, and available labor may limit the excavation to a single cluster of contiguous units. This means that the rest of the site remains unstudied, leaving the project with little knowledge of the horizontal stratigraphy of the site, though a good idea of the vertical stratigraphy within the excavated area.

Individual or **isolated units** are discontinuous (Fig. 3.4c). They sample horizontal stratigraphy by testing several portions of the site and may be called **test pits** for this reason. Individual units yield useful information about the diversity of functions at the site, the temporal range over which these occurred, and the spatial organization of activities. Sometimes isolated units are placed at regular intervals along grid lines (e.g., at 2-m intervals). Sometimes individual units are placed randomly, using a table of random numbers, to test a certain percentage of the entire site (e.g., a 1 or 10% sample). The samples taken from each unit for analysis by environmental archaeologists often are small and may be unreliable for many reasons (e.g., Schmidl et al. 2007).

In many cases, contiguous and isolated units are combined so as to study part of the site intensively while testing other areas of the site. Often isolated units are expanded subsequently into contiguous units to expose interesting areas of the site. For example, the project director may decide to excavate that unexpected ossuary

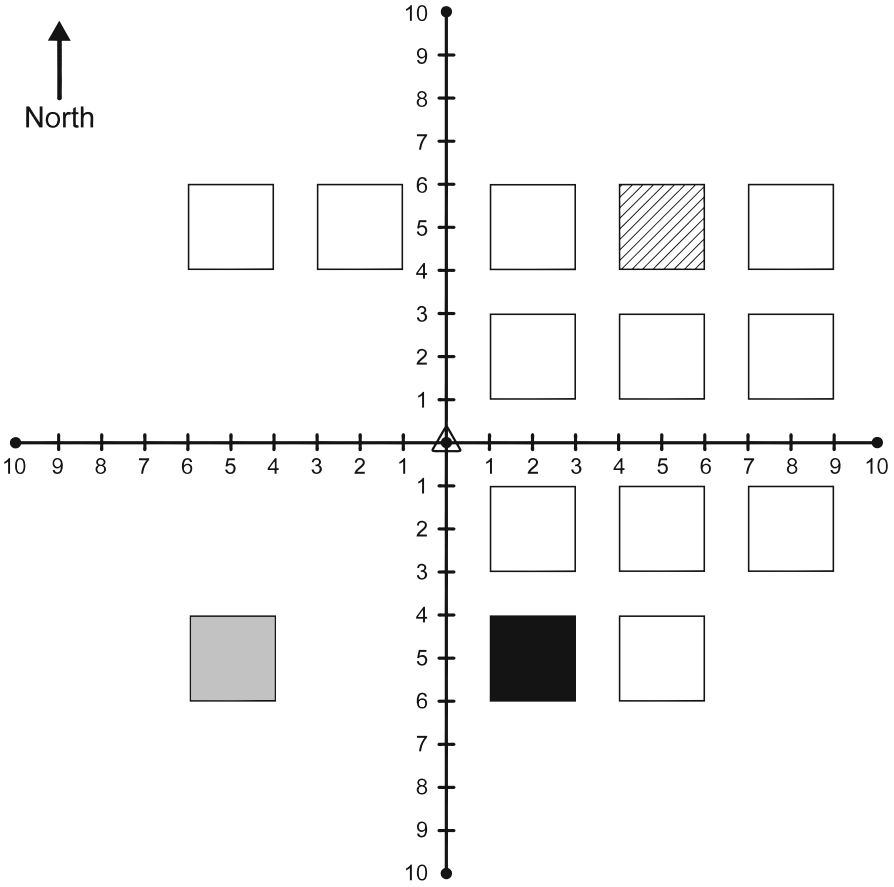

Fig. 3.5 Infinite grid with balks. The control point of the black unit is South 4/East 1. The cross-hatched unit is North 4/East 4. The gray unit is South 4/West 4. Each unit is separated from the adjacent one by an unexcavated balk. Modified from Napton and Greathouse (2009:209, Figure 9.21) and used by courtesy of Left Coast Press

using contiguous units, but continue searching for the trash heap by placing individual units at regularly spaced intervals across the site, perhaps in combination with noninvasive methods.

As field staff excavates vertically below the modern surface, distinct, or not so distinct, differences in the chemistry, contents, color, and texture of the matrix are encountered (Fig. 3.6; Zierden 2001:55; sediments and soils are discussed in Chap. 5). These define the site's stratigraphy. Theoretically, strata are still in the order in which they were deposited. As Fig. 3.6 demonstrates, stratigraphy can be difficult to interpret due to multiple events intruding upon earlier deposits and construction sequences that mix deposits of one time period with those of other periods. One of the goals of excavation is to learn about the history and function of sites from such stratigraphic evidence and the materials associated within each component.

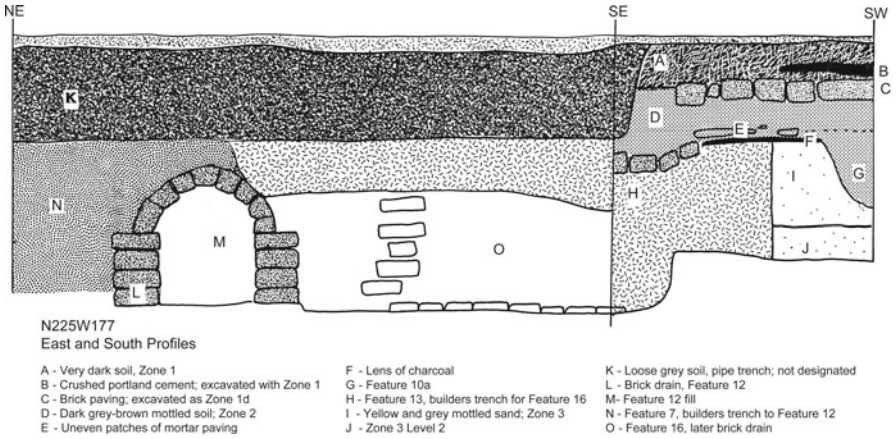

Fig. 3.6 Profile of the east and south walls of unit N225W177, Miles Brewton House, Charleston, SC (USA). See Fig. 3.2 for the location of Unit N225W177 on the property (just south of the cistern). From Zierden (2001:55) and used by courtesy of Martha A. Zierden and The Charleston Museum, Charleston, SC (USA)

Each stratum is excavated separately from the others in the excavation unit and the materials recovered from each stratum are considered separate samples. In most cases, the unit is excavated until there is no further evidence of human activity. Strata below this point are considered archaeologically sterile. Excavation should continue into this sterile zone to collect information about the landscape before the site was occupied and to ensure that a much earlier phase of occupation is not overlooked.

Strata may be termed levels or zones, referring to the more or less vertical stratification found during excavation. Vertical stratification is the depth component of the three-dimensional provenience record. Strata are designated using a sequence of numbers, letters, alphanumerics, or other codes often beginning with "Level 1" at the modern surface and working down so that "Level 8" might be the lowest level in the unit. Sometimes strata are relabeled after the field work is done to reflect the project director's interpretation of the site's history. Although this is intellectually satisfying, some sample bags will not be relabeled or will be relabeled incorrectly, becoming a perpetual source of confusion and error.

Excavators use one of two concepts to manage depth: natural stratigraphy or artificial, metrical increments. For the following discussion, "**zone**" refers to natural stratigraphy and "**level**" to metrical increments. The letters in Fig. 3.6 refer to natural stratigraphic zones. **Natural strata**, or zones, are the direct product of human and nonhuman site formation processes and may extend vertically for a meter or more within a unit. Because greater control over depth is needed than natural zones provide, and because natural stratigraphy may be discontinuous among units, field staff may define levels using **metrical** or **artificial stratigraphy** instead of natural stratigraphy. Using metrical stratigraphy, the unit is excavated in predefined increments, such as 5, 10, or 15 cm levels. This allows greater control over vertical

context, but may not capture the site's complex structure, function, and history. The two approaches often are combined by dividing larger natural zones into smaller artificial levels. The zones shown in Fig. 3.6 were excavated using artificial stratigraphy, though these are not shown in Fig. 3.6. Environmental archaeologists need to know which system was used and field staff needs to be consistent in the use of metric or natural stratigraphy and in the increments themselves to the extent that the contexts permit. Exceptions to the standard protocol should be clearly indicated when samples are sent to consultants.

They also need to be consistent in the standard of measurement used. The use of "metric" above does not mean measurements follow the Metric System. In the case of Fig. 3.6, the actual standard of measurement is the U.S. Customary System, often termed the English system. This choice is customary in the United States when English colonial sites are excavated as this system conforms to the standard of measurement used during the colonial period and subsequently at sites such as Charleston (South Carolina, USA). This is yet another fundamental aspect of field work that must be communicated clearly to consultants.

Stratigraphy is usually revealed in the **profile** or **section**, the sequence of sediment types in the exposed balk, wall, or face of the excavation unit (Fig. 3.6). Some traditions distinguish between profiles and stratigraphic series. In those traditions, profiles are uniform sediments with an internal structure and a stratigraphic series is a column of superimposed deposits of diverse origins (Shackley 1975:4). However termed, strata that appear to be a confusing array of unrelated colors and textures (or totally homogeneous) during excavation may be more clearly displayed, with more obvious relationships, in the unit's exposed walls. When excavation of a unit is complete, a "map" is drawn of the strata exposed in one or more of these walls; Fig. 3.6 shows profiles of both the east and south walls of unit N225W177. This "map" may be called a **stratigraphic profile** or **section drawing** because it is a record of the strata exposed in a specific profile or section. Careful measurements are taken of the depth and other characteristics of each stratum and the exposed profile is the source of many organic samples.

Discontinuities may interrupt the general stratigraphic sequence and often are excavated in more detail than the surrounding matrix. Some of the most common terms given these discontinuities are areas, features, pits, and ditches. Different archaeological traditions confound defining these names; suffice it to say they are applied to irregularities encountered during excavation and generally are smaller than houses. Unless otherwise specified, these and other ambiguous terms refer to a portion of the unit that is different from surrounding portions but whose function is unclear. Terms such as drain, roasting pit, builder's trench, and burial pit are functional interpretations used when field staff is more confident of the discontinuity's identity, though subsequent analysis may prove the interpretation wrong. This mixture of descriptive and functional terminology is likely to cause confusion during analysis and in future publications; neutral field descriptions are preferable.

Some discontinuities are more important for specific studies than are others. Inorganic materials from a footing trench may provide information about the construction sequence of a structure, for example. **Post holes** (the holes dug to accommodate

posts) and **post molds** (spaces left by posts sometimes containing remains of posts themselves) may define the outlines of structures that are otherwise invisible. Post holes may provide information about construction techniques, while the post molds yield information about building materials. Although neither is likely to provide nutritional data as a general rule, fill in such contexts may contain charred grains and the remains of commensal organisms. In some cases, offerings are found at the base of the hole, placed there before the pole was inserted, and have some symbolic significance.

A primary goal of field work is to find artifacts in their original temporal, spatial, and behavioral contexts. It is important to know which materials are from the same context and presumably are contemporaneous. This requires distinguishing modern materials from archaeological ones, knowing which materials date to the same time period and which are intrusive from another time period, and recognizing the boundaries of specific deposits. In the field, slight changes in color or texture indicate such boundaries, but their significance often is ambiguous. As a general rule, when uncertain about what such observations mean, these contexts are excavated as separate phenomena. This conservative procedure produces a large number of sample containers that may contain very little interpretatively useful material. Each container receives a distinctive identifier that may be a simple sequential number or part of a complex system of letters and numbers. The more complex the identifier, the more confident the project director can be that samples will be mislabeled and misinterpreted.

Recovery Techniques

Basic excavation decisions about where to place units and how to excavate each context are important aspects of recovery, but the term **recovery techniques** usually refers to in situ recovery, screening (sieving), or flotation rather than to the placement of units (see below, this chapter). Many different recovery techniques are used and most have merits in specific cases; none is adequate for every context or material type (e.g., Hageman and Goldstein 2009). The choice of recovery technique requires careful thought about comparability, quantification, and the nature of materials in each context. The literature on recovery techniques is voluminous and growing because inappropriate techniques have plagued archaeological research for decades (e.g., Hageman and Goldstein 2009; Keeley 1978; Shaffer and Sanchez 1994; Struever 1968). Recovery bias is unavoidable, but every effort should be made to develop a technique appropriate to the research design. When in doubt, it is best to recover materials as thoroughly as possible, deferring decisions about which of the recovered materials to study, and how much, until these choices can be guided by knowledge gained during excavation.

Most environmental data will be quantified in some way and should meet two requirements: (1) all archaeological materials must have an equal opportunity to be recovered; and (2) the recovery technique must be consistent. A sample assemblage

should contain materials in the same proportion as existed in the archaeological assemblage; the larger the sample, the greater the possibility that the sample assemblage will resemble the archaeological assemblage. A particularly important source of bias is introduced when field staff collects only those items that are "interesting" or large. Formal sample randomization controls conscious or unconscious bias. Another source of bias is the decision to confine excavations to features, or to use a more thorough recovery method for some contexts than for others. Only through strict use of uniform methods that limit biased recovery can it be argued, for example, that mammals were more frequently used than were fishes.

The most common standardized recovery method is **screening** or **sieving**. This encompasses a variety of approaches but broadly means that excavated matrix, typically dry, is passed through a screen with a mesh of some relatively small dimension. The mesh or **screen size** used in the field is often what is available in local shops. In the United States, screens with 1/2-in. (12.7 mm), 1/4-in. (6.35 mm), 1/8-in. (3.18 mm), and 1/16-in. (1.59 mm) meshes are used because these are standard commercial and residential sizes. Screens are affixed to any number of frame styles. A stack of screens may be used, with a large mesh size at the top of the stack and the smallest screen size at the bottom. Soil or sediment from the unit is placed (shoveled, dumped) onto these screens. Items too large to pass through the screen's mesh are collected in sample containers, usually plastic or paper bags. Material that passes through the screen becomes the "**back-dirt**" that accumulates underneath. Sometimes screens are agitated manually or mechanically, or water is sprayed over the contents of the screen to remove adhering material. **Water screening** or **water sieving** (using water to clean materials in the screen) should not be confused with flotation (see below, this chapter).

The screen size used has been repeatedly demonstrated to affect the type of materials recovered (e.g., Orton 2000:164). Watson (1972) identifies two criteria for determining the screen sizes to use: (1) the minimum size of an identifiable fragment and (2) the minimum size of a reliably recoverable fragment. A further consideration is whether the study requires that the full range of taxa used at the site be recovered or whether only certain taxa need to be included in the study assemblage.

When two different screen sizes are used, the results may suggest considerably different subsistence strategies. For example, the results for two different collections from a coastal site known as the Kings Bay site (GA, USA) are shown in Table 3.1 (Reitz 2004). One collection was recovered using a 1/4-in. mesh and the other using a 1/8-in. mesh. Although both fractions indicate that marine sharks, rays, and bony fishes were prominent in the assemblage, the 1/4-in. collection suggests that terrestrial mammals were used more frequently than appears to have been the case based on the collection recovered with 1/8-in. as the smallest screen size. Sample size might be responsible for the difference in these two collections. The 1/4-in. fraction is much larger than the 1/8-in. fraction. In addition, the 1/4-in. collection is from a zone and the 1/8-in. collection is from five features. It is impossible to know whether the differences between these two collections represent differences in screen size, in sample sizes, or in the broad human behavior that might produce

Table 3.1 Impact of screen size on two deposits at the Kings Bay Site (9CAM171A, GA, USA) deposited between AD 800 and 1565[a]

	1/4-in. Mesh	1/8-in. Mesh
Screen size	MNI%	MNI%
Terrestrial animals	21.4	7.0
Aquatic mammals	0.9	–
Birds	2.7	2.3
Reptiles	9.8	2.3
Sharks, rays, and bony fishes	60.7	83.7
Commensal taxa	4.5	4.6
Total MNI in sample	112	43

[a]MNI refers to the minimum number of individuals. Vertebrate MNI is reviewed in Chap. 13. Based on data from Reitz (2004)

a zone contrasted to the specific, more limited behavior represented in features. Thus, we cannot determine which of the two collections most accurately represents the environment or culture at this coastal site. If the second-order biases of recovery method and context had been controlled, differences in sample size would remain to be resolved, but that at least is a problem not introduced to the analysis by lack of an appropriate research design.

Screen crews usually sort through the materials caught in larger screens while in the field, leaving those captured by smaller meshes to be sorted in the lab. Their ability to recognize a wide variety of organic materials impacts subsequent interpretations. If something caught in the screen is not recognized as relevant to the study, it likely will be discarded. In their enthusiasm to get all of the excavated matrix processed, some screen crews force lumps of dirt through the screen, damaging whatever is inside. Although the screen crew may not appreciate this when surrounded by wheelbarrows full of dirt to be screened before day's end, they are the critical link between archaeological and study assemblages.

Even the smallest mesh, referred to as **fine-screening**, does not collect the smallest organic remains and many environmental archaeologists advocate flotation as a way to collect some types of small organic materials (Pearsall 2000:15–29). A distinction sometimes is made between **water separation**, in which the floating material flows out of the main tank into an external tray, and **flotation**, in which the floating fraction is skimmed manually (e.g., Limp 1974), but this distinction is blurred in many applications (e.g., Kipfer 2000:193) and both are considered flotation in the following discussion. Flotation relies on both the surface tension of water and the relative specific gravities of water and the archaeological materials. Inorganic materials and some organic materials sink (becoming the **heavy fraction**), while lighter materials float (forming the **light fraction**; Jarman et al. 1972). The heavy fraction always must be checked for organic remains that will not float. Some flotation devices force water through the tank and/or agitate the water to facilitate separating the heavy fraction from the light fraction. A few devices have achieved sufficient fame to be known by name, such as the Ankara machine

(French 1971:60), the Sīrāf unit (Williams 1973), the Izum (Davis and Weslowsky 1975), and the SMAP (Watson 1976).

Sometimes plain water is inadequate for recovering organic remains (Pearsall 2000:89–93). In such cases a chemical, such as zinc chloride ($ZnCl_2$), is added to the solution. This type of treatment is called **chemical flotation**. Some heavy liquid solutions may even float vertebrate skeletal and dental material (Bodner and Rowlett 1980; Struever 1968). The materials collected by chemical flotation must be washed thoroughly to remove as much of the chemical additive as possible. Typically only small volumes of material are processed using chemical flotation so as to limit the amount of chemical used and length of exposure. People using such chemicals should be trained to avoid injury and to ensure proper waste disposal.

Characteristics of the specific matrix and the materials must be considered. Generally, flotation is used to recover relatively large, carbonized botanical remains and screening is used to recover inorganic material culture and large animal remains. Close-grained clays, loams, and peats can be difficult to float. Sometimes samples are dried before flotation, which is problematic for organic remains from water-logged or anoxic conditions. Flotation violates the admonition to keep dry organic materials dry and is not suitable for the recovery of mineralized seeds because they are unlikely to float, a reason for checking what remains in the heavy fraction. In some cases, flotation tanks are designed to recover all of the cultural and most of the biological materials, replacing screening altogether (Pearsall 2000:18, 22). As will be seen in subsequent chapters, even flotation leaves much of the organic record unsampled.

The efficacy of fine-screened recovery and flotation is tested in a variety of ways. In one common test, small seeds are added to archaeological soil or to clean sand and observed to see if they float or sink (Pearsall 2000:93–97). If archaeological soil is used, the markers should be exotic to the site, or even the hemisphere. This test runs into problems at sites occupied after the expansion of European influence, when many organisms were transported rapidly far beyond their pre-fifteenth-century ranges (e.g., Crosby 1986).

In addition to the screen size and other devices used to recover archaeological materials, samples often are distinguished by what could be termed "sample type," meaning classification of samples by how they were collected (other than screen size), the intended type of analysis (e.g., ceramic, lithic, sediment, biological), and how they will be handled in the laboratory. Often sample type is linked to screen size, processing methods, analysis, and curation requirements (e.g., Dobney et al. 1992). The terminology used for sample types is highly variable; often following traditions established within specific academic units, laboratories, or regulatory agencies. The sample types described below are by no means the only types possible nor are their definitions universally accepted. It is essential that consultants understand what is meant by these and other terms for each specific project. It is unlikely that the sample types or the terms used to refer to them will be uniform among projects or among laboratories.

One of the most common sample types is the column sample. Field staff sometime reserves a section of each unit as a source of samples to send for more detailed

study. This smaller section is termed a column and the samples are referred to as **column samples** (Pearsall 2000:69–71). The column is located in a corner of a larger excavation unit and may be any dimension, but often is 25 or 50 cm square, depending on the size of the excavation unit itself. Often columns are excavated after the rest of the unit, which enables field staff to remove the column using the natural strata visible in the now-exposed profile. Column samples typically are removed by routine shoveling and troweling before being fine-screened or floated. They are compromises between the costs associated with thorough recovery and limited budgets.

In some instances, the column or some other component of the site is removed intact (Branch et al. 2005:123). Such **whole earth samples** (sometimes called **bulk samples**) are samples from which no material is removed in the field. This type of bulk sample ensures that all of the organic and inorganic materials in the sampled context are recovered without bias favoring one type of material over another. They require coordination in the laboratory to ensure that each type of material is removed appropriately and without harm or bias to other materials in them. Sometimes bulk samples are intended to be archived for future applications and are not processed at all initially. Many bulk samples languish or are discarded because plans were not made in advance to manage the logistics and costs involved in processing or archiving them.

Materials collected as they are encountered are deemed to be **in situ**, meaning they are collected directly from their original archaeological setting. This sample type enables materials to be recovered from potentially interesting contexts while controlling damage and contamination associated with other recovery techniques. In situ recovery relies on collecting soil and all its contents in either small or large amounts, but the terminology and procedures are highly variable. To field crew, this sample type refers to items observed in the unit matrix instead of in the screen or flotation tank. In some laboratories, materials collected from unusual or interesting contexts, such a caches of seeds or bones, are termed spot samples (Dobney et al. 1992). Some laboratories refer to samples studied in the lab as in situ samples. These differences should be clarified before field work begins and the term defined in subsequent reports.

Composite, **pinch**, or **scatter samples** are terms given to a specific type of in situ sample (Lennstrom and Hastorf 1992; Pearsall 2000:69). A composite sample is accumulated by taking small amounts (pinches) of matrix from a several places throughout a defined context and combining these into a single sample bag. For example, a liter of soil may be accumulated from four or five locations in a stratum. The objective is to collect material from throughout the context so that the composite sample represents the overall deposit. Such samples likely will contain materials invisible in the field.

Another type of in situ sampling is **point sampling** (also, confusingly, known as bulk sampling), in which a sample of the deposit is collected from a single location (Pearsall 2000:71). Point sampling takes a sample of a standard volume (e.g., 1 L) from this location (Lennstrom and Hastorf 1992; Pearsall 2000:73). The pelvic area of a burial, discrete lumps of palaeofeces, and the contents of ovens, hearths, and

post molds often are point sampled to avoid damage that might be caused by screening. If the contents of a vessel are sampled, these should be from the interior of the vessel to avoid collecting materials from the surrounding matrix. In the case of intentional burials, the burial itself will be recovered in situ; though the contents of the burial pit may be screened after point samples are taken.

Even these collection strategies are inadequate to recover some organic remains, such as pollen, insects, and starch grains. Some of these may be collected in composite or point samples, but most are studied from what traditionally are known in archaeology as **soil samples**. Soil samples are samples of matrix taken from the exposed profiles of excavated units, or from other specified contexts. These samples may actually be samples of sediments (Chap. 5). By whatever designation, they are a particularly important type of in situ sample. They are used to study sediments, soils, and organic evidence that cannot be collected by flotation or screening. Some of the methods discussed above could be considered soil samples as well. Many environmental archaeologists use these samples and it is better to take too many than to discover after field work is over that there are not enough for all the studies that need them.

Soil samples from one context should not be contaminated with materials from adjacent strata or sampling points. As Evans (1972:41) states: "Sampling is done at a point where the stratigraphy is most complete and most representative of the deposits as a whole, remembering at the same time that the exact location will be reflected in the composition of the snail fauna." Although Evans refers specifically to land snails, the principle applies to all organic samples, and stresses the merits of in situ recovery to capture significant details of context.

Samples may be taken by **augering** or **coring**. A simple screw auger may be very useful for prospecting, specifically to obtain a rough indication of underlying material or the depth at which sterile is likely to be reached. Most environmental archaeologists cannot use materials recovered by such devices because the contents are mixed with unassociated materials as the samples are drawn up through the profile. Wet and very loosely consolidated dry deposits generally cannot be augered. Pollen samples, however, are frequently obtained using peat borers.

Some archaeologists once argued that materials not recovered in situ (observed in the dirt not in the screen or flotation tank) have lost their context because their exact locations cannot be plotted and the materials affiliated with them may have lost a direct association observable in the field. This was (and is) used as a justification for not screening. Field staff cannot be expected to record or collect materials they cannot see or do not recognize, such as small seeds and land snails. Payne (1972, 1975) reported decades ago that more materials are recovered when a screen is used to capture small items than is recovered from simple in situ field recovery (excluding subsequent laboratory analysis). Failure to screen matrix even biases interpretations of large mammals (e.g., Orton 2000:164). For example, a restudy at Çatalhöyük (Turkey) found that the dominant domestic animals at the site were sheep (*Ovis*) and goats (*Capra*), not cattle (*Bos*) as had been indicated by studies of unscreened materials (Richards et al. 2003). In practice, in situ recovery and screening should be combined to ensure that materials of all size ranges and fragility are represented

in the study assemblage. This is not to say that in situ and screened fractions should be physically mixed; materials obtained through different recovery methods should normally never be combined in the same sample bag in the field or in the laboratory.

Project directors want to know which recovery technique is efficient or adequate in order to balance time, labor, and funds against data recovery. Instead of arguing here that all samples must be recovered with the finest recovery technique possible from every context, we urge project directors to think carefully about their research design and the recovery method(s) appropriate for that design, as well as to discuss options with environmental archaeologists ***BEFORE*** the budget is finalized and field work begins. Both should be prepared to alter that strategy if subsequent field work suggests that might be necessary.

Several very different sampling strategies are referred to using similar terms, and some similar sampling strategies are known by several different names. For example, in some cases, "bulk sampling" refers to large samples (e.g., 40–70 L) in contrast to much smaller **spot samples** (e.g., 20 g; Branch et al. 2005:123–125). In other cases "bulk sampling" refers to whole earth samples. This and other differences in terminology are obvious sources of confusion in subsequent studies and in publications. It is important to describe field procedures used to collect various sample types, precisely communicating to people who were not in the field how samples were collected and handled.

How Many Samples Are Enough and How Large Do They Need to Be?

Determining what constitutes an adequate number of samples and the appropriate size of those samples is a problem that begins in the field and continues through analysis (Orton 2000:148). The number and size of samples should reflect the relative proportions and distribution of sediments, soils, and organic materials at the site and be large enough to permit drawing conclusions relevant to the research design. Pearsall (2000:112, 305) identifies two aspects of the sample size issue: (1) how large does the sample need to be to have the full range of taxa represented, including rare ones; and (2) how large does the sample need to be to reliably reflect the ratio of one significant organism to another one, say of wheat (*Triticum*) to barley (*Hordeum*). On a case-by-case basis, subsampling and sorting experiments may indicate how much material needs to be processed to have rare taxa represented, or to have a reliable ratio of one taxon to other taxa (Pearsall 2000:112–116).

Smart and Hoffman (1988) suggest plotting the number of taxa against the number of specimens in each sample during the early stage of identification. At some point, the curve should level off, indicating the number of specimens that need to be identified to obtain a list of taxa that includes rare as well as abundant taxa. Figure 3.7 is an example of such a plot using vertebrate specimens identified from several

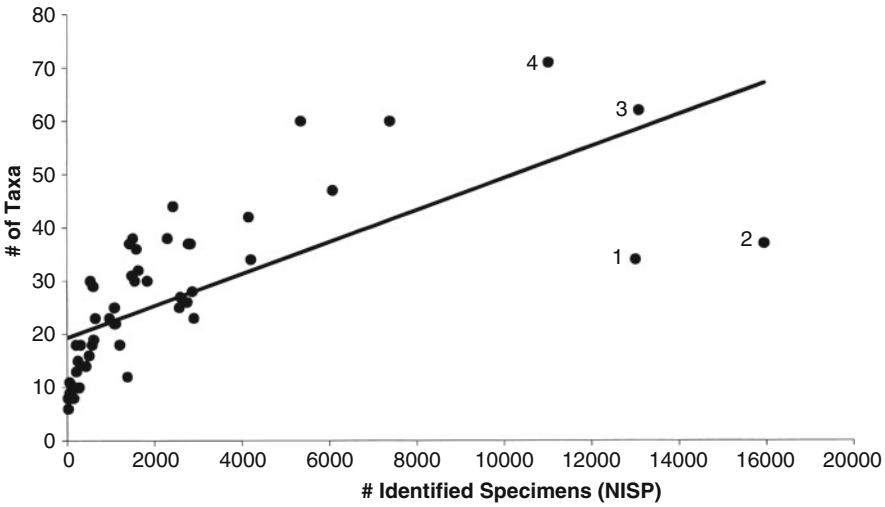

Fig. 3.7 Plot of the vertebrate number of identified specimens (NISP) and the number of vertebrate taxa identified in 52 collections from Charleston, SC (USA). Key: (1) Charleston Beef Market, 1739–1760; (2) Charleston Beef Market, 1760–1796; (3) 14 Legare household, late 1700s; and (4) Charleston Place, mixed residential and commercial functions, 1730s to late 1800s. For more information about these sites see Zierden and Reitz (2009)

collections deposited between CE 1712 and 1900 in Charleston (Zierden and Reitz 2009). In this figure, each dot represents a specific vertebrate collection from a site or temporal component of a site. The data are presented as the number of taxa identified in each collection plotted against the **number of identified specimens** (**NISP**; specimen count). This is a standard presentation designed to suggest a sample size adequate to capture most of the richness in such assemblages (e.g., Schibler and Jacomet 2010). In Fig. 3.7, one might presume that samples containing 4,000–6,000 specimens would be adequate to include most, though not all, of the taxa necessary to interpret these collections. Four outliers, however, are particularly interesting because two of them are late eighteenth-century markets and a third is a late eighteenth-century household. The fourth is a mixed residential and commercial block occupied between the 1730s and late 1800s. The unusual nature of these four collections would not have been observed in smaller samples, but highlights significant aspects of life in the city and the evolving urban landscape.

As can be seen, the contents of each context may vary considerably and the question of sample size will have to be revisited often. Other researchers prefer to carry out identifications until a specified number of specimens is obtained, using a predetermined standard count to make sampling decisions (e.g., Asouti 2003; Rhodes 1998). Some researchers may decide to study 10% of the samples available, using a table of random numbers to select which samples to examine. This very much depends on what has been collected during excavation and the overall research objectives.

Questions of sample size are likely to remain unresolved because it is always possible that important insights are hidden in the unstudied samples or in a portion of the unexcavated site. This presumes, of course, that the analyst has the luxury of choice and that an abundance of samples was recovered using good field methods from contexts appropriate to the research questions. Although statistical approaches for determining adequate numbers of samples and adequate sample sizes are beyond the scope of this volume, sampling decisions should be made under controlled circumstances in the laboratory, not in the field. Deciding what constitutes an adequate sample for analysis is impossible in the field, where taking too many samples or ones that are too large is better than taking too few. As should be clear from the foregoing, materials should be collected in the field as uniformly and consistently as possible, following an established protocol to avoid biases.

Off-Site Testing

What is the extent of human influence on soils? Which organisms are found in the area, when, and where? Over what terrain and how far did people travel to find pasturage, fire wood, medicinal herbs, water, shellfish beds, or other resources? Are non-anthropogenic soils nearby? Is there evidence for changes in land forms that suggest reconfiguration of shorelines, changes in stream-flow patterns, erosion, or tectonic activity? When environmental archaeologists visit sites, they may spend much of their time off-site, gathering knowledge vital to answering such questions and interpreting the archaeological context (e.g., Dumayne-Peaty 2001).

Given the extent to which landscapes have been altered by intentional and unintentional human activities, the distinction between on-site and off-site may be an artificial one, often based on the definition of a specific type of human activity at a specific time. Nonetheless, going beyond the specified boundaries of the present excavation area is an opportunity to become familiar with aspects of the locality that are unavailable at the site itself. Off-site surveys seek locations that have minimal evidence for human modifications or those that contain evidence of environmental changes that might have occurred before, during, or after the site was occupied. This is an opportunity to strengthen reference collections that will be used during identification and analysis (after the appropriate collecting permits and permission of the landowners are obtained).

The project's proposal and excavation permit likely were developed for a very limited number of sites, for a single site, for the route of a proposed pipeline, or even for the footprint of a swimming pool. The project director is responsible to the sponsoring agency for meeting the goals stipulated in the proposal and may not be paid for work outside the project's scope, no matter how important the results might be to interpreting the materials recovered from within the project boundary. Project directors may be unhappy when environmental archaeologists spend resources far from the site, but consultants may be unable to meet the project's goals if they are

confined to narrow limits. Off-site testing should be clarified before a proposal is submitted to a sponsoring agency.

That being said, however, neither environments nor cultures can be understood from the perspective of a few units excavated at a single site. Single sites should be examined in terms of their broader social and environmental contexts. Thus, non-anthropogenic contexts should be compared with anthropogenic ones; rural sites to urban ones; ritual sites to residential ones; early deposits to later ones; coastal sites to lacustrine ones; high-status sites to low-status ones, etc. Achieving this broader perspective may require accumulating data over many field seasons, adding urgency to the admonition that both field and laboratory procedures be well planned, clearly described, and replicable.

Anticipating Radiocarbon Dating and Other Studies

Some archaeological materials require chemical applications to improve their recovery, clean them, or stabilize them. The choice of treatment depends on the material involved and its condition. Conservation requires access to a professional conservator's laboratory. Some treatments use chemicals that may preclude future studies. Most people are familiar with the problem of contaminating samples for radiocarbon dating; similar problems exist for biogeochemical and biomolecular studies. It is best to handle, clean, and treat materials as little as possible, consistent with maintaining their integrity. It may be necessary to choose between survival of the specimen and its use in studies that require untreated specimens. Environmental archaeologists and the final curatorial facility can recommend treatments that balance these conflicting needs. If a specimen is treated, a record of the chemicals used should be kept with it at all times.

Record-Keeping and Laboratory Procedures

One reason for environmental archaeologists to visit the site during excavation is to become familiar with field terminologies and procedures. Even if environmental archaeologists are in the field during part or all of the field work, field staff can assist environmental archaeologists, curation facilities, and future scholars by ensuring that records such as maps, field notes, and catalogues are self-explanatory. Copies of the research proposal and the preliminary field report will help everyone understand the project's objectives and the site. Circulating the names and contact information of all members of the team encourages them to compare their results and enhances the research potential of everyone involved. The following are general guidelines for facilitating the transfer of materials from the field to laboratories. Details of how samples should be handled in the field, cleaned, and packaged prior to transfer to consultant laboratories should be discussed with consultants before

excavation. Each type of material has its own specific needs; many laboratories have limited facilities and specific instructions for samples they study.

The special needs and processing methods associated with the different abiotic and biotic contents of these samples may require separate samples or subsamples for each study (Piperno 2006:82, 95–96). With careful coordination, it is possible for labs to draw subsamples from a master sample, but each time the container is handled, opened, or shipped, the probability of contamination, damage, and loss increases. This gross sampling approach is inappropriate for some contexts and questions, particularly when distinct depositional episodes are represented by very small deposits (Dimbleby 1985:21). Unused samples should be curated for use in the future, though, regrettably few archaeologists or consultants have access to curatorial facilities appropriate for long-term survival of these materials.

Field and archaeological laboratory staff can help ensure that samples are in good condition when the consulting laboratory receives them by following a few simple steps. In the field, as a general rule, it is unwise to leave biological materials exposed in an open unit for several days as this will result in weathering at the very least; plastic tarps will not prevent this. Most organic remains are fragile and break when handled. They should not be exposed to rapid or extreme changes in temperature or humidity. Specimens should not be handled roughly or scrubbed vigorously. Desiccated, waterlogged, and flotation materials require special attention. If they are from a damp context they should remain damp until a conservator's advice is obtained. The same caution applies to desiccated and frozen remains.

Samples should be carefully packed. Most specimens should be clean and dry before being packed. Containers should be water-proof, rigid, and clearly labeled within and without (with a few exceptions, see below, this chapter). Packaging should provide protection from bad weather and shipping agents. Subsequent lab staff will be grateful if plastic bags are not closed with staples or knots; string or bag closures are adequate in most cases. Resealable plastic bags have a tendency to tear or come open. Avoid thin biodegradable plastics; these are designed to decompose relatively quickly, sometimes before the sample is studied. Aluminum foil is not appropriate packing for most organic materials, though radiocarbon samples are obvious exceptions. Foil provides no protection to fragile plant or animal remains when a bag of pottery is placed on top of the foil packet, nor does tissue paper of any sort, no matter how thickly applied. If an aluminum foil packet is constructed, resist giving it one final squeeze, which will ensure that the packet is indeed closed but that the contents probably are shattered. Samples of soil, ceramics, nails, daub, stone, and bags of shell should not be placed on top of biological materials unless the latter are housed in rigid containers that can bear the weight.

Labels are the only link between archaeological and study assemblages. It is critical that labels be unambiguous to maintain links between samples and archaeological evidence and to prevent mixing samples during subsequent studies. Field personnel should use a very simple, non-repetitive system that can be written multiple times with limited scope for error; for example, a sequential series of short numbers. The simpler the code, the more likely it will be written correctly multiple times. Field and lab records should link the simpler sample number (also known as

bag, lot, or field numbers, among other designations) with the necessarily more detailed provenience information. Ideally, the site name, unit, area designation, feature, zone, level, and other provenience information will be on the label, but the more detailed labels become the more likely it is they will be incorrect. The site designation is important because the consulting laboratory may be studying samples from several sites. If environmental archaeologists collect and label their own samples, they should follow the project's system and a record should be archived with the project files. The project director and environmental archaeologist should ensure that the recording system is understood; the assumption should be that errors will occur and procedures should be in place to spot them early to limit the resulting damage.

Legible and accurate labels should be maintained at all times; in most instances, labels should be placed both inside and outside the container. Interior labels may mildew if the materials are not dried properly, so a duplicate external label should be used. Labels written on plastic bags with some reputedly indelible marking pens will smudge when the bag gets wet, as it will. The provenience of the sample will be irretrievable when both "accidents" occur. If materials are submitted for chemical analysis, it may necessary to forego the interior label; making survival of the exterior one all the more critical. Labels should be checked for durability; many are not waterproof or ethanol-proof. The most durable notations on labels for materials that are dry are those written with a good pencil on acid-free card stock. With the passage of time, disintegration of labels is common (e.g., Iliopoulos et al. 2010). Field staff should assume all of these problems will occur and ensure a degree of redundancy.

It is important to be clear about which samples were found together, in the same context. A good drawing of the materials in situ, with the position of the samples marked, accompanied by a photograph, all of which are labeled with the bag numbers, is essential for accurate interpretation. Confusion arises if each bone from a dog burial, for example, is bagged separately and each bag has a different field number. Even greater confusion arises if there is more than one dog burial, each specimen of which is tagged and bagged separately; or one dog burial and a large number of disassociated dog skeletal parts from other locations in the site. It is rarely clear in the laboratory which bags contain different parts of the same dog and which contain dog remains from other contexts. Field staff should inform consulting laboratories if samples are from closed contexts as this is unlikely to be obvious.

Every move endured by archaeological samples is a hazard to survival. Field and laboratory personnel should expect that specimens will be roughly handled while in transit. Shipping containers should not be so large that they cannot be handled safely. Well-padded samples should be sent in securely taped, sturdy boxes. Specimens on the bottom will bear the weight of everything on top; "up" will become "down" during shipping. Do not presume that labels such as "This End Up" or "Fragile" are anything other than targets for package handlers. If sturdy packing supplies will be unavailable in the field, they should be purchased in advance.

Field records, including maps and excavation profiles, should accompany the materials. These records should include lists of proveniences, sequential sample numbers, and a brief description of each context. Field staff should anticipate that

basic site maps will be needed by all environmental archaeologists. Maps showing the site, its relationship to physiographic features such as marshes and streams, the excavation grid, and profiles are essential. Even maps and drawings smeared with sweat and insect repellant are appreciated and enhance the research potential of the materials collected. Field methods should be described in detail, including whether arbitrary or natural levels were used, what the metric increments were, definitions for zones, features, areas, etc., and whether depths were measured below surface, below datum, or from some other reference point. Volumetric information for the excavated units is important. It is equally important that the original weights and/or volumes of samples be recorded before they are processed and that these original data be communicated to all consultants. Each consultant should know what fractions or materials have already been removed from the samples they study. If a conservation treatment was used, what was it and which materials were treated?

Limbrey (1975:280; italics in the original) notes "*Interpretation whose correlation with the archaeological evidence is in doubt is worse than useless*." Field work produces a lot of samples and analytical costs can easily exceed the budget. Samples should not be distributed for study until a preliminary archaeological assessment is conducted to establish which samples are from contexts that are from the targeted time period, behavioral context, or otherwise conform to the research priorities, thereby determining which samples may be worth the expense involved in further study from the perspective of the archaeological context itself. Most field work presumes that each context has a distinctive depositional history; field staff routinely isolates deposits that seem different in any way. In the laboratory, samples can be assessed using knowledge unavailable in the field to identify those that are too superficial, of questionable date, redeposited, exposed in the field too long, inadequately protected from post-excavation damage, or compromised because information is incomplete, illegible, or missing. Some contexts are so mixed or damaged that they are unsuitable for study and the integrity of others is ambiguous. Samples from such contexts should not be sent for further study.

After the general merits of each sample are understood, these should be discussed with consulting researchers to further determine which samples merit study by environmental archaeologists and which do not. Often field staff needs information from environmental archaeologists to prioritize the final list of samples that warrant costly additional study by specialists. Communication and flexibility are essential.

Goldberg and Macphail (2006:335–336) suggest guidelines for determining which samples to study and methods to use in geoarchaeology, but these can be paraphrased to apply to all archaeological samples. First, is this analysis really necessary; will it help interpret the site or the region? Second, exactly which of the standard analytical procedures address the specific research questions; will the data be useful? Each discipline has basic criteria for an appropriate study, but beyond that, what other data are needed? Third, is the context still intact? Does the deposit still represent conditions in the time period being studied or has it been altered in such a way that it is no longer possible to be sure? These and related questions assist in selecting samples for further study and deciding which methods should be used.

The Ethics of Archaeology

Local, provincial, national, and international norms, procedures, and laws protect many archaeological sites. To obtain permits, project directors must justify why they have selected a site for study, how much of the site they will disturb, how long it will take, and what will happen to the excavated materials. Non-archaeologists should recognize that it may not be possible to excavate in precisely the best location at a site, to export the samples, or to keep the materials for a long time. Under no circumstances should laws governing archaeological research be violated.

Many countries and indigenous peoples have seen their cultural patrimony removed, never to hear of it again. They are justifiably cautious about excavation and export permits. It is also important to the field of archaeology to have trained professionals in every country. Projects should engage local scholars, students, and the public in their research and ensure that reports and publications are provided to the host country or community in a timely manner. This applies to environmental archaeologists, too, regardless of their disciplinary affiliations.

Disseminating results is an important aspect of research. Most consultants' findings are initially written as reports. Due to the growth of salvage, mitigation, or rescue archaeology, the number of reports is vast. This "gray" literature is not readily accessible to professionals, let alone the public. Organizations such as the Association for Environmental Archaeology and the Society of Archaeological Sciences sponsor journals that are more reliable sources of data and interpretations than are reports or websites because the papers in them are reviewed by knowledgeable researchers before publication. Known as **peer review**, such scrutiny is a hallmark of good research.

Environmental archaeologists are strong advocates for long-term, professional curation of comparative collections, studied and unstudied samples, and the associated notes in a repository that meets or exceeds the standards of organizations such as the International Council of Museums and the American Association of Museums (e.g., Carter and Walker 1999). Because excavation is destructive, it is important that excavated materials be available for reexamination (e.g., Orton 2000:191). Environmental data from archaeological sites may be used to address many more questions than the initial researcher is able to explore. Restrictions on space in journals often limit what can be included so that interesting data are unpublished. Other researchers may need access to unpublished data or want to know more details about a study. Some publications require that the curatorial facility be identified in the article. Materials and notes should be curated where conditions such as temperature, light, humidity, and pests are controlled. In many parts of the world it is difficult to meet such standards, but every effort should be made to place materials in as secure a setting as possible. Archival arrangements should be made as the project budget is developed to facilitate long-term care.

Applications

Two major questions for every site are: when was it occupied and for how long? Embedded in these questions are additional questions: were specific activity areas occupied at the same time and did the site accumulate gradually during a continuous occupation or did it form intermittently during repeated, briefer periods of occupation? Answers to these questions are important for interpretations of residential patterns, seasonal patterns of resource use, and environmental impacts. Often very few absolute dates are available to guide interpretation of the depositional sequence at specific sites or regional settlement patterns. Stein et al. (2003) approach these questions through a study of coastal shell-bearing sites located on the Pacific Northwest Coast (USA). They advocate estimating the accumulation rate for individual excavation units and the site as a whole. The authors define two types of accumulation rates. **Relative accumulation rates** assess the presence or absence of human occupation and the types of activities associated with each occupation. **Absolute accumulation rates** assess the intensity of occupation. Multiple radiocarbon dates, at least one for each stratum, are required to estimate absolute accumulation rates. The total accumulation is the difference in the depths below surface of at least two samples. The duration of accumulation is the difference between the mean radiocarbon ages of any two samples. The rate of accumulation is calculated by dividing the total accumulation by the duration of accumulation. Stein et al. (2003) report that the size of the deposit, the duration of the depositional event, the number of samples studied, horizontal and vertical distribution of samples, and differences among date of deposition, actual sample age, conventional ^{14}C age, and calibrated age all influence interpretations of accumulation rates. The authors define three accumulation rates: slow (2 cm/100 years), intermediate (<50 cm/100 years), and rapid (>50 cm/100 years). Having multiple samples improved the accuracy of the calculations, as did having samples from more than one activity area or depositional event. They conclude that most of the middens in their study consist of discrete deposits that accumulated at intermediate or rapid rates over short time periods (ca. 500 years) followed by periods of abandonment that might be as long as 1,000 years. Accumulation rates assessed for multiple individual excavation units provide far more information about occupational history than do accumulation rates for the entire site. These results should be considered when deciding how many and which units to excavate if settlement patterns and occupational sequences are among the research objectives, as well as when deciding which samples and how many to submit for dating. The authors observe that accumulation rates can be estimated using curated materials, an additional argument for archiving high-quality samples for future study.

Both field collection and routine museum methods are second-order changes that jeopardize archaeological interpretations; examples of the attendant biases are distressingly numerous. Beads, for example, receive a great deal of care in the field and special handling by museum curators because they are evidence of complex social organization, symbolic thought, and manual dexterity. Some of this care, however, makes it difficult to distinguish between non-anthropogenic and anthropogenic modifications. Early beads and other forms of ornamentation are significant

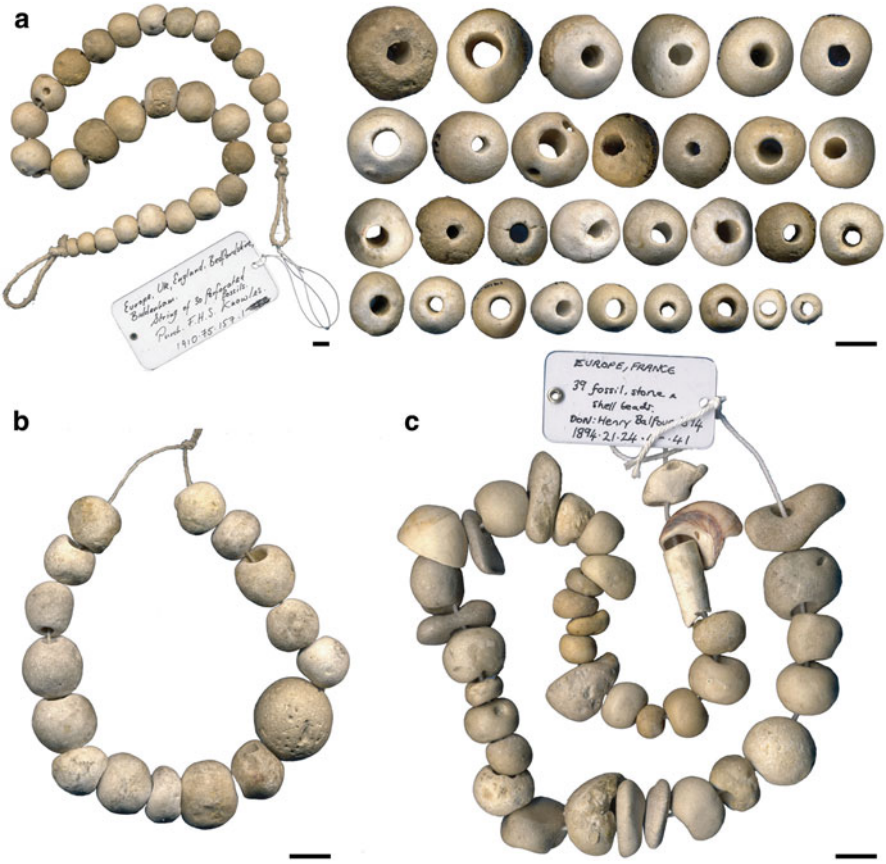

Fig. 3.8 Museum-curated archaeological collections of fossil sponges (*Porosphaera globularis*): (**a**) fossils from Biddenham (UK), cultural attribution is Acheulean, *left*: specimens strung with a cotton thread, *right*: unthreaded specimens; (**b**) strung specimens from Saint-Acheul (France), cultural attribution is Acheulean; (**c**) strung specimens from Paris (France), cultural attribution is unknown, though it may be Acheulean. Scale = 1 cm. From Rigaud et al. (2009:28) and used by courtesy of the authors and Elsevier

evidence for the trajectory and timing of human evolution. The earliest bead manufacture traditions in Africa, southwest Asia, and Australia are associated with anatomically modern humans, but some may be evidence of similar behavior by Neandertals in Europe (e.g., Zilhão et al. 2010). Rigaud et al. (2009) test one example of possible Neandertal bead manufacture by examining fossil sponges (*Porosphaera* [*Coscinopora*] *globularis*). These small (11–19 mm) spherical animals were extinct by the end of the Mesozoic era, but fossils may have been collected by early peoples from suitable deposits. Worms often bore central holes into these sponges to shelter inside; however, holes in fossil *P. globularis* from Acheulean sites in England and northern France (ca. 200,000 years ago) may be evidence of bead manufacture (Fig. 3.8; Rigaud et al. 2009:29). Rigaud et al. (2009)

report on their efforts to determine if the archaeological *P. globularis* were modified by Neandertals or by ancient worms. They collected modern reference materials from a non-anthropogenic context near Rügen (Germany) and compared possible beads with those in a verified *P. globularis* necklace from a Bronze Age burial in Kent (UK). They report that documentation is either lacking or poor for many of the purported Neandertal beads, making it impossible to assess from the records whether these were beads made by Neandertals. Holes in some beads are complete and larger than those in materials from non-anthropogenic contexts. The authors could not determine, however, whether this regularity is due to selectivity by Neandertals or by modern collectors. Many of the abrasions around the perforations are recent. These abrasions, as well as microchipping and ground facets, could be caused by overzealous cleaning or by the cotton thread used by collectors and museum staff to string the sponges into necklaces (Fig. 3.8). Rigaud et al. (2009) think that some of the enlarged, abraded perforations were present before curation damage occurred, but cannot determine the original context or condition of the specimens in most cases. They advocate new excavations using systematic, unbiased recovery methods that will not permit field staff to select sponges of particular sizes and shapes. Although they do not mention post-recovery care, new materials should not be zealously cleaned or subjected to additional physical trauma after excavation.

Summary

Failure to incorporate the special needs of their studies into research designs and field work is an impediment to the contributions of environmental archaeologists. Poor planning and inappropriate excavation techniques alter the study assemblage just as much as site formation processes. It is important that field staff thinks about the consequences of excavation and handling so as to control as much inadvertent bias as possible. Some decisions made in the field so seriously compromise samples that there is little or no justification for continuing the study.

At the same time, environmental archaeologists should understand that field personnel, no matter how well-prepared, do not control what they encounter. Despite the most thorough planning, archaeologists excavate the unknown. Field staff cannot simply dig whatever seems interesting, or return to the site and collect more materials when the samples already excavated prove unsatisfactory for whatever reason. There is no guarantee that more field work will produce better samples for a specific research question; data may simply be absent or inaccessible.

Developing a sound research design in advance of field work serves as a way to clarify questions, materials, and methods in order to achieve a better fit between field methods and subsequent studies. A thoughtful and flexible research design will enable project directors and environmental archaeologists to enhance coordinated studies and take advantage of the opportunities each site offers to explore the past.

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Chapter 4
Biological Classifications and Nomenclatures

Classifications, nomenclatures, and reference collections or standards are among the most basic tools used by environmental archaeologists. Their use is second nature to environmental archaeologists and a chief impediment to communication with non-specialists. Most laboratory research is devoted to attributing archaeological specimens to a recognized **taxon** (taxonomic unit; plural: taxa), a process known as identification (O'Connor 2000:39). Agreeing upon the names by which organisms, their parts, and other phenomena are known enables communication about what is under consideration and what it means. The principles of classification are basic to the reference collections and standards used during identification, to the process of identification itself, to the choice of analytical methods, and to subsequent interpretations. Although it is possible to understand some of the conclusions made by environmental archaeologists without knowing the conventions upon which identifications are based, the ability to follow arguments leading to those conclusions, or to evaluate their validity, is limited without some knowledge of these conventions.

Classifications and nomenclatures are the focus of basic research as competing theories about evolution and the nature of life are tested. Such research clarifies relationships among organisms, stimulating revisions in classifications and nomenclatures. These revisions reflect improved knowledge about evolutionary relationships underlying the **morphology** (external form) and **anatomy** (structure of the organism) used to study archaeological materials. It is rare for environmental archaeologists to propose taxonomic revisions, though they make substantial contributions to such studies (e.g., Gilbert et al. 2005; Sanjur et al. 2002; Vilà et al. 2006). On the other hand, environmental archaeologists need to be familiar with the reasons for these revisions because these may influence methods applied to archaeological materials and their interpretations.

For purposes of organizing this volume, archaeological materials are considered either geological or biological in origin. Geological and biological classification schemes share objectives of hierarchical order, uniqueness, clarity, and stability, but they differ in many ways. This chapter reviews biological classifications and nomenclatures; geological nomenclatures are considered in Chap. 5.

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We follow the classification schemes in two widely used biology textbooks, *Biology* by Campbell et al. (2008) and *Biology: A Guide to the Natural World* by Krogh (2009), with reference to the Integrated Taxonomic Information System website (ITIS) for specific nomenclature. These sources are used because they are familiar to many students, not because they are the most accurate or the final word. Dictionaries of biology, such as *The Penguin Dictionary of Biology* (Thain and Hickman 2004), are extremely useful. Readers may wish to follow classifications discussed in this chapter through the editorial sequence of these and similar textbooks or to compare the ITIS website with other reputable taxonomic websites sponsored by professional societies and governmental bodies.

Characteristics shared at the domain and kingdom levels are reviewed here as background to Chaps. 6–12. It is humbling to realize that many of the organisms most familiar to us, and upon which we are so dependent, are very minor components of the biological world as a whole (Fig. 4.1; Wheeler 1990:1040).

Vernacular or Common Names

Folk taxonomies reveal people's concepts about their world, associations they perceive among organisms and between themselves and other organisms, as well as attributes they consider important in each organism (Jones and Luchsinger 1986:11). The names used in folk taxonomies are **vernacular** or **common names**. Some are very similar, or even identical, to scientific names, whilst others group organisms into categories very different from the ones biologists use. A species may have many vernacular names, even within the same language. For example, the English vernacular name for *Cervus elaphus* is red deer in Europe and elk or wapiti in North America. Sometimes the same common name refers to different species; the vernacular "elk" refers to *Alces alces* in England and *C. elaphus* in parts of North America. "Corn" is maize (*Zea mays*) in the Americas and barley (*Hordeum vulgare*), oats (*Avena sativa*), rye (*Secale cereale*), or wheat (*Triticum* spp.) in Eurasia and Africa. English vernacular distinguishes between edible mushrooms and toxic toadstools, a distinction with no taxonomic validity. Some members of the genus *Amanita*, for example, are highly toxic (fly agaric [*Amanita muscaria*]) and others are edible (Caesar's mushroom [*Amanita caesarea*]; Rayner 1947; Rolfe and Rolfe 1974:284).

Folk taxonomies capture many important relationships among peoples, environments, and cultures. For most archaeological applications, however, they lack the clarity and precision needed to communicate among scholars working in diverse linguistic settings. Some organisms studied by environmental archaeologists have no vernacular names, and it is not customary to use vernacular names for other organisms, even when such names exist. When vernacular names are used by environmental archaeologists, they usually have a formal link to a specific scientific classification.

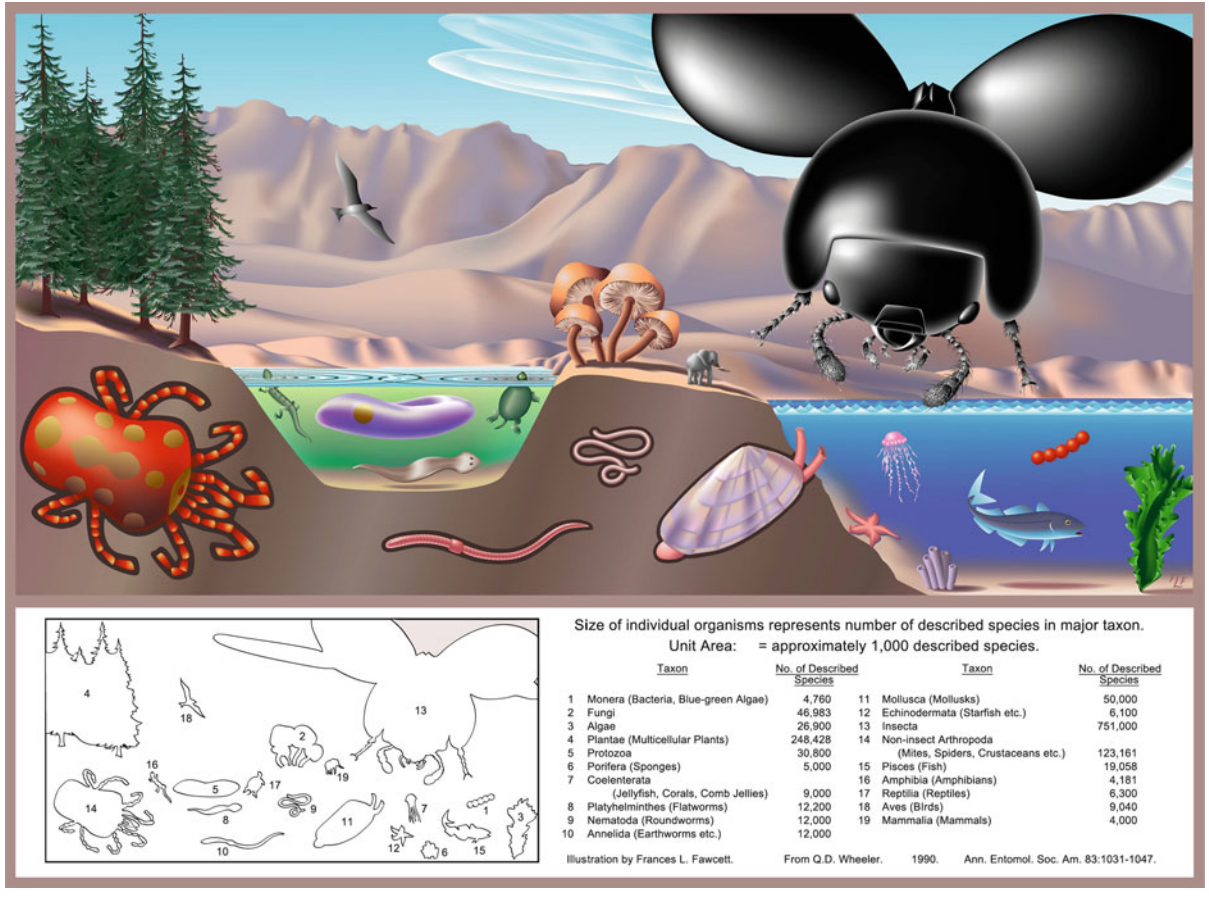

Fig. 4.1 Species scape. Illustration by Frances Fawcett. From Wheeler (1990:1040). Used by courtesy of Frances Fawcett and the Entomological Society of America

Table 4.1 Some of the ranks and name endings used in botanical and zoological nomenclature[a]

Botanical ranks (endings)	Zoological ranks (endings)
Domain	Domain
Kingdom	Kingdom
Subkingdom	Subkingdom
Division (-phyta)	Phylum
Subdivision	Subphylum
Superclass	Superclass
Class (-opsida)	Class
Subclass (-idae)	Subclass
Superorder	Superorder
Order (-ales)	Order (-formes)
Suborder (-inales)	Suborder
Superfamily	Superfamily
Family (-aceae)	Family (-idae)
Subfamily (-oideae)	Subfamily (-inae)
Tribe (-eae)	Tribe
Subtribe (-ineae)	
Genus	Genus
Subspecies	
Section	
Subsection	
Series	
Subseries	
Species	Species
Subspecies	Subspecies
Variety	
Subvariety	
Form	
Subform	

[a]Botanical terminology follows Jones and Luchsinger (1986:44) and zoological terminology follows Brusca and Brusca (2003:25–26). Note that zoological endings are highly variable and that the subclass ending for plants is the same as the family ending for animals

Scientific Taxonomic Classifications

A hierarchical taxonomy uses a nested set of classificatory levels to express interrelated hypotheses about evolutionary relationships among organisms. Each level within the classification is signified by distinct, formal endings (Table 4.1; Brusca and Brusca 2003:25–26; Jones and Luchsinger 1986:44). Environmental archaeologists rely on the principles and conventions of these scientific taxonomic classifications to facilitate communication. **Systematists** are biologists who study the **phylogeny** (evolutionary history, development, lineage) and relationships among organisms. **Taxonomy** is the subset of systematics that provides names for organisms using

descriptions and classifications reflecting an organism's evolutionary history and biogeography.

The foundation of modern systematics is traced to the Swedish naturalist Carl von Linné (Carolus Linnaeus in the Latinized form) and his *Systema Naturae* (1758). This work proposes a system for naming organisms that is now referred to as binomial nomenclature. Codes derived from this system endeavor to ensure that an organism has one and only one correct name and that this name is not shared with any other organism, thereby promoting classifications and names that are both unique and universal.

Scientific nomenclature specifies that every organism should have a two-part name (**binomen**) that includes a genus name (plural: genera) followed by a **trivial** or **specific epithet**, forming the species name. The binomen is an organism's scientific name. The system accepts subspecies names, forming a **trinomen** (three names), which begins with the mandatory binomen. By convention, the first letter of the generic name is capitalized but those of the specific epithet and subspecies name are not. All parts of the binomen or trinomen are italicized, or underlined. Underlined text is particularly common in material written before computers made italicization feasible. Several organisms may share a genus name, but only one organism within that genus carries the specific epithet. Thus, the genus name "*Ursus*" is applied to many different kinds of bears, but there is only one *Ursus maritimus* (polar bear).

A **species** (plural and singular are identical) is the most basic living unit. It is defined as "*…a reproductive community of populations (reproductively isolated from others) that occupies a specific niche in nature*" (Mayr 1982:273; italics in the original). Although this definition is broadly recognized, it has limitations. Perhaps the most serious of these for archaeologists is that it does not readily accommodate **hybrids** (progeny of two different taxa) or domestic forms. The more practical aspect of species is that many taxa within the same genus are extremely similar in anatomy and morphology, but very dissimilar in their ecological and anthropological implications.

The most basic higher category above the trivial or specific epithet is the genus. A **genus** is a group of species that are similar because they share a common phylogeny, having evolved from a common ancestor (Mayr et al. 1953:48–49). Prior to the advent of genetic analysis these relationships were proposed on the basis of phenotypic characters, such as size, shape, or color, rather than their genotype. A genus includes one or more species. Members of a genus typically share many morphological and anatomical features. Genus-level identifications are relatively more common in environmental archaeology than trivial- or specific-epithet identifications because archaeological remains often are from only part of the organism, not the whole, or because critical characters, such as color or reproductive structures, do not survive after death.

The proliferation of names after *Systema Naturae* was published led to **synonyms** (multiple names for the same organisms) and **homonyms** (the same name used for different organisms). To end this confusion, several organizations defined codes for assigning and revising scientific names, establishing commissions to confirm names as valid or invalid. Animals are governed by the International Code of Zoological Nomenclature (ICZN), plants by the International Code of Botanical Nomenclature (ICBN), cultivated plants by the International Code

of Nomenclature for Cultivated Plants, and bacteria by the International Code of Nomenclature of Bacteria. These codes are maintained by organizations such as the International Botanical Congress and the International Commission on Zoological Nomenclature. Taxonomic classifications are revised as new insights emerge about relationships among organisms and the resulting name changes are governed by these codes. Despite attempts to establish a single uniform code for all organisms, differences continue to exist in terminology and naming conventions. For simplicity, the following discussion largely draws upon zoological conventions (Brusca and Brusca 2003:24–27; e.g., International Commission on Zoological Nomenclature 2003:94–97, 179–181, 262). Slightly different conventions govern names in other groups, though all of these codes have the same objectives (e.g., Jones and Luchsinger 1986; Traverse 2008:605–613).

In most cases, the valid name of a taxon is the oldest available name, provided it has not been invalidated by another provision. When assigning taxonomic names, it is important to be familiar with the history of the name to distinguish between names that are current and those no longer in use. A **synonymy** is the series of changes a scientific name has undergone, published as an annotated list of scientific names that taxonomists have given an organism over time. Synonymies provide a brief history of the species' nomenclature and are consulted when there is doubt about which name is valid. Printed sources are often out-of-date because revisions occur frequently, particularly as the genetic relationships among taxonomic categories are scrutinized. Even websites are not updated as frequently as necessary. Some discrepancies arise because authorities do not agree about theories underlying proposed revisions.

Systema Naturae was written in Latin, the international language of the time. Latin persists as the primary language of scientific names. Although many names have Greek origins or are from other language families, most taxonomic terminology follows Latin rules of spelling, number, and gender regardless of the linguistic origin of the name. For example, **patronyms** (scientific names based upon the names of persons) follow the rules for nouns in the genitive case: names honoring men end in "i" and names honoring women end in "ae." The genus and trivial epithet must agree in number and gender.

In zoological nomenclature, if a person's name and a date follow the species name, this identifies the person who described and named the organism and the date when the description was published. The author's name is not italicized and the date is separated from the author's name by a comma as in the scientific name for domestic cattle: *Bos taurus* Linnaeus 1758. If the author's name is in parentheses, it indicates that this person revised a name proposed by someone else and that the animal is now classified in a different genus than was originally proposed, as in the case of white-tailed deer: *Odocoileus virginianus* (Zimmermann 1780). In some cases, the author's name is abbreviated; typically, "L." indicates the author was Linnaeus. A slightly different convention is followed by botanists; the name of the original author is retained in parentheses, followed by the name of the revising author; dates are rarely given (Jones and Luchsinger 1986:41). Authors' names and date often are omitted in archaeological usage.

A number of other conventions are followed in zoological nomenclature. The endings of names in the higher categories indicate ranks in the hierarchy, e.g., "-iformes" for order in fishes and birds, "-idae" for family, and "-inae" for subfamily (Table 4.1). The family name may be transformed into a common name by dropping the ending "ae" and putting the first letter in lower case. So a horse (*Equus caballus*), in the family Equidae, is referred to as an equid. The plural, equids, refers to all members of this family, which includes donkeys (*E. asinus*), zebras (*E. zebra*), and other equids. When the same genus is referred to several times in a document, the name should be spelled out completely the first time and abbreviated subsequently, as in the case of *Equus* in this paragraph. This can only be done if there is no chance for confusion; that is, no other genera beginning with "*E*" are under discussion in this paragraph.

In plant taxonomy, family names conventionally end in "-aceae," subfamily names in "-oideae," tribes in "-eae," and subtribes in "-ineae." Exceptions are allowed for some traditional family names, including grasses (Gramineae [Poaceae]), mustards (Cruciferae [Brassicaceae]), legumes (Leguminosae [Fabaceae]), carrots/parsley (Umbelliferae [Apiaceae]), and sunflowers/asters (Compositae [Asteraceae]), among others and both sets of names for these families continue to be used in the literature (Jones and Luchsinger 1986:42–43).

Other abbreviations are used in archaeological applications. It is common to find that the genus of an animal is followed by "sp." or "spp." instead of a specific epithet. This indicates the researcher is confident about the genus attribution, but uncertain as to the trivial attribution. The singular form, "sp.," means a specific genus is certain but the trivial name is uncertain; the plural form, "spp.," means various species of the genus are possible. For example, *Equus* spp. indicates the researcher is sure the specimen is an equid, but not certain which of several equids it might be. Sometimes the abbreviation "cf." (from the Latin *conferre*, to collect, unite, join) is used, signifying that the researcher is confident that the genus attribution is correct, but less confident of the trivial assignment. *Equus* cf. *caballus* indicates that the researcher is confident the archaeological specimen is an *Equus* but less confident that it is the domestic horse *E. caballus*, because the specimen might be similar to those of other members of the genus *Equus*, such as the donkey (*E. asinus*). The specimen most closely matches criteria for *E. caballus*, however, and the researcher is fairly sure that it is a horse, but uncertainty lingers. In botany, subspecies are indicated by the abbreviation "ssp." or "subsp." (Jones and Luchsinger 1986:51). None of these abbreviations (sp., spp., ssp., cf., subsp.) are italicized and italics normally are not used for taxonomic names higher than genus.

The Taxonomic Hierarchy

A goal of taxonomy is to develop a classification system expressing theories of evolutionary relationships on a scale encompassing all organisms through a nested series of categories of descending rank from domain to subspecies or lower

(Table 4.1). This scheme is referred to as a **taxonomic hierarchy**; in current use, it leads to a **phylogenetic tree**. Hierarchical categories extend below (**infraspecific categories**) and above (**higher categories**) genus and **trivial** or species epithets. Infraspecific categories include increasingly smaller groups of organisms as one moves down the taxonomic hierarchy; higher categories encompass increasingly more organisms as one moves up to family, order, class, phylum (or division), kingdom, and domain. Taxonomic categories change fairly frequently and it may be necessary to refer to synonymies to understand which organisms are discussed in older publications. All higher categories in the taxonomic hierarchy are plural, whereas the genus and trivial or specific names are singular.

Taxonomic classifications are based on a number of features, particularly anatomy, morphology, and **physiology** (function). These features include attributes such as color, support, locomotion, digestion, respiration, behavior, reproduction, cellular structure, molecules, protein sequences, hemoglobin, immunology, and symbiotic organisms, depending on the organism being classified. Before it was possible to examine chemical, genetic, and molecular characteristics, systematics relied heavily upon basic body plans (singular: **bauplan**; plural: baupläne) defined using characteristics measurable through visual inspection or low magnification. Some aspects of baupläne are valuable in the identification of archaeological materials because they are based on attributes of materials that survive site formation processes (e.g., wood, teeth, shells). Chemical, cellular, and molecular characteristics are not as readily used, but they are increasingly important attributes in many archaeological studies (e.g., Buckley et al. 2009; Richter et al. 2011).

Infraspecific Categories

Most infraspecific categories are unofficial, but nonetheless are useful for interpreting biological materials. Species are **polymorphic** or **polytypic**, exhibiting degrees of variation that provide environmental and cultural information. Discerning patterns in this variation sometimes require classifications below the level of species, such as subspecies, variety, deme, race, form, morph, breed, and hybrid. Most of these infraspecific categories reflect patterns of geographical variation among populations of the same species. For some organisms, the variation is largely the product of domestication. Infraspecific categories incorporate concepts of change and variation fundamental to interpretations made by environmental archaeologists. Some of the most difficult interpretations environmental archaeologists make require them to decide whether characteristics observed in archaeological specimens are evidence of intraspecific variations, environmental changes, seasonal cycles, cultural preferences, **sexual dimorphism** (differences in body size and other features that distinguish males from females), or domestication.

"**Cline**" refers to a gradual change in character expression within a species over an environmental gradient (e.g., altitude, latitude, insular, continental). Clinal variation

may be generalized into eco-geographical rules familiar to anthropologists. These include **Bergmann's Rule**, that body size of **endotherms** (animals that generate heat metabolically) tends to be relatively larger in cooler regions of a species' range than in warmer regions, and **Allen's Rule**, that the extremities of endotherms tend to be relatively smaller in cooler regions than in warmer ones (Thain and Hickman 2004:21, 74). Clinal variation is a potential source of new species if it leads to reproductive isolation. Clinal differences in size and shape may be mistaken for evidence of environmental change, seasonal variation, domestication, cultural choices, or responses to ecosystem processes, such as predation and, especially, overexploitation.

The only infraspecific category with formal taxonomic standing in zoology is the subspecies. A **subspecies** is a distinctive segment of a species that is geographically and morphologically separate from other members of the species. Subspecies (and varieties) are morphological variants of polytypic species, the patterns of variation correlating with specific segments of the species' range (Thain and Hickman 2004:674). Because subspecies in animals are geographical variations within a species' range at a given point in time, animal remains recovered from archaeological sites rarely, if ever, are identified to the subspecific level. A modern subspecies living near the archaeological site, in theory at least, did not live near the site 5,000 years ago. The subspecies level is used much more frequently in botany (e.g., an Andean quinoa or goosefoot subspecies: *Chenopodium quinoa* ssp. *milleanum*).

The term "**variety**" arose from a theory, subsequently disproved, that each species has a fixed pattern and anything that does not fit this idealized pattern is a variant, a variety. We now know that species are polytypic and this meaning of variety is no longer used. Botanical nomenclature, however, continues to use the designation. In plant taxonomy, a variety may be the equivalent of a subspecies, or a further division of a subspecies (Thain and Hickman 2004:728), depending upon whether the taxonomist is a lumper (who will treat it as a subspecies) or a splitter (who will assign it to a division of a subspecies). In either case, plant varieties are distinct populations that can still interbreed. When used in botany, variety may be abbreviated as "var." Depending on the interpretation of the taxon, variety is included in the scientific name in a number of ways (e.g., *Genus species* L. var. *speciodes* or *Genus species* L. ssp. *specoides* Author var. *speciodoides* Author). A variety of squash, for example, may be written as *Cucurbita pepo* L. ssp. *ovifera* (L.) D. S. Decker var. *ozarkana* D. S. Decker. This last example identifies the author (Linnaeus) and revisor (D. S. Decker).

The terms deme, race, form, and morph are used occasionally to indicate observed infraspecific variation. A **deme** is a minimal population unit, recognizing that neither the species nor the subspecies is the smallest unit of a population. The smallest unit of a population with evolutionary significance is a local group of individuals (of a species or of a subspecies) whose geographical distribution is restricted (**endemic**). Members of a deme interbreed because they are in more or less frequent contact with each other, but they are somewhat isolated from other members of that species. In botanical classifications, **races** or **ecotypes** are segments of a population that exhibit genetic adaptations to a specific environment and whose phenotypes withstand transplantation to new environments. **Forms** and **morphs** have no taxonomic validity but are important botanical designations that distinguish among individuals

with small variations from the type. White-flowered individuals of a normally red-flowered species are a form or morph of that species. When used in botany, "form" may be abbreviated as "f." (e.g., *Genus species* f. *form name*), but this is rare.

Breeds and cultivars are variations within domestic species; **breed** refers to domestic animals and **cultivar** to domestic plants. The distinction between a subspecies and a breed or cultivar is that a subspecies is restricted to a geographic area and evolved through reproductive isolation, whereas a breed or cultivar is the product of selection by people: a domestic organism selected for specific useful characteristics. Some of these domestic organisms may be geographically limited; others are widespread. Plant cultivars may be designated by the abbreviation "cv." or a single inverted comma, such as a camellia cultivar *Camellia japonica* cv. Purple Dawn or *Camellia japonica* 'Purple Dawn' (Jones and Luchsinger 1986:51–52). The concept of form has been proposed as a way to reflect differences between domestic and wild animals. Proposals range from eliminating scientific names for domestic animals to adding a designation such as the prefix "f.d." (for forma domestica; e.g., *Bos primigenius* f.d. *taurus*) or quotation marks (*Bos primigenius* "familiaris") to indicate a domesticated animal (International Commission on Zoological Nomenclature 2003:81–84; Corbet and Clutton-Brock 1984; Gautier 1993; Gentry 2006; Gentry et al. 1996, 2004; Groves 1995; Wilson and Reeder 2005).

Hybrids are the product of interspecific reproduction. Natural hybrids occur occasionally among animals but are very common in plants. Some hybrids are more viable than either parent (**hybrid vigor**). In other cases, the offspring is sterile. Although not significant in most evolutionary studies, hybrids are important in the context of domestication. One of the most famous examples of hybridization is the mule (*E. caballus* x *E. asinus*; the "x" denoting hybridization between the two species). A mule is a sterile cross between a female horse and a male donkey that can only be produced by human intervention. Identifying the time and place when mules were first bred is important to our understanding of the history, causes, and consequences of animal domestication. Modern and ancient wheats are hybrids. Designations for plant hybrids follow similar conventions (Jones and Luchsinger 1986:51).

Higher Categories

Higher categories permit generalizations because members within each higher category share probable genealogies reflecting testable hypotheses about phylogenetic relationships. Higher categories often are based, or revised, on comparisons of **DNA** (deoxyribonucleic acid) and proteins, but typically members of a taxonomic group share similar anatomies and behaviors. Levels within higher categories are designated by terms such as "infra," "sub," and "super." Higher categories are used frequently in environmental archaeology because archaeological specimens often cannot be attributed to a genus or lower category. Among the most commonly used higher categories are phylum (animals; plural: phyla) or division (plants), class, order, family, and subfamily. Many interpretations are based on information subsumed within these categories.

Table 4.2 The higher classification of the white-tailed deer (*Odocoileus virginianus*) with a brief list of some characteristics of each category

Category	Taxonomy	Description
Domain	Eukarya	Multicellular organisms; cells with a membrane-enclosed nucleus
Kingdom	Animalia	Multicellular, heterotrophic eukaryotes
Phylum	Chordata	Possesses a notochord
Subphylum	Craniata (Vertebrata)	Cranium, vertebrae, and bone and/or cartilage present
Grade	Tetrapod	Descendants of four-footed ancestors; contains four classes: Mammalia, Aves, Reptilia, and Amphibia
Class	Mammalia	Animals with hair and mammary glands
Subclass	Theria	Placental mammals with both a short and a long gestation period
Infraclass	Eutheria	Placental mammals with a relatively long gestation period
Superorder	Ungulata	Terminal phalanges covered with hooves or nails
Order	Artiodactyla	Herbivorous animals having hooves with an even number of toes: four or two; includes sheep, pigs, cattle, giraffes, and deer
Suborder	Ruminantia	Possesses a specialized part of the digestive track called a rumen
Infraorder	Pecora	Advanced ruminants, often with horns or antlers
Superfamily	Cervoidea	Antlers usually present only in males
Family	Cervidae	Antlered ruminates; 16 recent genera and 44 species
Subfamily	Capreolinae	New World deer
Genus	*Odocoileus*	Widespread American genus containing more than one species
Species	*virginianus*	A ruminant with antlers in males only; widespread in the Americas; common in American archaeological sites of all time periods

A **family** includes one genus or a group of genera of common phylogenetic origin, separated from other families by a distinct evolutionary gap. The family is usually distinguished by shared, obvious characteristics. Lions (Felidae: *Panthera leo*) and Norway rats (Muridae: *Rattus norvegicus*), for example, are classified into two mammalian families whose members have markedly different features. Unlike the genus, which may have a localized distribution and a recent evolutionary history, members of a family often are found on several continents and share a long evolutionary history. A **subfamily** is a taxonomic category dividing a family into smaller units. White-tailed deer are members of the family Cervidae and the subfamily Capreolinae, which includes *A. alces* (elk, moose), *Mazama* spp. (brocket deer), and *Rangifer tarandus* (caribou, reindeer). Several anatomical features distinguish Capreolinae from Cervinae, a different cervid subfamily that includes *Cervus* spp. (elk, wapiti, red deer) and *Axis* spp. (axis deer).

Taxonomic categories above family are difficult to define briefly. In most cases, members of an order, class, phylum or division, and domain share a long evolutionary record and are essentially global in distribution. These categories are defined by very basic characteristics. White-tailed deer are members of the Order Artiodactyla because they have an even number of toes, among other features (Table 4.2).

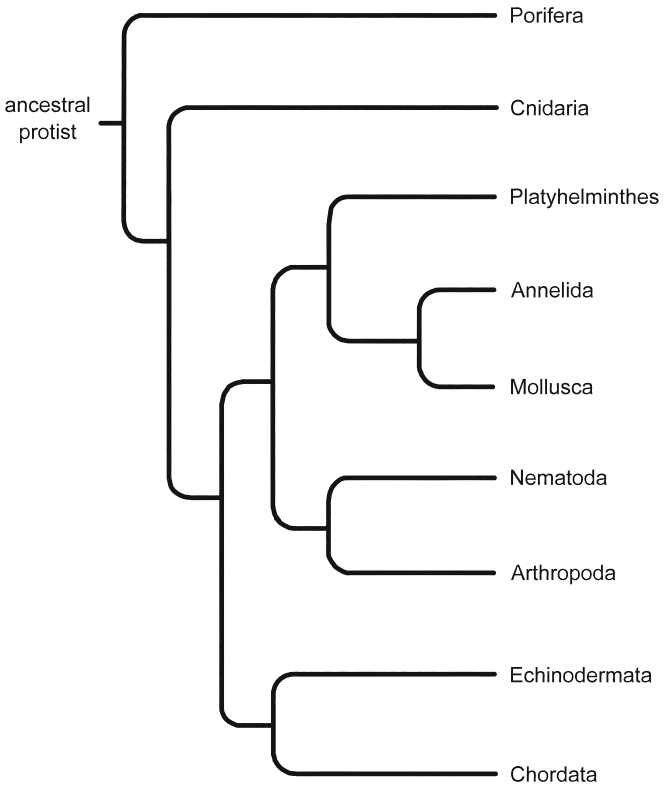

Fig. 4.2 Evolutionary relationships proposed for some animal phyla

Bilateral symmetry (one plane separates the organism into two similar halves), fur, suckling young, **endothermy** (condition of being endotherms), and a four-chambered heart link them with other members of the Class Mammalia. Higher categories reflect broad patterns of evolutionary or phylogenetic relationships.

Cladistics

Much systematics research uses **cladistic** analysis, a combination of molecular data, cell ultra-structure, and traditional taxonomic criteria focused on establishing relatedness through lines of descent (Campbell et al. 2008:542–548; Krogh 2009:345–346). Figure 4.2 shows evolutionary relationships proposed for some animal phyla. Relatedness is established by distinguishing between shared ancestral characteristics and characteristics derived subsequently. Each taxon must be **monophyletic**, that is, derived from a single ancestral species that did not give rise to species in other taxa (Campbell et al. 2008:543). Cladistic analysis often relies upon molecular sequences, such as the base pair lengths of DNA or **RNA** (ribonucleic acid; Krogh 2009:346).

The resulting phylogenetic tree is a **cladogram**, a repeatedly branching dichotomous diagram in which each branch suggests a classification based on the relative temporal sequence in which a pair of evolutionary branches arose from a unique, common ancestor. A **clade** is an evolutionary branch on this diagram that has a single common ancestor. Members of a clade are the descendants of that ancestor and are distinguished from members of other clades by characters unique to that clade, though related to members of other clades through common ancestry. **Cladogenesis** is a pattern of evolutionary change that produces biological diversity by budding new species from a parent species.

Evolutionary processes produce some structures that are either homologous or analogous. **Homologous structures** reflect shared ancestry and genetic affinities, thus they are said to have the same ancestral origin. The wing of a bird is homologous with the forelimb of a mammal. In some animals, modifications are so great that homologous structures cannot be recognized without reference to intermediate stages in their evolution. **Analogous structures** result from convergent evolution, in which similar characteristics evolve in response to similar stimuli but do not indicate a shared ancestry. The legs of a mammal and those of a crab are analogous as are some cactus and sponge spines. The characteristics used to define clades, as well as traditional classifications, are homologous, not analogous.

Some argue that the taxonomic hierarchy derived from the Linnaean tradition and followed in this volume should be replaced by cladistics, but these two classifications have very different objectives (Krogh 2009:346). Both traditional taxonomy and cladistics express theories about evolutionary relationships. Molecular studies clarify evolutionary relatedness and have led to changes in classifications originally based on anatomy and physiology. Cladistic reclassifications, however, rely upon parsimonious explanations of changes in a very few genes, producing a nomenclature that may be too short lived to be useful in archaeological applications.

More importantly, the goal of cladistics is not classification. In environmental archaeology, the initial objective *is* classification, to achieve clear, enduring taxonomic attributions that can be communicated across linguistic boundaries as a basis for exploring complex relationships among peoples and their environments, with particular interest in the causes, processes, and consequences of change and continuity through time and space, especially domestication. Cladistic analysis is unable to resolve **polyploidy hybridization**, found in plants with multiple sets of chromosomes (Chap. 13), or **reticulate** (non-dichotomous) evolution found in both plants and animals. As one of the goals of this volume is to be a tool for non-specialists, it seems appropriate to follow traditional nomenclature where cladistic phylogenies diverge from the taxonomy used in most archaeological applications or where cladistic classifications are unable to capture the diversity of the human sphere of influence.

Classifications

Organisms are classified into one of three domains: Bacteria, Archaea, and Eukarya (Table 4.3; Campbell et al. 2008:551–552, 567; Krogh 2009:360). Members of these domains are either **prokaryotes** (Domains Bacteria, Archaea) or **eukaryotes**

Table 4.3 Domains, super groups, and three kingdoms[a]

Domain Bacteria
Domain Archaea
Domain Eukarya
Excavata
Chromalveolata
Rhizaria
Archaeplastida
Kingdom Plantae
Uniknota
Kingdom Fungi
Kingdom Animalia

[a]Following Campbell et al. (2008:567, 578–579) and Krogh (2009:360). For a different classification, see Brusca and Brusca (2003:2)

(Domain Eukarya) based on attributes of their cells. Many members of Domains Bacteria and Archaea are organized into large groups instead of kingdoms. Likewise, the number of kingdoms in Domain Eukarya is subject to debate (e.g., Carlile et al. 2001:11–15). There once were four eukaryote kingdoms (Protista, Fungi, Plantae, Animalia), but Protista has been divided into several groups that are not well defined at the kingdom level (Campbell et al. 2008:566, 575, 578–549, 598; Krogh 2009:360). At the present time, eukaryotes are divided into five supergroups, most of which contain members of the former Kingdom Protista; but the term "protist" continues to be used to refer to those eukaryotes that are not considered to be fungi, plants, or animals. Members of the three eukaryotic kingdoms listed in Table 4.3 are the ones most commonly studied by environmental archaeologists. Some taxonomic differences among plants, animals, and other organisms may lead to confusion. Hence, two examples are summarized here, one for animals and one for plants (Tables 4.2 and 4.4).

The classification of viruses is complex. Campbell et al. (2008:382) define **viruses** as "…infectious particles consisting of nucleic acid enclosed in a protein coat and, in some cases, a membranous envelope." They can reproduce only within a living host cell, which is why they are often considered to be non-living (Krogh 2009:394). Viruses occupy the cells of organisms to reproduce and are inert outside of the living cell of a host. Their **genomes** (genetic material) are distinctive from those of prokaryotes and eukaryotes. Direct evidence of viruses in the archaeological record is minimal, but indirect evidence for their role in human affairs is extensive (Chap. 6).

A prokaryote is a microscopic, unicellular organism that does not have a nucleus (Campbell et al. 2008:559, 566–570; Krogh 2009:397–403). Many prokaryotes have cell walls and are mobile. They may be autotrophs or heterotrophs (Krogh 2009:400). Bacteria and archaea reproduce asexually as one cell splits into two identical cells. Neither bacteria nor archaea produce reproductive cells such as spores or pollen. At one time, bacteria and archaea were both classified in the Kingdom **Monera**, which included archaebacteria and

Table 4.4 The higher classification of black pepper (*Piper nigrum*) with a brief list of some characteristics of each category

Category	Taxonomy	Description
Domain	Eukarya	Multicellular organisms; cells with a membrane-enclosed nucleus
Kingdom	Plantae	Multicellular autotrophs
Subkingdom	Tracheobionta	Vascular plants
Division	Magnoliophyta	Angiosperms, flowering plants
Subdivision	Pterophytina	Generally large, conspicuous leaves, complex vascular system
Class	Magnoliopsida	Dicotyledons, embryos with two seed leaves
Subclass	Magnoliidae	Relatively primitive dicotyledons
Order	Piperales	Aromatic palaeoherbs
Family	Piperaceae	Herbs, woody climbers, shrubs, small trees
Genus	*Piper*	Genus includes black pepper and betel pepper
Species	*nigrum*	Black pepper

eubacteria. The reassignment of bacteria and archaea into separate prokaryote domains reflects their distinct evolutionary histories. The cell walls of most bacteria contain carbohydrates and **amino acids** (organic compounds such as those found in proteins). Archaea are classified as their own domain because their cell walls are composed of a material not found in other organisms (Krogh 2009:403–404). Their genomes are unique; 56% of the archaea genome is not shared with bacteria or eukaryotes. Some prokaryotes are **pathogens** (disease-producing organisms). Bacteria and archaea have few, or no, hard tissues that survive archaeological deposition. Their study often relies on indirect evidence, such as plant and animal remains showing evidence of disease known to be caused by a prokaryote, artistic renderings showing a pathology associated with prokaryotes, or historical accounts. Bacteria and archaea are reviewed in more detail in Chap. 6.

Most organisms studied by environmental archaeologists are eukaryotes. Eukaryotes generally have complex cell structure, are multicellular, and some of their DNA is contained within a cell nucleus (**nuclear DNA**, **nDNA**, **nuDNA**; Campbell et al. 2008:575–576; Krogh 2009:398). At some point in their lives, some parts of many, if not most, eukaryotes are protected by structures made of a durable material that may survive site formation processes, facilitating archaeological study (Traverse 2008:72–75). The two most durable materials are chitin and sporopollenin, which are found in some members of all eukaryote kingdoms. **Chitin** is a strong, high-molecular weight nitrogenous polysaccharide (an amino sugar or complex carbohydrate) that is chemically inert and resistant to acidity and biodegradation (Brusca and Brusca 2003:54; Carlile et al. 2001:99–100; Traverse 2008:57–58, 674). Chitin is found in some fungi and diatoms, as well as in a wide variety of invertebrates. **Sporopollenin** is a chemically inert, durable organic material made of carbon, hydrogen, and oxygen (Traverse 2008:59–60). The quantity of sporopollenin produced by each organism is highly variable (Traverse 2008:63). Sporopollenin is

resistant to most decay processes, with the exception of oxidation and prolonged high temperatures.

Protists are eukaryotes, but share few features with other members of this domain other than nucleated cells (Campbell et al. 2008:578–579; Krogh 2009:408–412). Protists may be unicellular, colonial, or multicellular. Generally they are microscopic (e.g., *Amoeba*), but some are very large (e.g., kelp). Some are autotrophs, others heterotrophs, and some obtain nutrients through both processes (**mixotrophs**). Most reproduce asexually, but some reproduce sexually and others use both forms of reproduction. In **asexual reproduction**, one cell splits into two identical cells. In **sexual reproduction**, genetic materials from two individuals are combined to form a new, unique, individual. Most protists are mobile and aquatic, but some are neither. Some contain extremely durable hard materials (e.g., diatoms), but most do not (Traverse 2008:72). Unless they have hard parts, the remains of protists are uncommon in archaeological deposits, though they are extremely common in life and play significant roles in environments and cultures. Protists are discussed further in Chap. 6.

The Kingdom **Fungi** includes heterotrophic eukaryotes that are **sessile** (immobile, fixed to a substrate) decomposers (Campbell et al. 2008:636; Krogh 2009:417–427, 437–438). Although most fungi (singular: fungus) are multicellular, some (yeasts) are not. Most reproduce via spores, which may be produced asexually or sexually (Krogh 2009:422). Fungi live in marine, freshwater, and terrestrial habitats. Many are pathogenic and others are critical to the production of foods, beverages, and medicines, among other products. The spores of fungi are protected by sporopollenin, though other fungal parts may contain either chitin or sporopollenin and may sometimes survive site formation processes. Fungi are reviewed in Chap. 6.

The Kingdom **Plantae** includes multicellular, photosynthetic, autotrophic eukaryotes that develop from embryos (Campbell et al. 2008:600; Krogh 2009:427–435). They are sessile and most are terrestrial, though some have returned to aquatic settings. Others are parasitic, having lost their autotrophic abilities. Some plants store food reserves as complex carbohydrates (e.g., starch). Pollen is protected by sporopollenin. Plants include organisms as diverse as liverworts, ferns, conifers, and flowering plants, which are considered in Chaps. 7–9.

The Kingdom **Animalia** consists of multicellular, heterotrophic eukaryotes that do not produce simple carbohydrates and obtain most of their nourishment directly or indirectly from protists, fungi, and plants (Fig. 4.2; Campbell et al. 2008:655, 696; Krogh 2009:442, 472). Although some animals are sessile, many are mobile, at least during part of their life cycles, and occupy marine, freshwater, and terrestrial habitats. Most have specialized tissues, such as nerves and muscles. Nutrients are stored primarily as **glycogen** (a form of starch) and fat. Chitin supports and protects portions of some animals, but most either have few hard tissues or their hard tissues are composed of other materials. Animals include such familiar organisms as ourselves, and very unfamiliar ones such as hydra. These are reviewed in Chaps. 10–12.

Reference Collections

As Faegri et al. (1989:237) observe: "Even the best key is inferior to a preparation," indicating the vital role reference collections play in environmental archaeology. Beginners in any discipline typically seek out illustrated guides or dichotomous keys. Although these are used by most environmental archaeologists, experienced researchers view them as supplements to, not substitutes for, reference specimens and standards (e.g., Hather 1993:viii, 2000:19; Pearsall 2000:99–100; Piperno 2006:88; Reitz and Wing 2008:378; Traverse 2008:96–97; van Geel 1986).

Dimbleby (1978:103) notes that the "…archaeological literature is rich in incorrect identifications…" The primary controls over misidentifications are reference collections, considerable experience with the materials being examined, and humility about one's ability to observe key characteristics. Good lighting and high-quality optics are helpful, if not essential. Levels of identification vary considerably from one group to another, not just because of the quality of preservation or completeness of the specimen, but because of inherent variability in the organisms themselves, and, in some cases, because the taxonomic affiliations of closely related taxa are unresolved. Some organisms, or at least some parts of organisms, are notoriously difficult to attribute to a taxonomic level that is interpretatively useful for many research questions (e.g., sheep [*Ovis aries*] and goats [*Capra hircus*]); a few can be attributed readily to a specific epithet, or at least to genus, with minimal room for doubt (e.g., maize), depending on the condition of the specimen. Thus, most lists of taxa represented in archaeological collections are dominated by higher categories in the taxonomic hierarchy. Sometimes it is not even possible to determine if a specimen is organic let alone assign a specific epithet. Heroic efforts to make identifications are misplaced.

Most **reference collections** consist of modern examples of soils, sediments, organisms, or parts thereof (e.g., egg shells, pollen) that are used to identify archaeological materials by comparison. Others are standards, such as oxygen isotope ratios in modern sea water. The distinction between these two types of collections is minor. Both reference specimens and standards are critical aids in identifying and interpreting archaeological materials as well as the focus of research in their own right. Reference collections are vouchers for research, verifying site formation processes, taxonomic identifications, and the isotopic and other values derived from the archaeological specimens. They ensure that studies that cannot be repeated can be reviewed or reevaluated.

Reference collections often are called **comparative collections** because the archaeological material is "compared with" the reference. In some cases, the organisms in question are extinct, requiring the use of palaeontological or archaeological specimens for reference. Using such specimens should be avoided if modern ones are available, if only because palaeontological or archaeological specimens may themselves be misidentified. It goes without saying that modern reference specimens must be identified correctly.

Ideally, the collection will contain multiple examples of each taxon to capture clinal variations as well as those associated with reproduction, growth, development, sex, and age because these all affect the morphology and anatomy of the archaeological specimen. Examples of an organism's growth habits under optimal and suboptimal conditions are useful. Growth and reproduction follow different patterns where fires, droughts, competition, or predation are severe compared with areas where such selective forces are less intense. Taxa should be from the immediate vicinity of the site under study, if they live there today, but also include individuals whose modern ranges are far beyond the site. These extraneous or exotic specimens accommodate environmental change, range expansions and contractions, as well as human behaviors such as trade, size and age preferences, and domestication. The collection should include domestic and non-domestic forms. Even archaeological collections from regions with no Eurasian domestic forms prior to the era of European expansion may contain Eurasian species introduced so early that they may appear to be local pre-colonial domestic forms if the site's stratigraphy was not adequately monitored during excavation. Some reference materials may be retained as whole specimens; others may be prepared as sections or slides. It is particularly useful to have specimens that are burned, waterlogged, desiccated, frozen, gnawed, trampled, and otherwise modified. If the collection only has one specimen, it is unlikely the full range of variation will be represented and the curator may be reluctant to "damage" the specimen by thin-sectioning, burning, or sampling tissues.

Reference collections consist of more than specimens and standards; they also contain associated data. The more biological, spatial, and temporal data associated with a specimen, the more valuable the specimen is as a focus of or an aid to research. The specifics of these associated data depend on the organism, but the best specimens have at least collection date, location, method of collection, and who collected them (e.g., Bridson and Forman 1998; Carter and Walker 1999; Metsger and Byers 1999). They are even more valuable if the habitats from which they were collected and their reproductive status are described. For many animals, data such as body weight, visceral weight, skin weight, and standard measurements facilitate subsequent research.

Although the reason for assembling a collection may be to derive a taxonomic or other attribution for archaeological materials, many environmental archaeologists conduct basic and applied research with the data associated with the reference collections themselves, independent of a specific archaeological study (e.g., Mercader et al. 2010). Reference collections permit inquiry into problems of identification and analysis, enable historical studies of change and stasis through time and space, and support research into fundamentals such as ecological affiliations, genetic affinities, and the influence of diagenesis on isotopic compositions. As vouchers, they ensure that identifications of archaeological materials can be verified and are links between traditional anatomical or morphological observations and biomolecular studies. They are often the sole means of verifying published data, which must be viewed with skepticism without this ability to verify.

Reference collections require time and effort to assemble. When developing them, laws and procedures governing specimen acquisition, transportation, and

handling must be observed, including those pertaining to loans from other institutions. Once reference standards or specimens and their data are prepared, they should be curated in a permanent facility that will maintain them properly. Often collection permits require that modern specimens be deposited with not-for-profit institutions committed to their long-term care and use. Supporting the vested public and professional interest in reference collections enables collections to meet their full potential as foundations upon which subsequent studies build. The validity of references is so important that most environmental archaeologists specify in their publications the reference standards or specimens used.

Summary

Taxonomy, reference collections, and reference standards are essential tools in environmental archaeology. The most common taxonomic levels used in environmental archaeology are genus and the trivial or specific epithet, some infraspecific categories, and a few higher categories. Environmental archaeologists must be familiar with the relationships and degree of certainty signaled by taxonomic conventions. Terminology that correctly conveys an organism's identity to international scholars over decades is important for many reasons. The organism's name suggests an array of characteristics with archaeological, cultural, ecological, and environmental implications. Familiarity with the characteristics implied by nomenclature and incorporated into reference collections and standards is fundamental to the field.

Attributes broadly associated with taxonomic affiliations are linked to site formation processes, field and laboratory procedures, ecological affiliations, and analyses. They guide much of the research of environmental archaeologists, and structure the remainder of this volume. In Chaps. 5–13, nomenclature, site formation processes, field considerations, laboratory procedures, and analytical approaches involved in the identification and analysis of sediments, soils, and organisms are reviewed, followed by a summary of contributions made by environmental archaeologists (Chap. 14).

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Chapter 5
Sediments and Soils

Sediments and soils record aspects of communities, drainage patterns, landscape histories, and site formation processes that place organisms, including humans, in their environmental and ecological contexts. Organisms, in turn, augment or facilitate interpretations of sediments and soils (compare Mudie et al. 2007 with Ryan et al. 2003). Today's landscapes are not the landscapes of the past; they have changed in response to numerous, complex, abiotic and biotic forces. Documenting these changes and distinguishing between non-anthropogenic and anthropogenic causes and the consequences of such changes are among the primary goals of environmental archaeology. Recreating the sequence of changes in environments and ecosystems requires combining information about climates, weather patterns, sediments, and soils, as well as depositional and erosional processes that produced the sedimentary environment and information about the organisms associated with them (e.g., Langdon et al. 2010). This information places the site and its contents into temporal, spatial, and functional contexts that include **landforms** (features of the earth's surface), habitats, and depositional setting, as well as past and present geomorphological processes (Table 5.1; Gladfelter 1977:522; Waters 1992:37). Regional stratigraphic studies and sedimentological analyses elaborate upon many of these processes.

The earth sciences and related disciplines make contributions to archaeology that are beyond this volume's focus on biological remains. Field staff may want to locate sites, site boundaries, or features within sites. They may want to know the source of the deposit, the date(s) of occupation, the occupational sequence, the location of subsurface features, or the provenance of inorganic artifacts found in the deposit. Answers to such questions guide definitions and interpretations of sites and the artifacts recovered from them, but they require approaches beyond those covered here. Comprehensive reviews are available elsewhere and readers are urged to consult these for a more thorough perspective (e.g., Brown 1997; French 2003; Goldberg and Macphail 2006; Holliday 1992, 2004). Here the emphasis is on those aspects of these disciplines that are particularly pertinent to interpreting organic remains. This is done with the admonition that organic remains should not be considered without reference to *all* aspects of their contexts, including features of the physical and chemical environment not included in this volume.

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Table 5.1 Some geomorphological contexts of archaeology[a]

Surface form	Site type	Description	Energy environment
Interfluvial	Aeolian sites	Open air	Wind (volcanic, loess)
Midslope	Cave sites	Open air or protected	Mass wasting or movement
	Colluvial sites	Open air or protected	Mass wasting, solifluxion
Lowland	Alluvial sites	Channel, overbank, basin, deltaic, fan	Fluvial
	Lacustrine sites	Lakes, ponds, dammed river channels; insular	Waves
	Littoral sites	Foreshore, backshore, storm beach, lagoon, tidal	Waves, currents, wind
	Aeolian sites	Open air	Wind (volcanic, loess)

[a]Modified from Gladfelter (1977:522) and Waters (1992:37)

Nomenclature

Water, wind, ice, gravity, and bioturbation are agents of transportation, deposition, and other landscape changes whose impacts are recorded in sediments and soils. Deposits that were not transported, that formed in situ, may document different processes and have different properties than those that were transported over even short distances. This difference distinguishes **sediments** (transported) from **soils** (in situ). These two terms have different meanings to archaeologists, engineers, geologists, pedologists, and sedimentologists (Goldberg and Macphail 2006:27; Stein 1992). In archaeology, as a general rule, a sediment is material that has been transported and a soil is an unconsolidated sediment near the surface of the earth that is a medium for plant growth (Stein 1992:194–195). If modified in situ from stable sedimentary deposits at the surface, some sediments may, of course, become soils (Shackley 1975:1; Waters 1992:40). Most archaeological sites contain sediments and sites accumulate through sedimentary processes; the samples archaeologists refer to as "soil samples" may actually be samples of sediments (Goldberg and Macphail 2006:27, 46; Shackley 1975:3). Many of the same concepts, terminologies, and methods are applied interchangeably between sediments and soils, though with slightly different meanings.

Sediments

In archaeological applications, sedimentology refers to the structure and texture of sediments as well as to biological, chemical, and physical aspects of sedimentary processes. Differences in these characteristics are used to reconstruct **depositional sequences** (superimposed layers of sediments) and environments. Sedimentary deposits in archaeological sites may be referred to as archaeological sediments or **archaeosediments**, many of which are directly or indirectly produced, influenced, or modified by human behavior (Rapp and Hill 1998:20; Waters 1992:16).

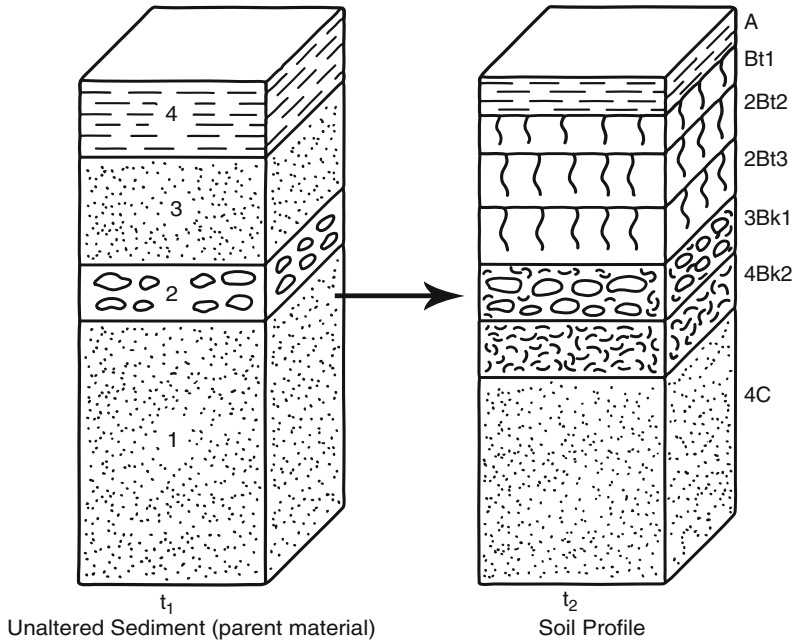

Fig. 5.1 The transformation of an unaltered sediment (parent material) composed of four distinct units of sand (1 and 3), gravel (2), and silt (4) stabilized at time 1 (t_1) into a soil at time 2 (t_2). Hypothetical soil horizons and their designations are shown in the soil profile. See Tables 5.4 and 5.5 for soil horizon nomenclature. From Waters (1992:41); © 1992 The Arizona Board of Regents. Used by courtesy of the University of Arizona Press

Sediments are layers of inorganic and organic materials found in locations different from those in which they formed. Sediments have weathered or eroded from **parent material** (solid, unaltered bedrock), been transported from their primary context by non-anthropogenic and anthropogenic processes, and been redeposited (Fig. 5.1; French 2003:35–36; Herz and Garrison 1998:37; Waters 1992:16, 41). Thus, sediments reflect the original parent material, the means and distance of transport, the depositional environment, and post-depositional alterations (Goldberg and Macphail 2006:60–62, 64). Most sediments are **allogenic**, having originated and been transported from elsewhere at various rates by diverse external forces (Allaby and Allaby 2003:16). Stability contrasts with the accumulation of sediments (**aggradation**) and the removal of sediments by erosion (**degradation**; Waters 1992:60).

Sedimentary deposits are classified on the basis of three processes (Table 5.2; O'Connor and Evans 2005:45): chemical precipitation (**chemical sediments** or **precipitates**), decomposition and accumulation of organic material (**carbonaceous** or **organic sediments**), and mechanical accumulation (**clastic sediments**; Goldberg and Macphail 2006:11). Chemical sediments are produced by direct precipitation from solution, often associated with caves and former lake basins (Goldberg and Macphail 2006:24–26). Other chemical processes include hydration, oxidation, reduction, and carbonation (Allaby and Allaby 2003:97).

Table 5.2 Sediment classifications[a]

Composition	Environment
Precipitates	
Calcareous	
Tufa	Springs, rivers, lakes, caves, deposited by blue-green algae
Lake marl	Lake bottoms, formed by certain algae
Bog iron, sulphates, sodas, silicates, phosphates	Miscellaneous, mostly aquatic
Organic sediments	
Peat	
Cladium	Fen
Sphagnum, *Eriophorum*, *Calluna*	Raised bog
Phragmites	Reedswamp
Wood and tree stumps	Carr
Lake mud or gyttja	Lake bottom
Clastic sediments	
Moderately to well sorted	
Gravel, >2.0 mm, rounded; consolidated as conglomerate	Glacial outwash, sea storm beach, fast-flowing water
Scree, >2.0 mm, angular; consolidated as breccia	Cold climates, primary ditch fills
Sand, 2.0–0.06/0.05 mm; consolidated as sandrock/sandstone	Aeolian = coversand, water-lain as sea beach or river deposits
Silt, 0.06/0.05–0.002 mm (=60–2 μm); consolidated as siltstone	Usually aeolian = loess
Clay, <2.0 μm; consolidated as claystone/mudstone	Still and/or deep water, e.g., lakes and oceans
Poorly sorted	
Till or boulder clay	Ice sheet or glacier
Solifluxion/gelifluxion	Cold-climate slope deposits
Stony, humic loam	Slopewash, e.g., under cultivation by rill erosion (= colluvium)
Volcanic deposits	Various volcanic environments
e.g., tephra, acids, pyroclasts, lava	

[a]Modified from O'Connor and Evans (2005:45) and used with their permission

The primary organic sediment is peat, which forms in wetland ecosystems under anoxic conditions and is classified by plant content, wetness, and **humification** (decomposition of organic material; Aaby 1986; Evans 1978:71; Goldberg and Macphail 2006:26; Odum and Barrett 2005:513). Different types of peat are associated with specific types of **palustrine wetlands** (marsh), bogs, fens, wet prairies, or temporary ponds, though the nomenclature is highly variable (Odum and Barrett 2005:428–429). Bogs may be **ombrotrophic** (rain-fed), **minerotrophic** (fed by inflowing streams and precipitation), and **blanket** or **raised** bogs (in upland settings; Barber and Langdon 2001; Holliday 2004:264). Each of these organic sediments is associated with different organisms. Wetlands containing peats are often

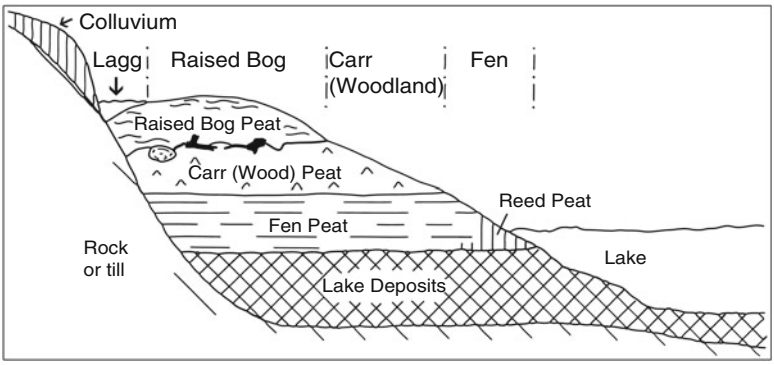

Fig. 5.2 Relationship between vegetation and sediments at a lake edge, showing differences among peats. From O'Connor and Evans (2005:62) and used by courtesy of Terry O'Connor

divided into fen and bog wetlands (Fig. 5.2; Allaby and Allaby 2003:400; O'Connor and Evans 2005:62). Fen wetlands are associated with neutral or alkaline groundwater and are typically dominated by sedges and bog wetlands with acidic conditions and peat moss (*Sphagnum*; Odum and Barrett 2005:428–429). **Swamps** are forested wetlands.

Clastic sediments are the most common deposits in archaeological sites overall (Goldberg and Macphail 2006:13). Properties of clastic sediments include composition, fabric, structure, and texture (Goldberg and Macphail 2006:13–24). **Composition** refers to major minerals, accessory minerals, and rock types contained within sediments. In sedimentology, **fabric** refers to the arrangement or orientation of sediments and **packing** (contacts between particles) of grains in the matrix (Goldberg and Macphail 2006:19). **Structure** refers to **bedding** (the layering of stratified sediments) reflected in differences in composition, texture, or color. Some of these terms also are used to characterize soils, with slightly different meanings (e.g., Holliday and Goldberg 1992). In pedology, for example, fabric is the total arrangement of soil constituents, shape, size, and frequency (Goldberg and Macphail 2006:20). Farmers and gardeners use these terms with different meanings.

Texture refers to attributes such as the size of predominant particles or grains, the proportions of particles of different sizes in the deposit, and their shapes (Allaby and Allaby 2003:544; Goldberg and Macphail 2006:14–19). Texture is assessed by the visual appearance and feel of damp material and the relative proportions of four major size classes or grades: gravel, sand, silt, and clay. Texture names derive from the proportion of these four size classes. Particles differ from each other in size gradations along a continuum that is divided somewhat arbitrarily into major classes and several subclasses (Fig. 5.3; Goldberg and Macphail 2006:15; Rapp and Hill 1998:22; Waters 1992:24; Wilkinson and Stevens 2003:52). Some of the characteristics used to classify soils are now used for both soils and sediments. Considerable variation exists among the systems used to define and classify texture, largely reflecting differences between sedimentologists and pedologists, but also national traditions (Fig. 5.4; Herz and Garrison 1998:42).

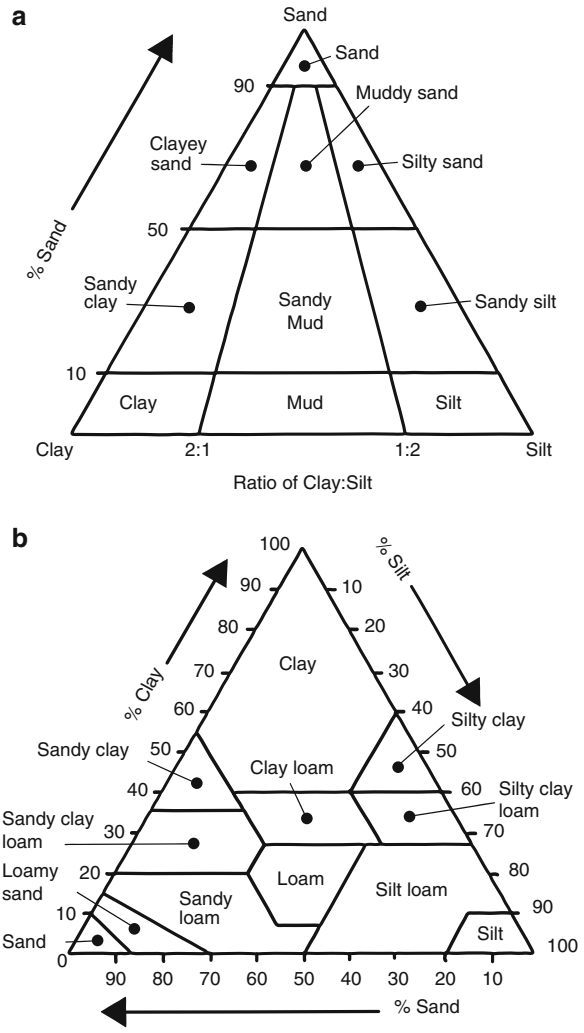

Fig. 5.3 Ternary plots showing the classification of clay-sand size material for: (**a**) sediments; and (**b**) soils. The plots are read by locating the intersection point describing the proportion of sand, silt, and clay in the material and reading the description. From Wilkinson and Stevens (2003:52) and used by courtesy of the authors and The History Press

Grain size nomenclature and classifications are characterized in a number of ways (e.g., Table 5.3; Avery 1990; Udden 1914; Wentworth 1922). Figure 5.5 shows a visual key for estimating grain size in sands (Wilkinson and Stevens 2003:53). One of the most common classification systems is the Udden-Wentworth grain size classification system in which grain diameter is expressed in inches. Grain size may also be reported in metric units or as *phi* (ϕ). The *phi* scale is logarithmic and ranges from −12 ϕ (boulders) to +14 ϕ (clay; Krumbein 1934; Waters 1992:20–21). Positive *phi* values are for grain diameters finer than 1,000 μm and negative values indicate diameters larger than 1,000 μm (Allaby and Allaby 2003:409). Following Shackley (1975:11–12), some grain size classifications are:

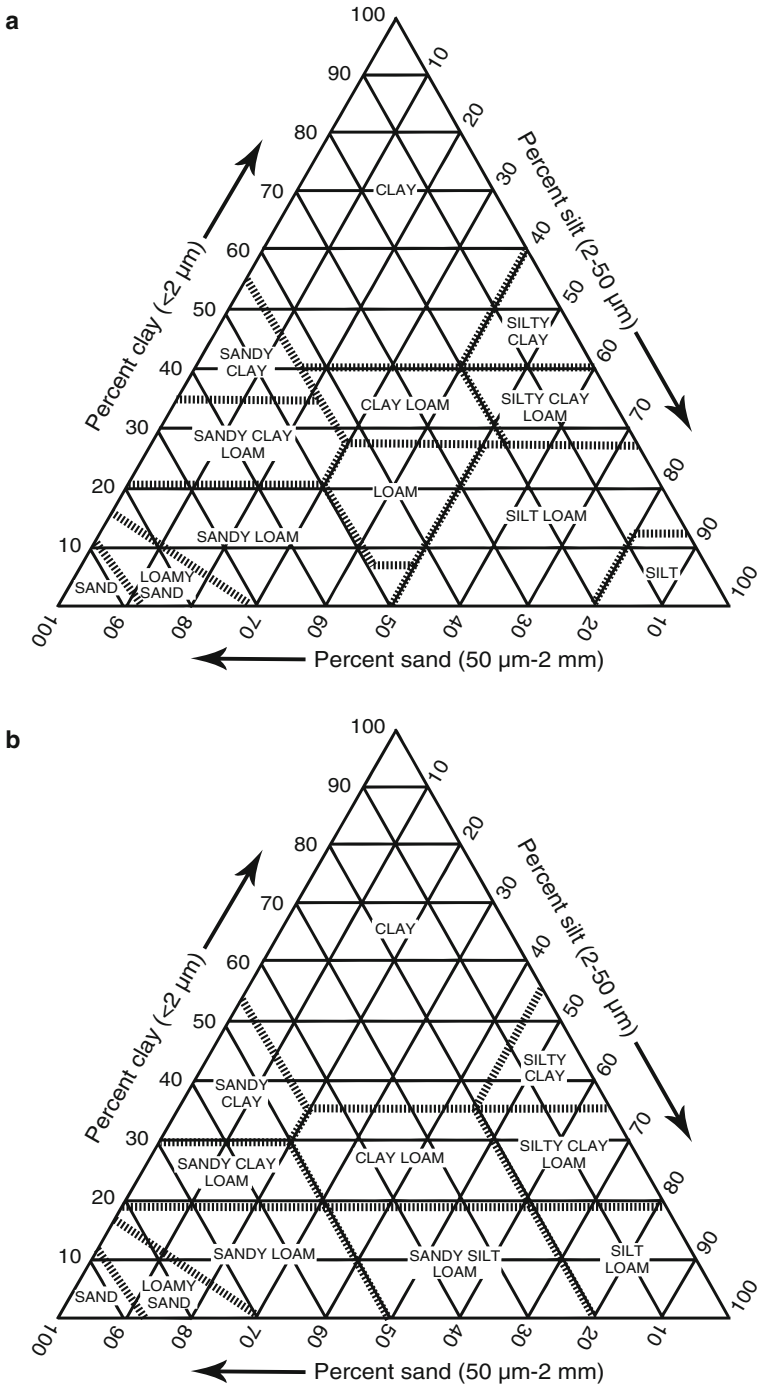

Fig. 5.4 Particle size ternary plots for: (**a**) United States; and (**b**) Great Britain. From Herz and Garrison (1998:42) and used by courtesy of the authors and Oxford University Press

Table 5.3 Common grain size scales used in geology and pedology[a]

Wentworth class (geology)	Size range	Phi (ϕ) units	UK soil science class equivalent	Size range	USA soil science class equivalent
Gravel					
Boulder	>256 mm	−8 to −12	Boulder	>600 mm	
			Very large stone	200–600 mm	
Cobble	64–256 mm	−6 to −8	Large stone	60–200 mm	
Pebble	4–64 mm	−2 to −6	Medium stone	20–60 mm	
			Small stone	6–20 mm	
Granule	2–4 mm	−1 to −2	Very small stone	2–6 mm	
Sand					
Very coarse sand	1–2 mm	0.0–1			1–2 mm
Coarse sand	0.5–1 mm	1–0.0	Coarse sand	0.6–2 mm	0.5–1 mm
Medium sand	250–500 μm	2–1	Medium sand	212–600 μm	250–500 μm
Fine sand	125–250 μm	3–2	Fine sand	63–212 μm	100–250 μm
Very fine sand	63–125 μm	4–3			50–100 μm
Silt					
Coarse silt	31–63 μm	5–4	Coarse silt	20–63 μm	silt = 2–50 μm
Medium silt	15.6–31 μm	6–5	Medium silt	6–20 μm	
Fine silt	7.8–15.6 μm	7–6	Fine silt	2–6 μm	
Very fine silt	3.9–7.8 μm	8–7			
Clay	0.06–3.9 μm	8–14	Clay	<2 μm	<2 μm

[a]The symbol "μm" indicates a micrometer or micron; 1 μm is the equivalent of 10^{-3} mm. Data and values are from Avery (1990), Goldberg and Macphail (2006:12), Hodgson (1997), Soil Survey Staff (1999), Udden (1914), and Wentworth (1922). Note that many of these terms have different meanings among the disciplines that use them

(a) **Sand** is a loose, clean-grained material of grain sizes 0.5–4 ϕ. A dry sample squeezed in the hand falls apart when pressure is released. Coarse sand (0.5–1 ϕ) has grains that grate against each other and can be seen without magnification. In fine sand, this effect is less obvious, but individual grains remain distinguishable.

(b) **Silt** is fine textured than sand, has a silky feel, and grain sizes are between 4 and 8 ϕ. It may be slightly gritty, but individual grains cannot be seen without magnification. The sediment forms a sludge when wet.

(c) **Clay** forms hard lumps or clods when dry; when moist it is sticky, cohesive, and plastic. Grain diameters are greater than 8 ϕ. Individual particles cannot be seen or felt. It forms excellent casts and is particularly sensitive to weathering by temperature and rainfall.

It is rare to find deposits composed entirely of sand, silt, or clay; often sediments consist of combinations that are classified by the proportion of each size class in the mixture (Shackley 1975:11–12; Waters 1992:24). These mixtures are classified as:

(d) **Sandy loam** is mostly sand (50%), with enough silt (30%) and clay (20%) to be cohesive. It forms a cast when moist, but the cast is easily broken.

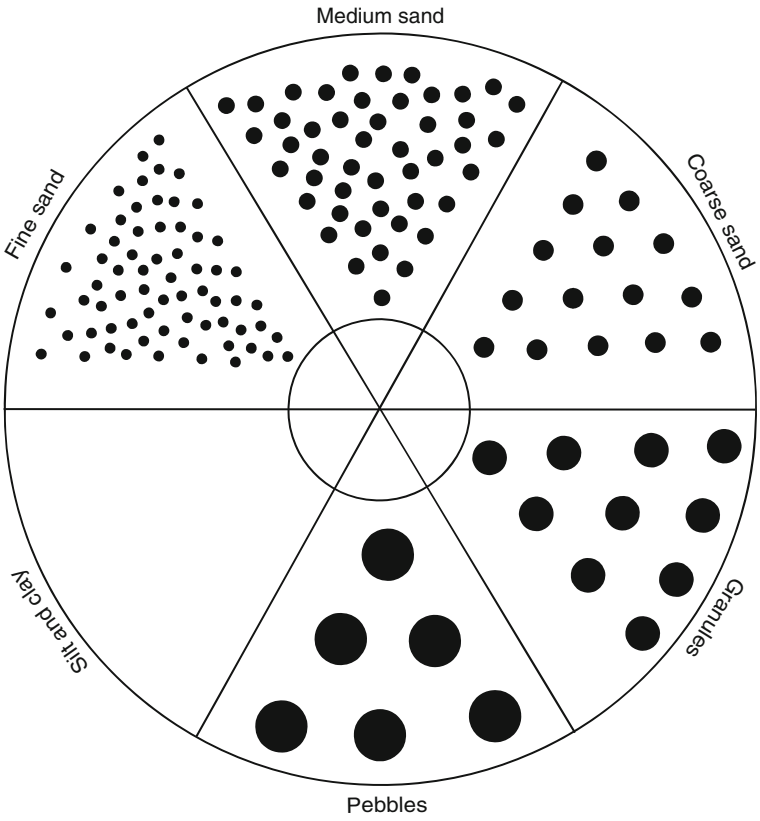

Fig. 5.5 A visual key for estimating grain size in sands. From Wilkinson and Stevens (2003:53) and used by courtesy of the authors and The History Press

(e) **Loam** feels gritty, but is reasonably smooth and rather plastic. It contains nearly equal parts of silt and sand and about 50% clay. Moist loam forms a good cast.
(f) **Silt loam** has a slightly silky feel and forms clods when dry. The lumps are easily broken and the resulting material may be soft and floury. Wet silt loam forms a thick sludge and makes good casts. It consists of at least 50% sand and silt combined with 12–25% clay.
(g) **Clay loam** is fine textured and readily breaks into clods or lumps that are hard when dry. It is plastic and cohesive when moist and contains nearly equal amounts of sand and clay.

Particle sorting (the proportion and number of size classes) and particle shape provide additional information about transportation, rate of deposition, and depositional environment. Particles are said to be **well sorted** (a single particle size dominates) or **poorly sorted** (many different particle sizes are present; Fig. 5.6; Compton 1962:214; Waters 1992:24). **Particle shape** or **morphology** (Fig. 5.7; Compton

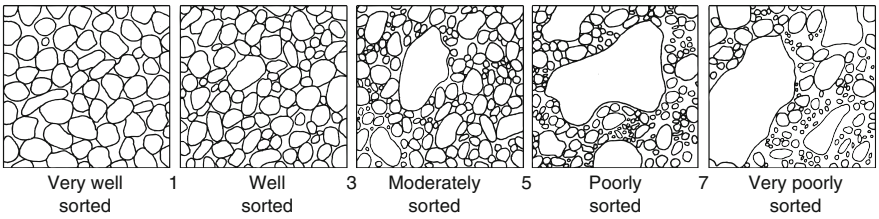

Fig. 5.6 The range of sorting observable in clastic sediments, specifically a sand deposit viewed under a ×10 hand lens. The *numbers* indicate the number of particle size classes represented by approximately 80% of the material. Modified from Compton (1962:214)

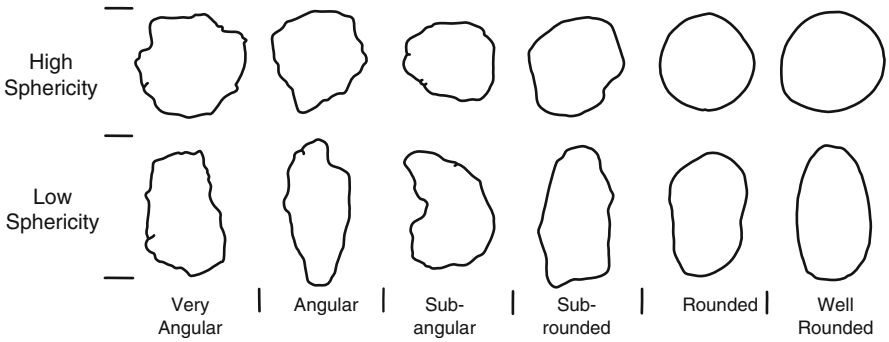

Fig. 5.7 Terms for degree of rounding and sphericity in sand grains as seen under a ×10 hand lens. Modified from Powers (1953:118) and used by courtesy of SEPM (Society for Sedimentary Geology)

1962:215; Powers 1953:118; Waters 1992:28) describes **form** (overall shape), **roundness** (sharpness/angularity of corners and protuberances), **sphericity** (how closely the grain's circumference approximates a sphere), and **surface texture** (features on the surface of the particle; Goldberg and Macphail 2006:17). Shape may be characterized by reference standards or determined from measurements and ratios of representative particles (e.g., Fig. 5.8; Shackley 1975:43–51; Waters 1992:27; Zingg 1935). As the longest and shortest dimensions become more equal in length, the grain becomes more spherical in shape.

Sedimentary structures and **bedding** refer to the organization of sediments into strata (layers, beds, laminae, lenses) indicative of the energy environment required to transport and deposit the materials (Table 5.1; Evans 1978:69; Gladfelter 1977; Shackley 1981:3; Waters 1992:36–38). These are broadly classified as volcanic, aeolian, aquatic, and terrestrial sediments, associating generalized depositional environments with characteristic sediment types. For example, lake sediments often are finely bedded compared with glacial deposits, which may not be bedded at all. **Volcanic** or **pyroclastic** materials (ash, lava, tephra, flow debris) are clastic sediments that cannot be associated with strictly aeolian, aquatic, or terrestrial sediments.

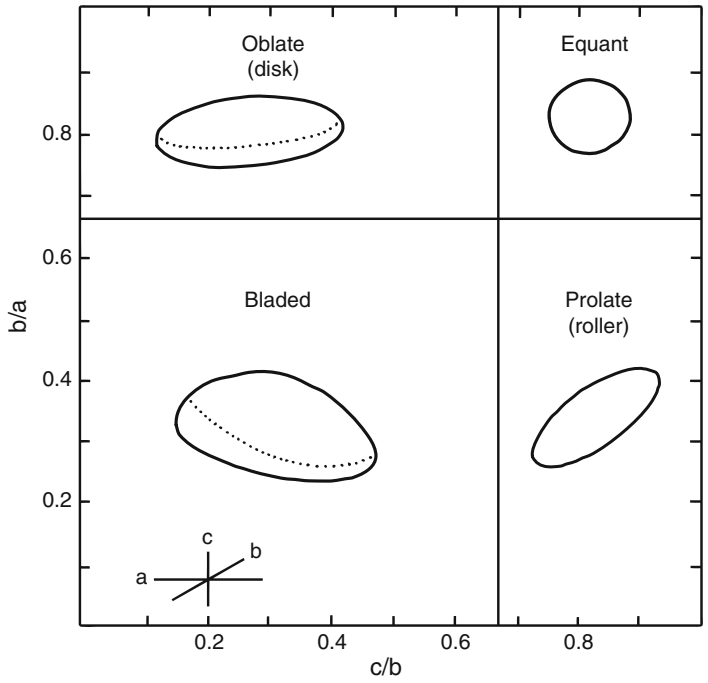

Fig. 5.8 Classification of the shape of gravel size particles. The *a* axis is the longest, the *b* axis is intermediate, and the *c* axis is the shortest. The ratios of axes *b* to *a* and *c* to *b* divide gravels into four shape categories. Modified from Zingg (1935) and Waters (1992:27); © 1992 The Arizona Board of Regents. Used by courtesy of the University of Arizona Press

Sediments in **aeolian (eolian)** environments are eroded, transported, and deposited by wind and often exhibit fine-grained sedimentation. The two main types of aeolian sediments are sand and silt, the latter forming deposits known as loess. **Loess** is silt that typically originates in deposits formed through outwash from glaciers and is fine enough to be transported considerable distances by wind (e.g., Bettis et al. 2003). Sandy, aeolian sediments are typical of dunes in deserts and along coastlines. Wind-blown sand forms by a process known as **saltation**, in which sands are picked up and deposited in stages.

Coastal (waves and tides), **alluvial** or **fluviatile** (moving fresh water), **lacustrine** (standing fresh water), and **spring** (where groundwater emerges) sediments are associated with **aquatic depositional environments**. These indicate riverine, lacustrine, lagoonal, or palustrine wetlands (Odum and Barrett 2005:428–429). Sediments are transported and deposited by rivers and streams are known as **alluvia** (singular: alluvium). Stream deposits, channel patterns, terracing, valley shapes, floodplain characteristics, and stream gradient are important aspects of fluvial environments. **Lagoonal** and **tidal** situations form where fresh and saline waters mix. Coastal and offshore sediments can reflect significant changes in terrestrial environments as well as changes in marine conditions. **Eustatic changes** are global changes

in sea level associated with expansions and contractions of glaciers, resulting in marine waters transgressing up or regressing down continental shelves, with related changes in stream gradients and coastal features. **Isostatic changes** occur when landforms rise and fall as the weight of ice on the earth's crust changes during glacial cycles. Shorelines are created, remodeled, modified, eroded, and submerged by these forces as well as by tectonic uplift, subsidence, waves, tides, currents, and winds, and biological agents, including people (e.g., Scudder 2001). Some aquatic settings are **high energy environments**, as when seawater surges through a cave, in contrast to relatively quiescent **low energy environments**, such as in some lagoons.

Terrestrial sediments are highly diverse and formed by a variety of processes. Among these are colluvium, precipitates, glacial deposits, and organic sediments (e.g., peats). **Slopewash deposits** form by slow downslope creep due to gravitational forces. **Colluvium** (hill wash) is weathered material that has moved down a slope under the influence of gravity (by soil creep), often with water as the transporting medium. Both may be evidence of erosion following deforestation such as might follow a fire, occur during a drought, be associated with pastoralism and cultivation, or result from clearing woodlands. Mass movement downslope of rocks, sediments, and soils under the influence of gravity is termed **mass wasting** or **mass movement** (Table 5.1; Waters 1992:230).

Precipitates in temperate regions are primarily carbonates (**calcareous**, CO_3). Carbonates include **calcite** ($CaCO_3$), **aragonite** (also $CaCO_3$), and **dolomite** ($[CaMg(CO_3)_2]$; Weiner 2010:77, 83–88). Calcite and aragonite are **polymorphs**; they differ only in the arrangement of their atoms (Weiner 2010:77). Both are composed only of calcium carbonate and have layered structures. **Limestone**, primarily formed from calcite, is one of the most common calcareous sedimentary rocks (Allaby and Allaby 2003:86, 318). **Chalk** and **marble** are primarily carbonates (Allaby and Allaby 2003:93–94, 333), the latter metamorphosed through the action of heat and pressure within the earth's crust, making it harder than most unaltered limestones. Thick horizons with relatively high concentrations of calcium carbonate compared with the parent material may be referred to as **calcic** (Allaby and Allaby 2003:81). In tropical and subtropical regions, **siliceous** deposits (silica, e.g., quartz, flint, and glass) may form **silcrete** (a hard mass dominated by silica). Strong evaporation leads to deposits such as those forming in salt pans, which are made of, or held together, by chemical precipitates (**evaporites**; Allaby and Allaby 2003:173, 475).

Glaciers erode, entrain, transport, and deposit any materials over which they pass. **Glacial tills** (or **boulder clay**) form as glaciers erode rock. They contain poorly sorted boulders and pebbles often in a matrix of much finer materials. Immediately below the leading edge of the glacier, outwash sediments of sands and gravels are deposited. These are usually poorly sorted with little bedding. **Solifluxion** debris originally referred to the product of downslope movement of water-saturated materials associated with glaciers, though the term can refer to water-saturated, unconsolidated, weathered materials (**regolith**) just above the parent material in other environments (Allaby and Allaby 2003:506). **Scree** is rocky debris that

accumulates on hill slopes and at the base of cliffs after being detached by alternating freeze and thaw cycles.

Aspects of particles larger than silt grade, such as surface texture, may identify a grain's origin and depositional history. Particles with well-worn, rounded shapes suggest they were transported for a considerable period of time compared with particles with angular shapes, which likely experienced little transport. Unworn surfaces indicate little or no transport; dull, polished surfaces indicate water transportation; and rounded, matte surfaces suggest wind transport. Aeolian transport produces particles with crests and ridges; glacial transport leaves tiny striations due to abrasion. Angular particles suggest little or no transport and are mainly found in solifluxion debris and scree, compared with rounded grains, which indicate transportation by wind and water. Gravels are associated with strong wave action or river currents and clays with still waters.

Soils

Soils are **autogenic**, forming largely through internal processes. They contain inorganic and organic materials that are unconsolidated, located at or near the surface, support plant growth, initially are products of in situ biological, chemical, and physical weathering from the underlying parent material, and consist of distinct layers of mineral and/or organic constituents that relate to their history of formation (Fig. 5.1; French 2003:36–40; Holliday 2004:3; Stein 1992:194–195; Waters 1992:41). Pedologists study the composition, distribution, and formation of soils guided by many of the same questions asked of sediments. What are the origins of the material; the method and environment of deposition; and the impact of post-depositional processes? Which aspects of soils are the result of non-anthropogenic processes and which are the result of human behavior, particularly behaviors associated with plant cultivation, animal husbandry, and construction projects?

Soils reflect the dynamic conditions under which they form. Soil formation (**pedogenesis**) occurs in response to climate (e.g., temperature, moisture), parent material, time, topography, and the activities of organisms, including people (French 2003:36; Goldberg and Macphail 2006:43). Soils altered by human activity (**anthrosols**) may be relatively thick, extending as much as 50 cm below what was the original surface. Soils subsequently may be altered by such processes as erosion, compaction, pollution, desertification, salinization, and nutrient depletion (Goldberg and Macphail 2006:43; Herz and Garrison 1998:40; Holliday 2004:44–45). They contain materials contemporary with their formation and those incorporated later through biological, chemical, and physical processes. The organic component consists of **humus** (decayed organic matter with little or no remaining structure), as well as living and dead organisms (Allaby and Allaby 2003:268). Soils may be relatively modern and lie at the surface (**surficial**) or they may have formed in an earlier landscape and be buried (**paleosols**). Paleosols may or may not develop under the

influence of human activity (e.g., Wilkinson 2005). Some, such as those formed on emerging coral reefs, are **biogenic**; they are formed by specific organisms.

Soils are classified by their main inorganic components: sand, silt, and clay (Fig. 5.3b). Although soils are not organisms, soil taxonomy uses Linnaean hierarchical concepts and terminologies such as order, suborder, family, and series (Holliday 2004:16–19, 46). It can be confusing to biologists when they find a soil referred to as a family or species and read about heritable attributes and genotypes for abiotic materials. Nonetheless, the concept of a hierarchical order of relatedness over time in origin, function, and structure underlies the analysis and interpretation of both abiotic and biotic phenomena.

Soils are distinguished from one another by distinctive mineral and organic properties reflected in such terms as boundaries, color, texture, structure, consistence, chemical properties, and organic content (e.g., Holliday 2004:34). These characteristics define **soil horizons** or **horizontal zones** (relatively uniform layers that can be distinguished from adjacent layers) that form as biological, chemical, and physical constituents move through the **soil profile**. A soil profile is revealed in a vertical section of an archaeological excavation unit and shows the distinctive horizons produced by the deposition and movement of materials through deposits (Figs. 3.6 and 5.9; Garrison 2003:90; Goldberg and Macphail 2006:51–52; Holliday 2004:44–45; Waters 1992:41, 45–49). Soil horizons are evidence of stability because they cannot form and mature when there is active erosion or deposition. Soil formation, however, may be interrupted many times. The sequence of soil formation must be understood so as to reconstruct environments, document environmental change, or interpret the temporal and behavioral context of artifacts. Soil erosion and enhancement are important signatures of human-induced environmental change. Contemporary soils will appear at the surface of the unit and paleosols appear elsewhere within the archaeological stratigraphy.

Soils traditionally are grouped into six **diagnostic** or **master soil horizons** designated by capital letters: O, A, E, B, C, and R (Fig. 5.9; Table 5.4; Garrison 2003:90; Goldberg and Macphail 2006:47–50; Holliday 2004:264–270; Holliday and Goldberg 1992; Waters 1992:46–58; Wilkinson and Stevens 2003:57; see Limbrey 1975:76–83 for a different classification). In a completely undisturbed deposit, O horizons are at the top and C horizons at the bottom, though undisturbed sequences are rare (Holliday and Goldberg 1992; Limbrey 1975:81). **O horizons** consist of superficial organic material such as leaf litter, humus (below the litter and above the mineral soil), and, in permanently waterlogged contexts, peat. **A horizons** contain mixed mineral and organic matter and are generally darker because of the humus and minerals they contain. The terms **mor**, **moder**, and **mull** refer to classifications of humus associated with different levels of acidity, the types of organisms (e.g., bacteria, earthworms, insects) involved in the decomposition of organic matter, and the ability of plants to thrive (compare Goldberg and Macphail 2006:48 with Limbrey 1975:78, 137). The transfer of dissolved and solid substances, usually downward through the profile (**eluviation**) leaves a leached horizon (Waters 1992:41–42). **E horizons** are **eluvial horizons** that have lost iron and aluminum compounds, organic matter, and clay to some degree (Holliday 2004:267). **B horizons** are **illuvial horizons** in which

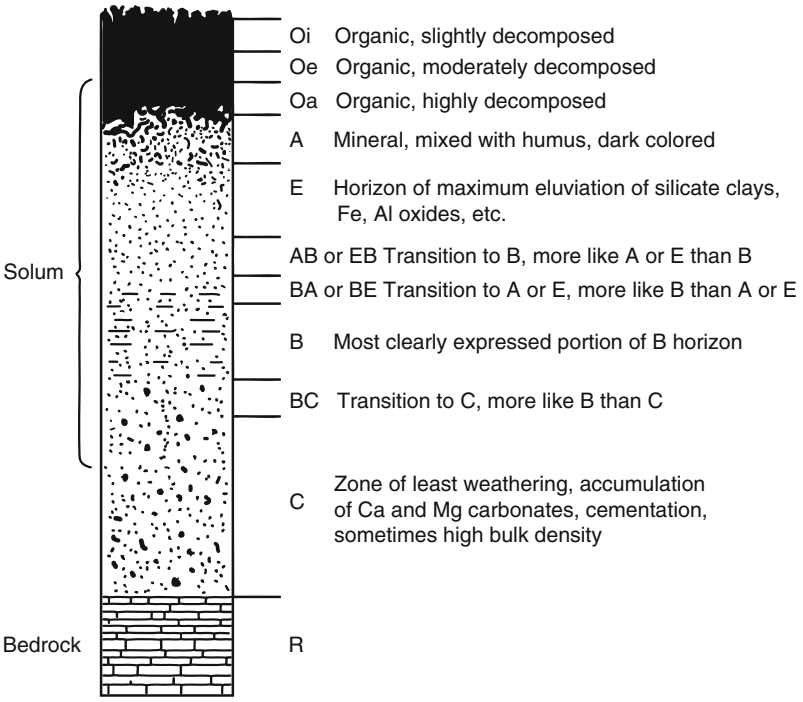

Fig. 5.9 An example of soil horizon nomenclature; terminology elaborated upon in Tables 5.4 and 5.5. The **solum** is the upper part of the soil horizons, A and B, of a paleosol. From Garrison (2003:90) and used by courtesy of the author and Springer

transferred materials that are rich in clay and carbonates accumulate (Holliday 2004:267). **Podzolization** is a form of leaching in which iron, aluminum, humus, and clay are removed from upper soil horizons and deposited in the B horizon (Holliday 2004:267–269). **C horizons** consist of hard, slightly weathered materials little affected by pedogenesis (Holliday 2004:4–6). Regolith is the unconsolidated, weathered material just above the parent material (Allaby and Allaby 2003:457; Goldberg and Macphail 2006:64). It may not be able to support plant life without the development of a soil on top of it (Herz and Garrison 1998:37). **R horizons** (sometimes referred to as D) are unweathered parent materials.

Subhorizons within each master horizon are denoted by lower case letters. For example, the Oa horizon in Fig. 5.9 is an organic layer that is highly decomposed (Tables 5.4 and 5.5; Holliday 2004:4–6). An Ap horizon is a mineral horizon that formed directly below the O horizon and was cultivated or used as pasture at some time in the past (Holliday 2004:4–6; Waters 1992:46).

Soils have both vertical and horizontal configurations. **Boundaries**, or contacts (**facies**), are intersections between soil horizons that may be abrupt or gradual, indistinct or distinct (Garrison 2003:101–102; Limbrey 1975:269–270; see Allaby and Allaby 2003:199 for a different definition of facies). Blurred, indistinct boundaries

Table 5.4 Soil horizon nomenclature and descriptions following the United States Department of Agriculture[a]

Horizon	Description
O	Dark-colored organic remains at the surface in un-decomposed (Oi), partially decomposed (Oe), or fully decomposed (Oa) state. Extremely rare in the archaeological record
A	Mineral horizon forming directly below the O horizon. Includes a mixture of humified organic and mineral particles, with the latter dominating. Usually darker than the underlying horizons. Where the horizon properties are determined by farming it is termed an Ap horizon.
E	Only present where clay has been washed through the profile. In these circumstances, this horizon occurs immediately below an O or A horizon and is characterized by a light color and a lack of clay and organic particles
B	The mineral horizon formed beneath an O, A, or E horizon, but with little similarity to the properties of the parent material. The B horizon contains clays and minerals washed down from overlying horizons and will thicken with time. Some subdivisions of the B horizon include Bhs Concentration of organic matter with iron and aluminum Bk Concentration of calcium carbonate Bo Residue of iron and aluminum Bq Concentration of silica Bt Concentration of clay Btn Concentration of clay together with sodium Bw B horizon of red color but lacking illuvial clay By Concentration of gypsum Bz Concentration of compounds more soluble than gypsum
C	Parent material, which, if weathered, is termed a Cr horizon
R	Consolidated, hard bedrock

[a]Organized from the top of the soil profile to the bottom, including the parent material. Modified from Waters (1992:46–48) and Wilkinson and Stevens (2003:57) and used with permission of the authors and The History Press

are found where soils were mixed between adjacent horizons, whereas sharp, abrupt boundaries indicate that little or no melding occurred across horizons. **Conformable** (indistinct) boundaries imply a slow rate of accumulation compared with **unconformable** (distinct) boundaries that suggest sudden breaks in development. A classic case of an unconformable contact might be two horizons separated by a tiled floor, which clearly establishes a **terminus post quem** (TPQ), a time after which activities above the floor occurred. Care must be taken to distinguish boundaries from **laminae** (layers) or **pans** (hard layers "cemented" by concentrations of minerals) that occur within horizons and may be evidence of short-term phenomena.

Horizon terminologies are highly variable and can be confusing when compounded by international differences in nomenclature. Soil horizon nomenclature, diagnostic horizons, and soil orders often overlap or are used together (Tables 5.4, 5.6, and 5.7; Holliday 2004:16–17; Waters 1992:46–48). For example, the Ap soil

Table 5.5 Selected subordinate distinctions within soil master horizons[a]

a	Highly decomposed organic material
b	Buried soil or horizon
c	Concretions or hard nodules cemented by iron, aluminum, manganese, or titanium
e	Organic material of intermediate decomposition
f	Frozen soil
g	Strong gleying has occurred
h	Illuvial organic matter
i	Slightly decomposed organic material
k	Accumulation of calcium carbonate
m	More than 90% cemented or indurated
n	Accumulation of exchangeable sodium
p	Mechanical disturbance such as plowing or pasturing
v	Plinthite, iron-rich, humus-poor reddish material
x	Fragipan, layers that are firm, brittle, and coarse
y	Gypsum
z	Accumulation of salts more soluble than gypsum

[a]Modified from Holliday (2004:4–6). For a complete list and description see Holliday (2004:4–6)

Table 5.6 General concepts for selected diagnostic horizons in soil taxonomy[a]

Epipedons (*diagnostic surface horizons*)	
Anthropic	Deep, dark, humus-rich diagnostic surface horizon, high in phosphorous content (mollic)
Histic	Surface horizon very high in organic matter (O)
Mollic	Deep, dark, humus-rich surface horizon with abundant cations (A, A & B)
Ochric	Surface horizon that does not meet the qualifications of any other epipedon (A)
Plaggen	An artificially made surface layer produced by long-term manuring
Diagnostic subsurface horizons	
Albic	Light-colored horizon with significant loss of clay and free iron oxides (E)
Argillic	Horizon of significant clay accumulation (Bt)
Calcic	Horizon of significant accumulation of calcium carbonate (Bk)
Cambic	Some reddening or structural development; reorganization of carbonates if originally present (Bw)
Kandic	Heavily weathered, clay-rich horizon low in bases (Bt)
Natric	Horizon with significant clay accumulation (argillic) high in sodium (Btn)
Oxic	Intensely weathered horizon virtually depleted of all primary minerals and very low in bases
Petrocalcic	Calcic horizon strongly cemented by calcium carbonate (K)
Spodic	Horizon of significant accumulation of aluminum and organic matter with or without iron (Bh, Bs, Bhs)

[a]These are very general definitions of terms used in the soil classification system of the US Department of Agriculture (based in part on Wilding et al. 1983). For a complete list and criteria see *Soil Taxonomy* (Soil Survey Staff 1999). Modified from Holliday (2004:16) and Holliday and Goldberg (1992:247–252)

Table 5.7 General concepts of the soil orders in soil taxonomy[a]

Term	Definition
Alfisols	Soils with argillic horizon, but no mollic (A-Bt), that are lower in bases than mollisols; typically found in humid, temperate regions
Andisols	Soils formed in volcanic ash and related volcanic parent materials (A-C, A-Bw)
Aridisols	Soils formed in desert conditions (entisols can also be found in deserts) or under other conditions restricting moisture availability to plants (high salt content; soils on slopes); with or without argillic horizon, but commonly with calcic, gypsic, or salic horizons (A-Bw-Bk; A-Bt-K; A-By)
Entisols	Soils with little evidence of pedogenesis (A-C, A-R); very few diagnostic horizons
Gelisols	Permafrost soils; very common in high latitudes
Histosols	Organic soils, such as peats
Inceptisols	Soils exhibiting more pedogenic development than Entisols, with appearance of diagnostic surface and subsurface horizons that are not as well developed as in most other orders (A-Bw)
Mollisols	Soils that are humus-rich (mollic) and high in bases throughout; typical of continental grasslands
Oxisols	Soils with an oxic horizon; found in tropical regions and include many soils formerly termed laterites and latosols
Spodosols	Soils with spodic horizons (O-A-E-Bh/Bs/Bhs); typical in cool, humid climates under coniferous forests
Ultisols	Highly weathered soils that have argillic horizons and that are very low in bases (A-Bt); typically found on older landscapes in warm, humid climates
Vertisols	Soils high in clay content in climates with distinct wet and dry seasons and that shrink and swell markedly

[a]For a complete list and criteria see *Soil Taxonomy* (Soil Survey Staff 1999). To classify a soil the guidelines and criteria for diagnostic horizons and classification in soil taxonomy should be followed (Soil Survey Staff 1999). This table presents only the principal characteristics of the soil orders. Modified from Holliday (2004:17) and Holliday and Goldberg (1992:247–252)

horizon may be referred to by the diagnostic surface horizon (**epipedon**) named "**plaggen**," which is a **cultosol** (anthropogenic) surface created by long-term manuring, but the Ea soil horizon may be defined as a "leached/eluviated upper subsoil," a diagnostic subsurface horizon known as "albic" in a soil order known as podzol or spodosol (compare Holliday 2004:14–18 with Goldberg and Macphail 2006:48–50). The primary aspects of sediments, soils, and associated site formation processes that affect organic materials are clear regardless of the terminology used.

Soil color usually reflects characteristics of the source of the material, weathering, physical and chemical conditions, and post-depositional alteration more so than environments, but provides an essential clue to the depositional sequence (Holliday 2004:193–196; Limbrey 1975:256–259; Rapp and Hill 1998:36–38). Color may be **primary** (from the source material) or **diagenetic** (derived through post-depositional alterations). Color may be the result of high water or fluctuating water tables (e.g., oxidation–reduction mottling, **gleying** or **gleization**) or weathering processes (e.g., biochemical alteration, humification, leaching, accretion). Color, combined with structure and texture, may indicate which agents produced changes in soil color.

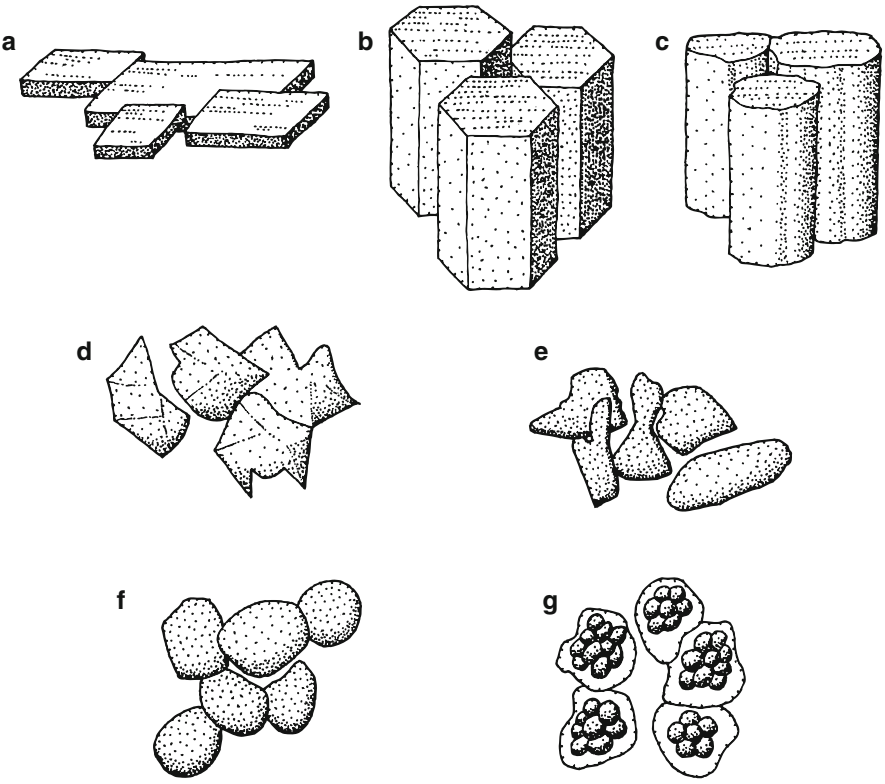

Fig. 5.10 Shapes of particles used in sediment and soil descriptions: (**a**) platy; (**b**) prismatic; (**c**) columnar; (**d**) angular blocky; (**e**) subangular blocky; (**f**) granular; and (**g**) crumbs. From Shackley (1981:12)

Color involves three properties: **hue intensity** (dominant spectral color: red, green, blue, yellow), **value** (lightness, darkness), and **chroma** (degree of color saturation or grayness, purity of color). Color descriptions are standardized by comparing the soil to color chips on a Munsell soil color chart until the chip nearest in color is found. The result is recorded using the format: *hue value/chroma, description*.

Thus a color might be noted as Munsell 7.5 YR 7/2, pinkish gray. This reads as 7.5 Yellow Red Hue, seven value, two chroma, described as pinkish gray on the Munsell chart. This same scale is used for sediments.

Soil structure refers to the arrangement of individual sand, silt, and clay particles (Limbrey 1975:265–267; Waters 1992:28, 44–45). A **ped** is a lump or aggregate of individual soil particles. Ped morphology or shape is described as granular or crumb, angular or subangular blocky, prismatic or columnar, and platy (Fig. 5.10; Shackley 1975:44–46, 1981:12). Depending on how well-formed and distinct peds are, ped development may be classified as weak (indicating young soils), moderate, or strong (indicating older soils). Specific soil structures are characteristic of different soil types. Compressed soils may have closely packed peds. Some soils are structureless; they contain no peds. Such structureless soils are termed **single grained** (unconsolidated

Table 5.8 Coherence[a]

Moist sediments
0 = Non-coherent
1 = Very friable (crumbles under gentle pressure)
2 = Friable (crumbles under moderate pressure)
3 = Firm (crumbles under moderate pressure, with noticeable resistance)
4 = Very firm (crumbles under strong pressure but is difficult to crush between the fingers)
5 = Extremely firm (crumbles only under very strong pressure)
Dry sediments
0 = Loose (non-coherent)
1 = Soft (weakly coherent and fragile, breaks under light pressure)
2 = Slightly hard (weakly resistant to pressure and easily broken between thumb and fingers)
3 = Hard (resistant to pressure; can be broken by hand but difficult to break between thumb and forefinger)
4 = Very hard (only broken in the hand with difficulty)
5 = Extremely hard (cannot be broken in the hand)

[a]From Shackley (1981:11).

Table 5.9 Cementation[a]

Weakly cemented	Brittle and hard but can be broken in the hand
Strongly cemented	Brittle but cannot be broken in the hand
Very strongly cemented	Will require a strong hammer blow to break

[a]From Shackley (1981:11)

particles) or **massive** (cohesive mass). Additional aspects of soil structure include roundness, sphericity, and surface texture. As in sediments, texture ranges from very angular to very well rounded (Fig. 5.7). Peds also are classified by size, packing, and swelling (Limbrey 1975:268–269).

The way soils respond to handling is another important characteristic. **Consistency** refers to the cohesiveness of peds, an indication of their ability to resist handling, plowing, digging, and other mechanical stresses, measured by the resistance of peds to crushing (Limbrey 1975:267–268). Consistency is described in terms of dry, moist, and wet conditions. Coherence (Table 5.8; Shackley 1981:11) and cementation (Table 5.9; Shackley 1981:11) refer to the strength of the bonds between individual grains (**coherence**) and the degree to which they are chemically bound by something other than clay minerals (**cementation** or **induration**; Shackley 1981:11). Common cementing media in pans are carbonates, iron or manganese compounds, silica, gypsum, and salt. Indurated soils are very hard and strongly cemented. **Plasticity** refers to the ability to form small lumps of moist soils into "worms" by rolling in the hand, an attribute important in ceramic technology.

Paleosols formed in earlier landscapes and were buried by subsequent processes. The sequence of complex changes that occur in paleosols may be difficult to recognize, especially if the sequence is interrupted by intrusive deposits or is truncated. Interpreting paleosols requires considering chemical and physical post-depositional processes, and the development of new horizons subsequent to burial. Bioturbation affects both modern soils and paleosols. Earthworms may completely remove humic horizons from paleosols (Atkinson 1957; Canti 2003; Chap. 10). Much depends on

the depth and other characteristics of materials that overlie paleosols. If only a thin deposit overlies the paleosols, the buried soil will be influenced by processes related to the present-day surface. Some paleosols are buried so deep that there is little or no biological activity. Iron and manganese pans may form in buried soils depending on burial depth, water movement, and characteristics specific to the buried surface. Soils beneath earthworks and other structures are important sources of pre-construction environmental information because the soils may have been protected from fungi, pollen, roots, airborne insects, burrowing animals, and other subsequent soil-forming processes. Paleosols may change, however, as protective structures settle and decay.

The components of soils may be altered by fire (Limbrey 1975:325). Whether the organic matter in a soil is completely incinerated or slightly charred depends on the oxygen and organic matter available to the fire. If the soil contains little organic matter, iron compounds in the soil remain in a reduced state. If the soil is highly organic, iron compounds may be **oxidized** (exposed to oxygen-rich conditions) and the dominant soil color may be red from **hematite** (ferric oxide, Fe_2O_3). Tropical, desert, and Mediterranean soils may be red and hematite-rich without exposure to fire, however. Close examination of the surface texture of quartz sand grains show whether the soil itself burned, or burnt material such as charcoal was mixed with unburnt soil.

Field Procedures

Much of the data needed for analysis and synthesis are obtained initially from field observations that are augmented or verified by subsequent laboratory procedures. Field work involves recording profiles, collecting samples, examining and mapping topography, comparing the site being studied with others in the area, and examining non-anthropogenic deposits. A well-reasoned, problem-orientated approach, advance planning, and substantive site visits are essential to ensure agreement among all parties about the execution of these procedures and the knowledge needed if laboratory analysis is to meet the project's research objectives.

This emphasis on original field observations contrasts with organismal studies, which rely primarily on lab-based identifications. Nonetheless, organismal studies draw upon field descriptions of sediments and soils to interpret laboratory observations. Field records of depositional characteristics and the condition of organic materials are invaluable in the laboratory. Analysis of organic materials is enhanced by field observations indicating which biological remains are present in a sample context, their apparent condition, and whether radiometric dates are available for that context. Such notes might anticipate the need to distinguish between organisms and organic remains that originated in distant communities and those that originated in nearby locations, perhaps even from the immediate spot. Thorough records assist in selecting organic samples that can be examined profitably in more detail during laboratory analysis and aid in multi-proxy interpretations of specific deposits, the site, and the region.

Some data can only be collected in the field; it is generally difficult, if not impossible, to interpret sediments and soils first seen out of context, i.e., in the laboratory (e.g., Limbrey 1975:278). Thus, a full-time, on-site, skilled researcher responsible for collecting primary data is important. If such a person cannot be present throughout the excavation, recording and sampling protocols should be developed prior to field work and followed faithfully. Given the diverse demands placed on these materials, one person who is aware of the requirements and purposes of each procedure should be responsible for the samples. This reduces the likelihood of missing records, poorly collected or badly packed samples, and inadequate coordination.

Field notes provide information essential to the interpretation of both inorganic and organic materials (e.g., Goldberg and Macphail 2006:321–328). Notes should include the date, location, site name and number, grid reference, name of the person responsible for the record, and a description of the context. Notes should use widely accepted, standardized terminologies and formats to avoid errors and to ensure comparability among sites and archaeological traditions. They must be easy to use, simple to understand by everyone, capable of infinite extension, and complemented by a visual record. The system must facilitate the curation, interpretation, and publication of data and maximize use of data by others.

Field and laboratory analyses are guided by maps (Goldberg and Macphail 2006:309–312). Soil maps may be available; if not, it may be necessary to begin the study with a survey of modern sediments and soils well beyond the specific site. Topographic maps, aerial photographs, and satellite images are important sources of information.

Some typical field observations include moisture, organic content, color, texture, soil horizons, coherence, cementation, and structure (Goldberg and Macphail 2006:327–328). Variations in color classifications are introduced by lighting conditions, moisture content, and observer bias. Error is minimized by having all colors recorded by the same person, preferably under similar lighting and moisture conditions. It is best to collect both wet and dry samples, and record the color of both when they are collected. The Munsell soil color chart is more often used to describe moist samples; moisture content should be noted along with the classification. Color should be recorded from a freshly broken, unsmeared chunk. All of these observations are elaborated upon in the laboratory.

Once background descriptions are complete, the deposit is sampled. Archaeological strata are very thin compared with most geological strata. Samples from the profile exposed in the wall of an open archaeological unit offer greater control over this fine-grained stratigraphy than do cores. Stratigraphic layers will be more obvious in the unit's profile, making it easier to select good places to sample the site's history. This reduces the possibility of contaminating underlying materials with more recent ones. After the face is cleaned, it should be drawn and photographed before samples are taken, so that samples can be associated with vertical and horizontal contexts. In a masterpiece of understatement, Limbrey (1975:273) notes that "A well studied section should have a ragged and well used appearance, not the smart and polished look so beloved of some excavators. Obviously, photographs of the whole rather than of details have to be taken before the beginning of

detailed examination." This is a task best left for the analyst. If the analyst cannot be present throughout the field season, it is sometimes possible to leave a column in each unit for the analyst to sample during field visits.

Stout, non-biodegradable plastic bags or other clean containers, tape measures, clean trowels, spatulas, packing materials, and labels are necessary for most sampling. If the sample will be shared with people studying organic materials, bags and clean disposable plastic gloves that do not contain powder should be used. The sample should not be touched and tools and containers should not be reused unless scrupulously cleaned. These precautions are particularly critical if materials such as pollen, phytoliths, starch grains, and organic residues are anticipated.

Samples are taken at predetermined intervals by scraping material from the exposed face into a container or by pressing a sample container into the exposed section. Samples should be taken from a vertical section or face that is freshly cleaned by horizontal (rather than vertical) cuts to avoid contamination. They should be taken from the base of the profile first, working up the profile to avoid contamination by falling bits of debris. Samples should be from within a stratum rather than across strata, though stratigraphic boundaries may be unclear (e.g., Faegri et al. 1989:59). Some advocate that vertical sampling should be evenly spaced at regular specified intervals (e.g., 5 cm). If such a standardized approach skips over interesting aspects of the profile, these other contexts could be sampled as well. More complex deposits require shorter spacing between samples and the number of samples required is higher. In practice, spacing reflects the accumulation rate, the intensity of occupation, and the deposit's complexity. When sampling at close intervals, dig into the face at the sample point instead of scraping the surface around the point; scraping reduces the spacing interval and increases errors. The exact location and orientation of each sample should be marked on the sample container, which is then sealed and placed in a larger container for protection. It is best to avoid collecting samples that will be used for pollen analysis when atmospheric pollen levels are high.

If a soil monolith is taken, a container of the size of the block or column designated as the monolith is placed over or around the block and the block is cut out from the profile (Goldberg and Macphail 2006:331; Holliday 2004:36). Hammering a sample container such as a monolith or **Kubiena tin** (e.g., a metal box ca. 55 cm × 10 cm × 10 cm) into the designated block has the advantage of allowing the deposit to be removed intact. This could be considered a form of column sample (Orton 2000:157).

A coring device is sometimes used to collect samples (e.g., Faegri et al. 1989:60–68; Goldberg and Macphail 2006:316–321; Pearsall 2000:282–286; Traverse 2008:466). If the sample area is small (e.g., a small peat bog), one core may be sufficient, but, if large, more cores or more robust sampling devices may be required. The appropriate tool depends, in theory, on the deposit type and the depth required, but in practice it may depend on the budget and availability of gear and labor. The ordinary soil auger is useful in the initial penetration of dry deposits or to obtain a general idea of stratigraphy but is unlikely to be appropriate for recovering pollen or other organic samples because of the risk of contamination.

Sample size, number, and representativeness are confounding issues for all environmental archaeologists. The basic rule is to collect as many samples as possible to ensure that the sampled population is represented accurately (Goldberg and Macphail 2006:333). The size and number of samples needed is directly proportional to the research objectives, the "coarseness" of the deposit (the finer the deposit, the smaller the sample can be), and the number of researchers who will draw materials from the sample. Particle size analysis may require the largest amount of material; if samples are sufficiently large for this procedure, adding a little more material may provide for other routine sediment and soil tests. If samples will be used for other studies (e.g., insects, land snails, pollen, organic residues), this must be considered when deciding how to collect the samples, their size and number, which contexts to sample, and how to manage samples once taken. It is better to take too many samples or ones that are too large than it is to discover after field work is over that some studies cannot be done because the samples are too small or otherwise limited. Taking many separate samples from the same context is preferable to relying upon laboratories to subsample without introducing bias. Context heterogeneity must be considered when making sampling decisions.

However collected, sediment and soil samples change quickly once removed from their context; this is one reason for recording as much information as possible before samples are removed. The sample should be kept moist (unless already dry) and protected from contamination by other samples and modern organic materials. For some applications, however, it is preferable to allow the sample to dry slowly in the laboratory. An alternative method of curation is to deep-freeze the samples. Archived samples should be checked periodically to assess their stability; it may be necessary to add a fungicide or change the curational environment, though the addition of any chemical may preclude subsequent radiocarbon assay or some of the procedures reviewed in Chap. 13.

Laboratory Procedures

Laboratory procedures involve interpreting maps and other images, as well as analyzing particle size, morphology, fabric, chemical properties, and mineral composition (e.g., Garrison 2003; Goldberg and Macphail 2006). Some of the same procedures may be used for both sediments and soils; many elaborate upon or augment field observations.

If all of the samples cannot be studied within the time or funds available, subsampling may be required. Observer bias is controlled by using a uniform and consistent approach that does not permit the operator to select, consciously or unconsciously, interesting materials, leaving unstudied those that are less appealing. An unbiased approach is to take a 25–50% subsample using a **riffle box** (Pearsall 2000:111). A riffle box is sloped and gently vibrates materials placed into it, sifting them into a series of small containers attached to the lower edge of the box. The contents of one or more of these containers will be studied and the remaining

containers can be archived for future research. The number of containers studied is determined by the percentage of the overall sample selected for study. More samples and contexts can be studied using subsamples, but the sample size for each context is smaller.

Several preliminary steps may be followed to prepare samples for further study. Samples may be examined for inclusions (e.g., ash, charcoal, slag). This is best done twice: first after the sample is dried and, if necessary, again after any fine clay adhering to the grains is removed by wet sieving. Other preliminary steps may involve ultrasonic disaggregation (not used if the grain surface texture will be examined); dispersion in suspension; and chemical removal of organic matter, carbonates, and iron oxides. These procedures should not be applied to samples that will be used for biological studies because they remove (or destroy) cysts, pollen, starch grains, insects, snail shells, and other organic materials. **Bulk density** may be measured as one of these preliminary steps. This is the mass per unit volume of materials dried to a constant weight at 105°C (Allaby and Allaby 2003:78; Garrison 2003:133).

Particle Size

Laboratory analysis of particle size continues work begun in the field by refining the classification, determining the density of the particles, and calculating the ratios of one particle size to others (Goldberg and Macphail 2006:336–339). Particle or grain size analysis provides insights into such site formation processes as the agent of deposition (e.g., wind, water, ice), depositional processes (e.g., saltation), the depositional environment (e.g., dune, flood plain), and diagenesis (Shackley 1975:87). It is combined, usually, with morphological and chemical examination to sort out difficult sedimentary histories. In soils, particle size provides information about soil formation. Often size is estimated using a graduated series of sieves, though the smaller particle sizes may require other procedures (e.g., Goldberg and Macphail 2006:337). The results may be expressed on a triangular or ternary-type diagram (Fig. 5.11; Gardner 1977:383) or a graph (Goldberg and Macphail 2006:16, 340).

Quantifying the percentages of particle size classes raises questions about what to count and how much to count, questions that apply to many archaeological materials. Quantification of sediments and soils often is based on weight or volume. In some cases, however, a count is required. In studies of sediments and soils, as well as in many organismal studies, counts are estimated using a protocol based on a predetermined standard count (e.g., Clark 1982; Garrison 2003:129–131; Shackley 1975:137; Tolonen 1986:490). The guiding principles of any standard count are that only a portion of the sample is counted and the portion is selected following a protocol designed to obtain results that can be quantified and studied using statistical methods.

The contents of a slide are examined during a visual transect of the slide at some specified magnification until the predetermined standard count is reached. Most standard counts are made systematically while viewing samples on slides under

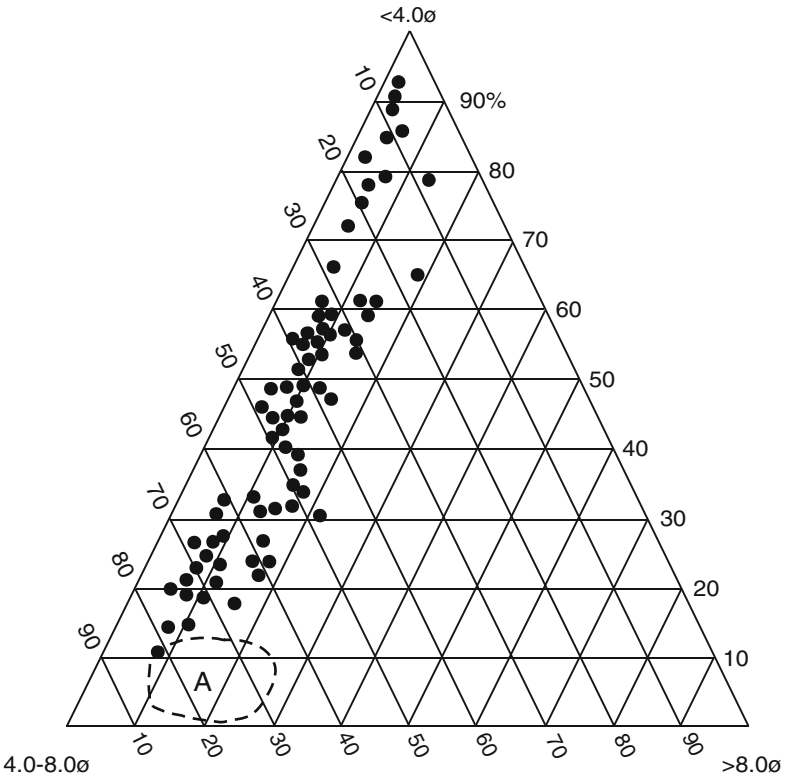

Fig. 5.11 Triangular diagram showing the composition of possible loess samples from Tell Fara (Northern Negev, Israel). The axes show the percentage of clay (>8.0 ϕ), silt (4–8 ϕ), and sand and gravel (<4 ϕ). One sample, designated by the label "A," has the characteristics of loess. From Gardner (1977:383) and used by courtesy of Elsevier

a microscope. Several different approaches are possible; defined by Orton (2000:185–187) as area-counting, line-counting, ribbon-counting, and point-counting. In **area-counting**, all grains (or selected types of grains) within the field of vision are counted. **Line- and ribbon-counting** are more selective, counting grains that are crossed by regularly spaced, parallel lines or that fall within broader, regularly spaced, parallel ribbons (transects, bands). Variations are introduced by the width and spacing of lines or ribbons. **Point-counting** relies on a two-dimensional grid; only grains that lie at points where the grid lines intersect are counted (Clark 1982; Tolonen 1986:489–490). The magnification, spacing of the transects, number of traverses across the slide, and number of slides viewed may all vary.

The issues raised by standard count analysis are fundamental to many of the procedures used by environmental archaeologists. Counts of between 100 and 1,000 grains are advocated in the literature, a range that clearly indicates how difficult it is to decide what an adequate sample is, how much to count, how to count it, and what to count. As a rule, it is best to work toward the higher count generally considered adequate for the specific research question.

Other Properties

Unlike size, morphology provides information about the spatial organization of the components, how they are distributed, the sequence of processes, and details of texture. Morphology measures shape, sphericity, roundness, and surface texture and is evaluated in terms of transport, erosion, and weathering (Farrand 1975; Goldberg and Macphail 2006:20–24; Rapp and Hill 1998:36; Waters 1992:26–27). One obvious example is the association between loess and glaciation. Further evidence of glacial events is found in marine sediment cores. Abrupt transitions from cold **stadial periods**, when glacial advance is most extensive, to warmer **interstadial periods**, when glaciation is reduced, are indicated by coarse-grained materials "rafted" into northern seas by ice (van Meerbeeck et al. 2009). **Micromorphology** examines features such as coatings, texture, fabric (in the pedological sense), and weathering in thin sections of clastic materials viewed through a microscope for details of changes in depositional processes (French 2003:47–58; Garrison 2003:149; Holliday 2004:37–38).

Fabric analysis assesses packing and organization among particles in clastic sediments (Waters 1992:27–28) or the total organization of soil (Goldberg and Macphail 2006:19–20). Gravels, for example, are described in terms of the ratio of three mutually perpendicular axes that define the longest (*a* axis), intermediate (*b* axis), and shortest (*c* axis) dimensions of their **clasts** (fragments that are the product of physical or chemical weathering; Fig. 5.8; Allaby and Allaby 2003:106; Garrison 2003:162; Waters 1992:27). Particles deposited in a moving medium tend to orientate themselves with their longest axis parallel to the direction of flow and the shortest axis transverse to it. This is used to study orientation of clastic particles in deposits such as glacial till and outwash sediments and clarify depositional histories. Pedologists may study fabric in terms of primary (depositional) and secondary (post-depositional) characteristics (Goldberg and Macphail 2006:20–21).

Chemical analyses include measurements of water content, total organic carbon, pH, nitrogen, phosphorus, potassium, calcium, iron, and aluminum. Water content is measured by drying samples at 105°C (Allaby and Allaby 2003:78; Goldberg and Macphail 2006:344). **Loss on ignition (LOI)** indicates the relative proportions of mineral to organic materials, obtained by comparing a sample's weight before and after it is heated at high temperatures to determine the **total organic carbon (OC)** lost in the process (Goldberg and Macphail 2006:344, 391). Temperatures and length of time are variable, but temperatures can be as high as 800°C for 6 h. Some of this loss may be due to the ignition of charcoal and carbonates rather than of uncharred organic content. The **C:N ratio** (the amount of carbon and its ratio to nitrogen) is indicative of biological activity and assessing the C:N ratio is an important step in some of the studies reviewed in Chap. 13. A number of these characteristics are transformed by chemical processes in the burial context and by human activity.

The base status of soils is measured in terms of pH and classified on a scale from acidic (pH < 6.5) to alkaline (pH > 7.5; Garrison 2003:99; Goldberg and Macphail 2006:52, 61; Limbrey 1975:57; Shackley 1975:65–66). Acidic conditions are described as being basic or having low pH. These soils typically are poor in nutrients,

may be associated with siliceous deposits, and support few plants and animals. pH values between 6.5 and 7.5 are termed neutral. Alkaline conditions are referred to as base-rich or having high pH. Alkaline soils are associated with calcareous conditions (e.g., chalk, limestone) and typically are rich in nutrients.

Several different chemical forms of phosphorus are found in soils; sometimes distinguished by terms such as organic, inorganic, and total phosphorus. Phosphorus in soils is found as the phosphate ion (Holliday and Gartner 2007). At a broad level, **phosphate** is an organic and inorganic (iron and calcium) compound containing elemental **phosphorus**. Total soil phosphorus contains organic and inorganic fractions, both of which can persist for an extended period of time. Phosphate is present in all ecosystems, its ultimate source being the parent material. Phosphate cycles from soil to autotrophs to heterotrophs and then back to the soil, with some loss via leaching and other processes (e.g., Odum and Barrett 2005:150). Human activity may alter the cycle by producing a net phosphate loss (e.g., through overgrazing) or gain (e.g., input from dung, human waste, plant and animal products, ash from fires). Decaying organic matter, urine, feces, and fertilizers contribute to phosphate gain. The phosphate content of archaeological soils varies with activity level, but is generally higher compared with areas with less human activity. The relationship between phosphate (or phosphorus) levels and the intensity of human occupation is used to locate sites and determine their sizes. These levels may define functions within sites, such as areas associated with burials, animal pens, waste disposal, paths, and fertilization (e.g., Canuto et al. 2010; Holliday and Gartner 2007). Phosphate analysis may distinguish between soils such as plaggen and soils not enriched by such intensive human activity.

Complex factors affect phosphate and phosphorus (Goldberg and Macphail 2006:347–350; Holliday and Gartner 2007). There is some mobility of phosphate in soils, not all of the phosphate that is added remains in its original context. The phosphate content of plants is dependent on soil type, growth conditions, and plant species. It even varies within the plant's own tissues. In animals, the phosphate content depends on age, sex, and food supply, among other factors. Thus phosphate is unevenly distributed not only within a site, but within an organism. When organic matter (e.g., plant debris) is burned, organic phosphorus is converted into an inorganic form. It may leach rapidly in sandy soils and peats until no evidence of the initial input remains. Microbial activity, weathering, soil moisture, pH, particle size, mineralogy, and time also affect soil phosphorus (Holliday and Gartner 2007).

Minerals are usually inorganic substances in crystalline form that have characteristic chemical compositions; rocks are composed of minerals. Mineral composition provides information about the identity of the parent rock and weathering processes (Goldberg and Macphail 2006:361–363). Identification focuses on minerals with a relative density greater than 2.9 (heavy minerals). Usually only the very fine sand fraction is studied. Sediments subjected to less weathering contain a higher proportion of heavy minerals than do heavily weathered ones, and there is a close relationship between heavy mineral assemblages and grain size. Mineral compositions are important aspects of raw materials used to make ceramic and lithic objects.

Applications

Assessing the impact of human activities on landscapes and soils draws upon both biotic and abiotic information, as well as knowledge of both anthropogenic and non-anthropogenic processes. Davidson et al. (2006) demonstrate that deep soils near Nairn (Scotland) reflect urban waste disposal practices, urban–rural interactions, and the influence of previous land management systems on present-day soils. Between CE 1794 and 1841, the population of Nairn grew from ca. 1,400 people to ca. 2,318, with agriculture as the primary economic activity. Town records indicate that domestic waste, livestock bedding material, dung, ash, and turf from walls and roofs all were discarded within the town and subsequently applied to nearby fields. Davidson et al. (2006) test the hypothesis that intentional application of this waste material deepened soils in nearby fields and enhanced their fertility. The authors sampled 120 locations extending from the Medieval town center outward for approximately a kilometer. They mapped the depths of the A horizon and examined particle size, micromorphology, and element composition, particularly phosphorus levels and ratios of oxygen to carbon (**O:C ratio**). Davidson et al. (2006) report finding substantial variability in topsoil depth, which may have been deepened by as much as 120 cm through the addition of waste material on arable lands in the 1790s. Some samples contained numerous small, black, carbonaceous particles and high levels of phosphorus. The authors conclude that turf was used as building material, which, in addition to ash from peat fires and other materials, accumulated in dung heaps or ash pits within the town. Subsequently, this waste was applied to outlying fields, increasing topsoil depth and improving soil quality (Fig. 5.12; Table 5.10; Davidson et al. 2006:780–781).

Studies of site formation processes and site functions often rely on comparisons of modern and archaeological processes and samples. Shahack-Gross and Finkelstein (2008) incorporate such a comparison in their study of oval compounds in the Negev Highlands (Israel). These compounds consist of rooms enclosing large internal courtyards. The objective was to determine whether these compounds were fortresses or pastoral-nomadic encampments. The compounds consist of rooms enclosing large internal courtyards. The authors examined sediments from a compound known as Atar Haroa occupied between the late tenth and early ninth centuries BCE. The archaeological samples were compared with local modern fodder plants, control samples from sediments beyond two recently abandoned Bedouin camps, gray sediments from Atar Haroa, and modern dung from these two recently abandoned camps (Fig. 5.13; Shahack-Gross and Finkelstein 2008:977). Micromorphology and mineralogy of the stratigraphic units from Atar Haroa show that the uppermost part of the occupational surface consisted of extremely disturbed soil containing bones, calcite from wood ash, gypsum from tamarisk (*Tamarix aphylla*) ash, fire wood, charcoal fragments, and fecal or dung spherulites. **Fecal spherulites** are calcareous spheres measuring 5–15 μm in diameter that form in ruminant guts and subsequently are excreted (e.g., Canti 1999). Upper strata in the rooms and the courtyard consisted of gray-colored anthropogenic deposits 2–10 cm thick.

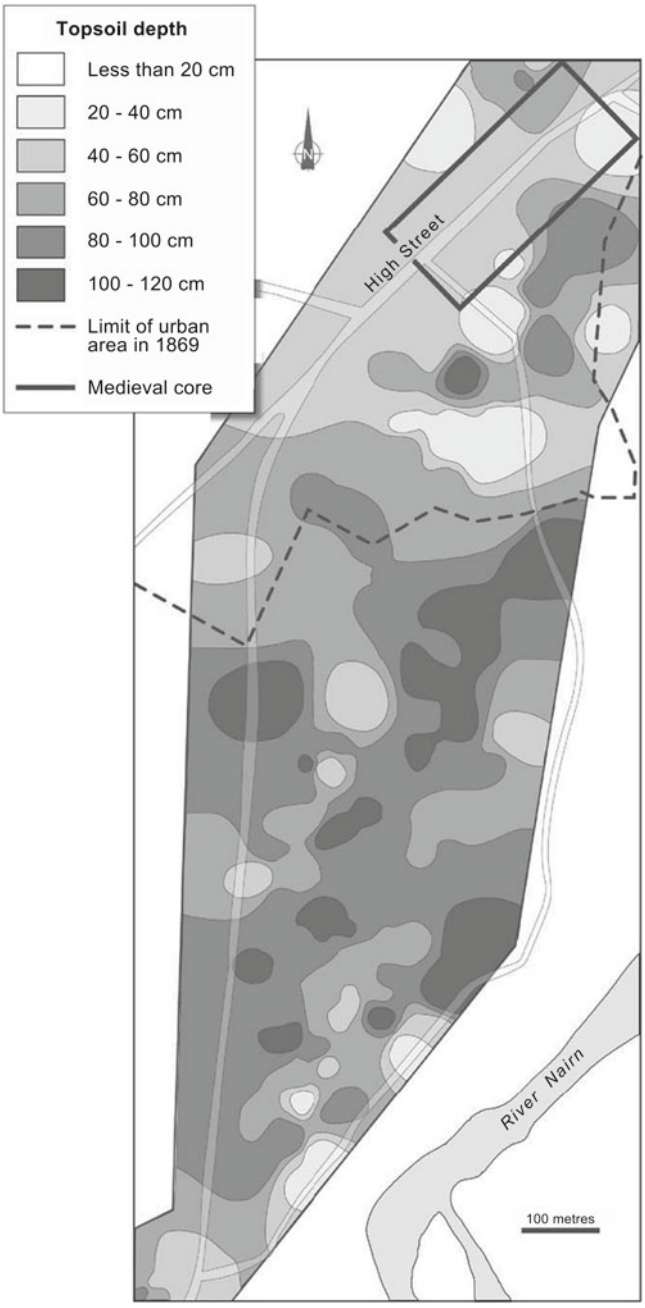

Fig. 5.12 Depth of topsoil in and near Nairn (Scotland). From Davidson et al. (2006:780) and used by courtesy of the authors and Elsevier

Table 5.10 Soil properties of the investigated profile at Nairn (Scotland)[a]

Horizon	Depth (m)	Munsell color (moist)	Sample depth (m)	Loss on ignition (%)	pH	Clay, <2 μm (%)	Silt, 2–20 μm (%)	Fine sand, 20–200 μm (%)	Coarse sand, 200–2,000 μm (%)	Total(mg/kg fine earth)				
										P	Pb	Zn	Cu	As
Apl	0.00–0.18	7.5 YR 2.5/2	0.03–0.11	5.49	5.1	2	11	58	29	645	16.5	18.5	8.4	2.0
Ap2	0.18–0.64	7.5 YR 3.5/2	0.19–0.27	4.33	5.1	2	12	51	35	857	–	–	–	–
			0.35–0.43	3.85	5.6	3	14	58	26	986	5.5	19.2	6.5	1.0
			0.53–0.61	4.02	5.7	2	9	55	34	902	–	–	–	–
Ap3	0.64–0.84	7.5 YR 3/1	0.64–0.72	4.84	5.5	3	14	60	23	1,268	11.2	12.5	4.6	0.5
Bhsb	0.84–0.98	7.5 YR 4/3	0.90–0.98	1.96	5.1	1	5	11	83	626	7.0	14.4	3.5	1.1
	>0.98	7.5 YR 5/4	0.98–1.06	0.50	4.9	1	3	12	84	254	–	–	–	–

[a]Methods: loss on ignition (425°C); pH (1:2.5); particle size distribution (laser diffraction); total P (sodium hydroxide fusion) of fine earth fraction (<100 μm); total lead, zinc, copper, and arsenic analysis by nitric acid/hydrogen peroxide digestion—not available. From Davidson et al. (2006:781). Used with permission of the authors and Elsevier

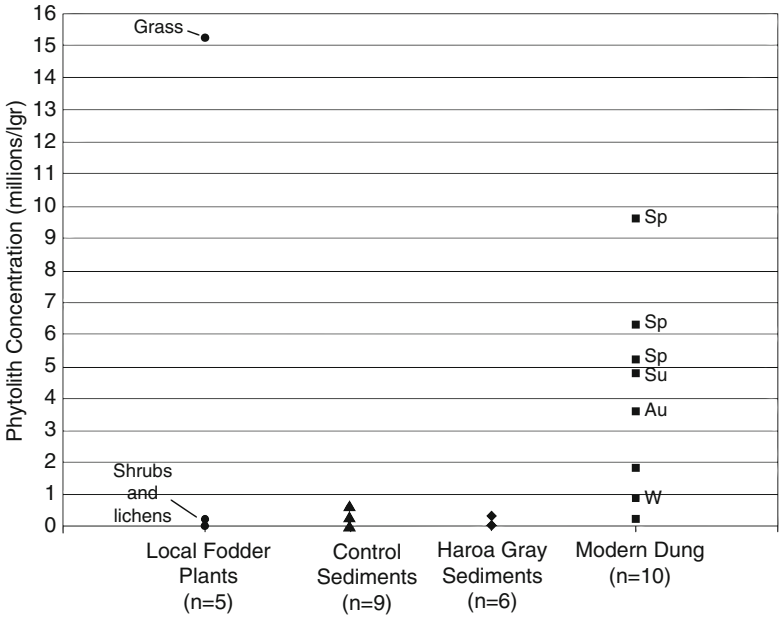

Fig. 5.13 The distribution of phytolith concentrations (as number of phytoliths per 1 g of sediment or per 1 g of ashed dung or plant material) in local fodder plants, control sediments, gray-colored anthropogenic sediments from the Atar Haroa (Israel) compound, and modern livestock dung. *Sp* spring; *Su* summer; *Au* autumn; *W* winter. From Shahack-Gross and Finkelstein (2008:977) and used by courtesy of the authors and Elsevier

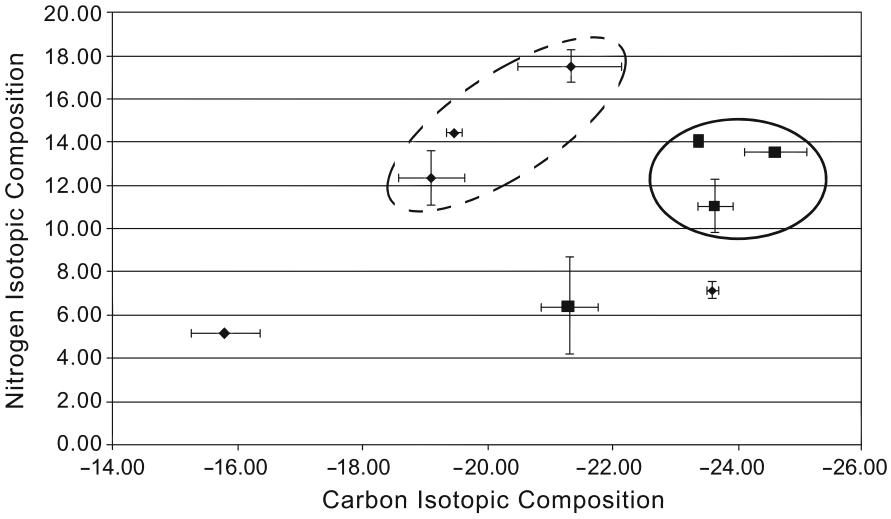

Fig. 5.14 The relationship between carbon and nitrogen isotopic compositions of the organic matter from control sediments, modern dung samples (*solid oval line*), and archaeological gray sediments (*dashed oval line*) at Atar Haroa (Israel). From Shahack-Gross and Finkelstein (2008:977) and used by courtesy of the authors and Elsevier

The gray sediments in the rooms originated from wood ash and dung; both of which were used as fuel. Gray sediments in the courtyard originated from degraded, unburned livestock dung. Evidence from phytoliths, as well as nitrogen and carbon isotopic compositions, supports the interpretation that the gray sediments originated in degraded livestock dung (Fig. 5.14; Shahack-Gross and Finkelstein 2008:977). Both the modern dung samples and archaeological gray sediments are different from the control sediments. Differences between the modern dung and the gray archaeological sediments may be evidence of differences in climate. Shahack-Gross and Finkelstein (2008) note that grinding stones were present but that sickle blades (evidence of farming) and arrow heads (evidence of weapons) were absent. They conclude that the compounds were domestic structures built by full-time nomadic pastoralists who processed grains (but did not harvest them), grazed their herds freely (but did not provide domesticated cereals as supplemental fodder), and used the compound as a livestock enclosure. Recognizing dung in archaeological sites has many other applications, such as identifying sites used by pastoralists and non-pastoralists, human and livestock diets, activity areas, site structures, herd management strategies, and secondary products (Shahack-Gross 2011).

Summary

Despite the brevity of this review, sediments, soils, and many other aspects of the physical world are vital to inferring human–environmental relationships from biological remains in the archaeological record. As the two applications show, studies of sediments and soils enhance interpretations of site formation processes, site organizations, and site functions critical to analyses of organic materials. Many of the methods and concepts basic to studies of sediments and soils are fundamental to studies of biological remains, as will be evident in the remaining chapters. Their study expands the interpretive potential of temporal, spatial, and behavioral evidence contained within both biotic and abiotic materials at site-specific, ecosystem, regional, and continental spatial scales; yielding more useful environmental and cultural insights than either can do alone. The important role of organisms in studies of sediments and soils becomes obvious in the following chapters.

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Chapter 6
Viruses, Bacteria, Archaea, Protists, and Fungi

Viruses, bacteria, archaea, protists, and fungi make up much of the biological world. Many of these are very small organisms known as **microorganisms**. Some are not organisms at all (e.g., viruses); others are not microscopic, though the parts recovered from archaeological sites may be small. Microorganisms are widespread and form the basis of food chains, contribute to nutrient cycling, and enhance soil fertility vital to the health of ecosystems. Some are restricted to specific habitats and are highly sensitive to changes in climates, water quality, and ecosystem processes. These provide direct and indirect information about environmental histories in aquatic and terrestrial landscapes of anthropogenic and non-anthropogenic origin. Some microorganisms have symbiotic or parasitic relationships with people or other organisms. Others are implicated in the deterioration of Paleolithic art at the Lascaux (Dordogne, France) and Altamira (Cantabria, Spain) caves, important World Heritage Sites (Saiz-Jimenez et al. 2011). Numerous species live in and on us, colonizing specific parts of the body and known collectively as a **microbiome**. Pennisi (2010) reports that 9 out of 10 cells in our bodies are members of this microbiome and that our own gastrointestinal system contains as many as 1,000 species.

Microorganisms provide information about the production and consumption of goods and services, residential patterns, and the health of people and the organisms upon which people depend. Some are consumed directly, but many more are used in products such as breads, fermented beverages, drugs, and dairy products. Others are ingredients in raw materials or are important in the manufacture of ceramic objects, leathers, dyes, and other products. Diseases associated with some of these organisms have been important in the evolution of our species, traveling the globe with us and influencing the course of their histories and ours. Such associations enable us to elaborate upon diseases, disease vectors, trade routes, migratory paths, waste management, sanitation, hygiene, and long-term relationships among people, domestic plants, and domestic animals.

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Nomenclature

The taxonomic classification of these organisms is in a state of flux as their evolutionary relationships, their affiliations with other organisms, and distinctions among them are explored (Tables 6.1 and 6.2; Campbell et al. 2008:Appendix E). Although many continue to elude direct archaeological study, their role in human history, in many cases, is profound and all archaeological interpretations should bear these organisms in mind.

Viruses

Although not, technically speaking organisms, many viruses cause diseases because they are, of necessity, parasitic. It is these that are most likely to come to our attention because of their roles in human affairs. The viral genome is encased in a protein coat (**capsid**) that may assume rod-like, polyhedral, or other shapes (Campbell et al. 2008:383). They may be referred to as RNA or DNA viruses depending upon which nucleic acid forms their genomes.

Prokaryotes: Bacteria and Archaea

Bacteria are the smallest organisms with a definite cellular structure. They are single-celled organisms that lack nuclei and mitochondria, but they are otherwise chemically and physiologically diverse (Campbell et al. 2008:568–569; Krogh 2009:397–403). Some bacteria decompose organic material in soils, thereby making nutrients available to other organisms. One of the attributes used to classify bacteria is their response to gram staining, a procedure that exposes them to dyes and iodine (Campbell et al. 2008:557). Some bacteria are **gram positive** (producing a deep violet color) or **gram negative** (producing a red color). Gram-positive bacteria have simpler cell walls and larger amounts of **peptidoglycan**, a material unique to bacterial cell walls, compared with gram-negative bacteria, whose cell walls are more complex and contain less peptidoglycan. Some bacteria form dormant, non-reproductive, cells (**endospores**) that resist chemical and physical decay and extreme temperatures. These can be viable for centuries, resuming growth when conditions improve (Campbell et al. 2008:560). **Rickettsiae** are small bacteria-like pathogens of some arthropods (e.g., fleas, lice, mites, ticks). They have lost much of their independence and require host cells for survival (Barnes 2005:18). Although generally they do not harm their hosts, they can cause disease in some animals, including people.

Archaea are highly diverse and their affiliations are poorly known (Campbell et al. 2008:566–567; Krogh 2009:403–405). Some archaea are classified in terms of

Table 6.1 Classification of some prokaryotes and protists[a]

Category	Examples
Domain Bacteria	Prokaryotes
Proteobacteria (gram-negative)	Alpha proteobacteria
	Beta proteobacteria
	Gamma proteobacteria
	Delta proteobacteria
	Epsilon proteobacteria
Gram-positive bacteria	*Bacillus anthracis*, *Clostridium botulinum*, *Staphylococcus*, *Streptococcus*
Cyanobacteria	Blue-green algae
Spirochetes	*Treponema pallidum*, *Borrelia burgdorferi*
Chlamydia	*Chlamydia trachomatis*
Domain Archaea	Prokaryotes
Euryarchaeota	Extreme thermophiles
	Extreme halophiles
	Methanogens, anaerobes
Crenarchaeota	Most thermophiles
Domain Eukarya, Protists	
Excavata	Diplomonadida, *Giardia lamblia*
	Parabasala, *Trichomonas vaginalis*
	Euglenozoa, Euglenophyta, *Euglena* spp., Kinetoplastida, *Trypanosoma* spp.
Chromaloveolata	Alveolata
	Dinoflagellata, dinoflagellates, *Karenia brevis*
	Apicomplexa, *Plasmodium* spp.
	Ciliophora, *Paramecium* spp.
	Stramenopilia
	Bacillariophyta, diatoms
	Chrysophyta, golden algae
	Phaeophyta, brown algae, *Laminaria*
	Oomycota, water molds, *Phytophthora infestans*
Rhizaria	Granuloreticulosa, foraminifera
	Actinopoda, radiolaria, radiolarians
Archaeplastidae	Rhodophyta, red algae, *Porphyra*
	Chlorophyta, green algae
Unikonta	Amoebozoa
	Myxogastrida, plasmodial slime molds
	Dictyostelida, cellular slime molds
	Gymnamoeba, *Amoeba*
	Entamoeba, *Entamoeba histolytica*

[a]Following Campbell et al. (2008:568–569, 578–579, Appendix E). In some algal nomenclatures, **-phyta** indicates a division, **-phyceae** indicates a class, **-ales** indicates an order, and **-aceae** indicates a family. In reference to zooplankton, **-a** indicates a phylum, **-ea** indicates a class, **-ida** indicates an order, and **-idae** indicates a family (Tomas 1993:2, 4). For a different classification, see Brusca and Brusca (2003:123–124)

Table 6.2 Classification of some fungi[a]

Category	Examples
Chytridiomycota	Chytridiomycetes, chytrids, flagellated spores
Zygomycota	Zygomycetes, Trichomycetes, zygote fungi
Ascomycota	Ascomycetes, sac fungi, truffles, mushrooms
Basidiomycota	Basidiomycetes, club fungi, rusts, smuts, shelf fungi
Informal group	Imperfect fungi, Deuteromycetes

[a]Following Campbell et al. (2008:652, Appendix E), Carlile et al. (2001:397, Appendix 2), and Krogh (2009:422–424). Molds, yeasts, and mycorrhizae are specialized forms found in several fungal phyla and are not taxonomic categories. In fungal nomenclature, **-mycota** indicates a phylum and **-mycetes** indicates a class (Carlile et al. 2001:13)

the environments they occupy: **thermophiles** live in extremely hot conditions; **halophiles** in extremely saline conditions; and **methanogens** or **anaerobes** where there is little or no oxygen. Although archaea may be the only organisms in extreme environments, they are found in many habitats, including the human digestive system (Krogh 2009:404–405). Some anaerobic archaea produce methane, a greenhouse gas, as a metabolic byproduct, and other archaea are involved in **nitrogen fixation**, a process by which atmospheric nitrogen is transformed into nitrogen-containing organic compounds (Krogh 2009:414).

Some prokaryotes are classified by their shapes (Fig. 6.1; Campbell et al. 2008:557; Thain and Hickman 2004:67). These shapes may be part of the organism's scientific name: **coccus** for spherical (plural: cocci), **bacillus** for rod-like (plural: bacilli), or **spirochete** and **spirilla** for helical shapes, for example. Spherical prokaryotes occur singly (cocci), as clusters (**staphylococci**), in pairs (**diplococci**), or in chains (**streptococci**). Rods also appear singly or in chains. Some prokaryotes have a "slime" layer (**capsule**) that prevents the organism from drying out, protects against host defenses, and binds individual cells into colonies (Campbell et al. 2008:558).

The Protists

The phylogeny of the former Kingdom Protista is unclear and its members are now divided into several kingdoms, though these organisms continue to be referred to informally as protists to distinguish them from other eukaryotes. There is little agreement concerning the taxonomic affiliations of these organisms (compare Brusca and Brusca 2003:121–178; Campbell et al. 2008:578; Krogh 2009:405–407). The external surface of protists may be protected by organic, calcified, or silicified scales, spines, and other structures (Throndsen 1993). Mobile protists use slender extensions such as cilia and flagella or pseudopodia to move (Campbell et al. 2008:579; Krogh 2009:408–411). **Cilia** (singular: cilium) are relatively short compared with the longer, whip-like **flagella** (singular: flagellum). **Pseudopodia** (singular: pseudopodium) are referred to as "false feet."

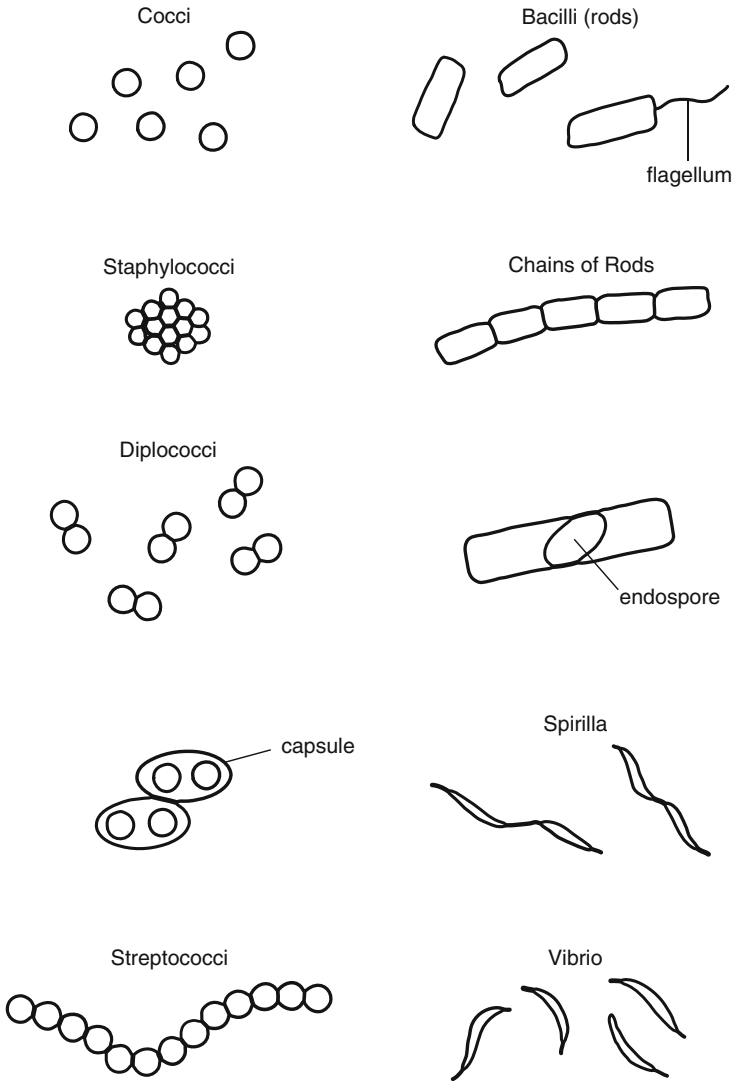

Fig. 6.1 Some bacterial forms. Terminology from Thain and Hickman (2004:67)

Protists currently classified by some as Excavata share few characteristics and are found in freshwater, marine, and terrestrial settings. Several members of this group are responsible for serious diseases in human beings. These include *Giardia intestinalis* (also known as *Giardia lamblia*), a parasite that inhabits the intestines of mammals, and *Trypanosoma*, which causes sleeping sickness and Chagas' disease (Campbell et al. 2008:580–581).

Chromalveolates are protists that are generally photosynthesizing organisms, including dinoflagellates, diatoms, golden algae, and brown algae (Campbell et al.

2008:579; Krogh 2009:407–408). These protists are widespread and abundant in oceans and many are highly sensitive to environmental variables. Most living dinoflagellates are photosynthetic, unicellular algae with two flagella (Brusca and Brusca 2003:149). Diatoms are aquatic, unicellular algae, some of which can live in damp terrestrial settings. Golden algae also have a variety of forms and growth habits. Brown algae include sea kelps (Laminariales), some of which form massive submarine forests that can reach up to 60 m in height (Campbell et al. 2008:586).

Some of these algae produce calcareous nannofossils known as coccoliths (Heimdal 1993; Wilkinson et al. 2008). **Coccoliths** are the calcite **tests** (plates, shells, scales) produced by planktonic algae, sometimes called coccolithophores. The "White cliffs" of Dover (UK) are soft, white limestones (chalk) consisting primarily of coccoliths. **Nannoliths** are associated with coccoliths and the two groups are referred to jointly as nannofossils, though their biological affinity is unclear (Wilkinson et al. 2008). Calcite plates produced by nannoliths are less than 20 μm in size.

Rhizarians include two marine groups often studied by environmental archaeologists: radiolarians and foraminifera. Radiolarians (or Polycystina) are mobile planktonic organisms with symmetrical, fused glassy silica shells perforated by pores through which project slender radiating spines (**axopodia**) used in locomotion and feeding (Brusca and Brusca 2003:161–163; Campbell et al. 2008:589–590; Thain and Hickman 2004:599). Radiolaria engulf food through these spines. Large quantities of their silica shells have accumulated on the sea floor. Foraminifera (informally known as **forams**; Granuloreticulosa) are multi-chambered protists with pseudopodia. The tests of forams can be common in exposed sediments of marine origin.

Archaeplastida include red and green algae, which are closely related to terrestrial plants (Campbell et al. 2008:590–592). The cell walls of some green algae contain sporopollenin (Traverse 2008:58–59).

Unikonta are highly variable organisms. Slime molds or mycetozoans are protists formerly classified as fungi (Campbell et al. 2008:593–596; Krogh 2009:411–412). The presence of **cellulose** (a complex carbohydrate) in the walls of slime molds (Myxogastrida) and water molds (Oomycota) distinguishes them from fungi, however (Carlile et al. 2001:12–13, 100). Most are sessile, though some have limited mobility. A plasmodial slime mold may form a mass several centimeters in diameter containing many nuclei within one cell. Cellular slime molds also form masses, but the mass consists of many individual cells. Slime molds are heterotrophs; they live on decomposing leaf litter and other organic refuse. The fungus-like protist *Phytophthora infestans* is the pathogen responsible for late blight in white potatoes (*Solanum tuberosum*) and devastating crop failures in the nineteenth century CE (Carlile et al. 2001:31, 420).

Amoebas and entamoebas are classified as Unikonta by Campbell et al. (2008:578), but Brusca and Brusca (2003:155) classify them as Rhizopoda. A distinction is made between naked amoebas and testate amoebas; **testate amoebas** have plasma membranes covered by a test (Brusca and Brusca 2003:157). Testate amoebas form cysts in unfavorable conditions, as do some other amoebas (Brusca and Brusca 2003:157). *Entamoeba histolytica*, associated with amoebic dysentery,

and *Escherichia coli*, a commensal amoeba in the human large intestine, usually are ingested by people as cysts (Brusca and Brusca 2003:157, 160).

Protists include a catch-all category: acritarch. **Acritarchs** are generally unicellular and are presumed to be algae, but their biological affinity is unknown (Traverse 2008:58, 670). At one time, dinoflagellate cysts and what are now called acritarchs were referred to as **hystrichosphaerids**, a term that lacks taxonomic status but was used until the mid-1960s (Traverse 2008:334, 683).

Fungi

Fungi are heterotrophic eukaryotes (Table 6.2; Brodie 1978; Campbell et al. 2008:636–637, 642, 652; Carlile et al. 2001:3–5, 397; Krogh 2009:419). They obtain nutrients by absorption either as saprophytes feeding on non-living matter or as parasites on organisms. Nutrients are absorbed through **hyphae** (tube-like branching filaments that form the body of the fungus; singular: hypha); they also share chemical information through hyphae (Fig. 6.2; Campbell et al. 2008:637). Hyphae intertwine beneath the ground into webs called **mycelia** (singular: mycelium; Krogh 2009:418). Mycelia can be very large. One is reported to be over 965 ha in size and at least 1,900 years old (Campbell et al. 2008:636). Hyphae in Ascomycota and Basidiomycota form spore-bearing structures known as **fruiting bodies**. When expanding toward a food source or forming a fruiting body, hyphae grow quickly. Spores, fruiting bodies, and hyphae of some fungi contain chitin identical to that of insects and other arthropods (Campbell et al. 2008:637).

Fungal spores are reproductive structures that are very different from the spores of embryo-producing (**embryophytic**) plants (Chap. 7). Fungal spores are produced in specialized structures (**sporosphores**; Carlile et al. 2001:548). Some spores are produced sexually (zygospores, ascospores, basidiospores); others are produced asexually (singular: **conidium**; plural: conidia; Carlile et al. 2001:12–14, 44, 53; Krogh 2009:422). Fungal spores have two major functions: survival during dormancy (e.g., cysts, resting spores) and dispersal (Carlile et al. 2001:187). Dispersal spores separate from the parent mycelium; survival spores often do not. Fungi may produce different types of spores for each role. Spores may be protected by sporopollenin, which enhances their survival (Carlile et al. 2001:234).

Some authorities divide fungi into five phyla (Campbell et al. 2008:652). One of these, Chytridiomycota, includes mainly aquatic saprophytic or parasitic fungi whose mobile spores (**zoospores**) swim using flagella (Carlile et al. 2001:12, 32–38, 225, 229; Krogh 2009:422–424). Some may be terrestrial and others occupy the essentially anoxic rumen of animals such as sheep (*Ovis aries*) and cattle (*Bos*), where they aid in the digestion of plant biomass (Carlile et al. 2001:37–38). One parasitic species, *Batrachochytrium dendrobatidis*, may be involved in the world-wide amphibian decline that began in the late twentieth century CE (Carlile et al. 2001:153).

Zygomycota, or zygote fungi, are primarily terrestrial saprophytes or parasites (Carlile et al. 2001:38–39). Some form hyphae that grow into the roots of plants

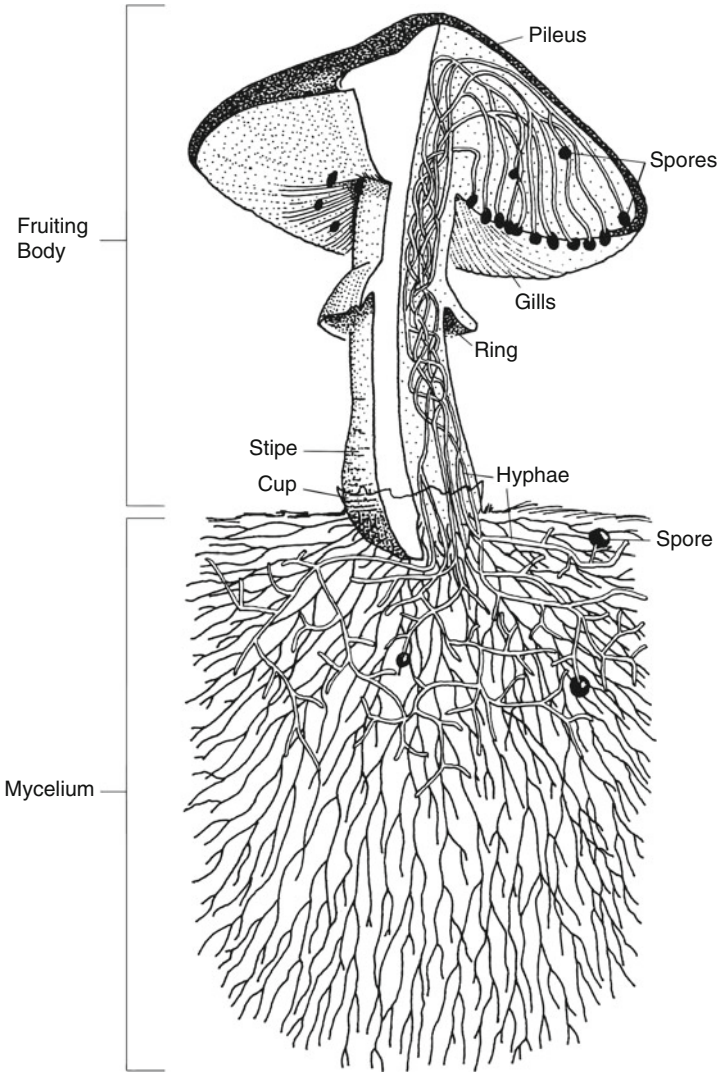

Fig. 6.2 Mycelium and fruiting body of a mushroom

(**mycorrhizae**; Krogh 2009:427). Many plants have symbiotic relationships with mycorrhizal fungi. The familiar black bread mold (*Rhizopus stolonifer*) is a zygote fungus whose mycelium grows on the bread's surface (Campbell et al. 2008:463). Zygote fungi bear their **zygospores** (resting spores) in **zygosporangia**, whose thick walls may protect the dormant structure within for months (Campbell et al. 2008:643). These fungal "zygotes" are multi-nucleate structures unlike **zygotes** (fertilized eggs) of plants and animals.

Ascomycota are likely to protect spores, hyphae, and other materials with chitin, and consequently are identified more frequently in archaeological deposits than are other fungi (Carlile et al. 2001:44). Ascomycota are parasitic, saprophytic, or lichen-forming species that occupy aquatic and terrestrial habitats. Some are unicellular, others multicellular. Some form sexual spores (**ascospores**) within fruiting bodies (**ascocarps**) that contain spore-forming sacs (singular: **ascus**; plural: asci; Carlile et al. 2001:44–46). Ascomycota also reproduce asexually, producing conidia.

Ascomycota are important archaeologically for many reasons. They include molds and powdery mildews that are significant plant parasites. Food-spoiling molds such as ergot of rye (*Claviceps purpurea* on *Secale cereale*) were recognized by the Greeks and Romans (Carlile et al. 2001:54; Krogh 2009:425). Ergot of rye produces gangrene and causes death if ingested in large quantities along with its cereal host; however, infected plants can be used to control hemorrhage. *Aspergillus oryzae* is used in the production of soy paste, saki, and antibiotics, though other members of this genus (e.g., *Aspergillus flavus*, *Aspergillus parasiticus*) produce aflatoxins and are potent carcinogens (Carlile et al. 2001:440, 503). Others cause skin lesions and ulcers. Some species of *Penicillium* are involved in cheese production (e.g., *Penicillium camemberti*, *Penicillium roqueforti*) and others produce antibiotics and other medicines (Carlile et al. 2001:502–505, 515–520). Morels are Ascomycota. Truffles (*Tuber melanosporum*) are subterranean ascocarps associated with trees such as oaks (*Quercus*) and beeches (*Fagus*), and are detected by pigs (*Sus domesticus*) and dogs (*Canis familiaris*) trained to recognize their characteristic odor (Carlile et al. 2001:50).

Basidiomycota have elaborate fruiting bodies known as **basidiocarps**, external structures within which **basidospores** are produced sexually (Campbell et al. 2008:647; Carlile et al. 2001:57). This phylum includes mushrooms, puffballs, and bracket or shelf fungi, many of which are saprophytic. It also includes rusts and smuts that are similar to Ascomycota. Some have mycorrhizae that form a mantle on the outside of the roots of plants. Both Basidiomycota and Ascomycota have **septa** (partitions, cross-walls) dividing the hyphae into compartments, but Basidiomycota are distinguished by their club-shaped **basidia** (singular: basidium), a transient reproductive stage within basidiocarps. A mushroom is a basidiomycete with a fruiting body differentiated into **pileus** (cap), **stipe** (stalk), and **gills** (**lamellae**, thin plates; Fig. 6.2; Shackley 1981:51). Basidia line the gills and forcibly discharge basidiospores when mature. The fruiting bodies of puffballs (Lycoperdales) originate like those of mushrooms, and differentiate structurally as basidia and basidiospores, but they remain enclosed until maturity. Puffballs may be edible before the spores form (e.g., Watling and Seaward 1976). Smuts are important plant pathogens; however, galls formed on maize (*Zea mays*) kernels by the maize smut (*Ustilago maydis*) are eaten as a traditional Mexican delicacy, huitlacoche (Carlile et al. 2001:66). Rusts are obligate plant parasites that often need two different hosts to complete their life cycles, and may produce up to five different types of spores. *Puccinia graminis*, the black stem rust of wheat, interferes with the normal growth of grasses (Carlile et al. 2001:68).

Yeasts, molds (or moulds), and lichens are no longer considered systematic groups despite their continued use in English vernacular taxonomy. Although most fungi are multicellular, **yeasts** normally are unicellular and do not have hyphae (Campbell et al. 2008:637, 640; Carlile et al. 2001:14; Krogh 2009:424). Yeasts are round, small (ca. 4 μm), and reproduce asexually by budding. Three of the four phyla of fungi contain some unicellular members, that is, yeasts. True yeasts are ascomycetes, one of the most familiar of which is *Saccharomyces cerevisiae*, used to raise bread dough and ferment beverages (Carlile et al. 2001:72–73, 482–492, 500–502). **Molds** are generally multicellular and reproduce asexually (Campbell et al. 2008:639–640). The term "mold" applies only to the asexual reproductive stage. At a later stage in development, these same fungi may reproduce sexually. The hyphae of molds may be 3–400 μm long (Carlile et al. 2001:85). **Lichens** are symbiotic composites of a fungus and a photosynthesizing protist (a green alga) or a bacterium (cyanobacterium; Campbell et al. 2008:649–650; Krogh 2009:426; Thain and Hickman 2004:406). The fungus is usually the dominant organism and is often an ascomycete. Lichens are characterized by fungal hyphae that form two layers. Between these layers is a loose array of fungal hyphae within which algae are located. Lichens may be **epiphytes**, attached to a plant for support but not parasitic on that plant.

Fungi Imperfecti (Mitosporic Fungi) is an informal group of fungi for which only asexual reproduction is known (Carlile et al. 2001:69). When a sexual stage is discovered for one of these species, it is reclassified into one of the other phyla (Campbell et al. 2008:640). These often are imperfect states of Chytridiomycota and Ascomycota. Some produce diseases such as tinea diseases (e.g., ringworm, athlete's foot; Carlile et al. 2001:437). Others are sources of antibiotics or serve other useful purposes.

Parasitism

Parasites obtain nutrients from living hosts, benefiting to the detriment of the host (Odum and Barrett 2005:283). **Endoparasites** (internal), **mesoparasites** (living in a body cavity with direct external access, such as the nose), and **ectoparasites** (external) yield insights into the range, movement, and antiquity of people, crops, livestock, pests, and diseases, as well as into climates and other environmental features. When parasitism is directly related to specific environmental conditions, it is possible to extend present-day relationships among parasites, hosts, and vectors to infer by analogy similar relationships in the past (e.g., Reinhard 2008). Some human diseases originate in animals that live in close proximity to people, particularly domesticated animals, or are associated with sedentism, urbanization, farming, and other cultural innovations (Barnes 2005:200; Ortner 2001; Waldron 2009:96). Some, such as influenza, pass back and forth between people and animals (Barnes 2005:345–349). As will be seen in other chapters, parasitism is not restricted to viruses, prokaryotes, protists, and fungi (Chap. 10).

Hosts are organisms that support parasitic symbionts during all or part of the parasite's life cycle. A **definitive** or **primary host** serves during the sexual reproduction stage (in those parasites that reproduce sexually), after which eggs are transferred to an intermediate host for larvae to develop further. **Intermediate hosts** house one or more larval stages until the parasite is transferred to the definitive host, where the cycle begins anew. In some forms of parasitism, a free-living larval stage precedes a parasitic adult stage (e.g., hookworms [*Necator americanus*, *Ancylostoma duodenale*] in humans). Sometimes the pathogen lives within the host but the host does not become sick (e.g., most staphylococcal and streptococcal bacteria). In such cases, the unaffected host may unwittingly infect other members of its species. If the organism must infect animals to complete its life cycle, it is considered an **obligate parasite**; **facultative parasites** can complete their life cycles as either free-living organisms or as parasites.

Hosts also support non-parasitic, commensal or mutualistic symbionts that cause no illness. Optimum conditions, such as those in the human intestines, permit massive numbers of bacteria to live without killing or sickening either their hosts or their fellow bacteria. It may be difficult to distinguish such commensal or mutualistic organisms from parasites, especially if the parasite does not make the host sick.

Many parasites are sessile or have limited mobility. If they require more than one host to complete their life cycles, vectors are used. **Vectors** transmit individual parasites or **propagules** (dispersive reproductive structures such as spores or ova; Thain and Hickman 2004:579) from one place to another. Transmission by vectors increases the likelihood that parasites will find new, favorable habitats in which to continue their life cycles. The vector may serve simply as a carrying agent, or it may have a physiological or pathological association with transported individuals or propagules. Many insect-borne parasites do not harm their vectors and some organisms are both hosts and vectors (e.g., Barnes 2005:33–37).

Transmission may be sexual, or via air, blood, feces, water, and direct contact with infected organisms. Airborne infection is the means by which viruses that cause mumps (RNA Paramyxoviruses) and measles (RNA Morbillivirus) spread. Endospores of anthrax bacteria (*Bacillus anthracis*) generally are dispersed via wind and rain, as well as on the hair and skin of infected animals, causing disease when inhaled. When a disease is transmitted directly or indirectly to a person from another animal, it is referred to as a **zoonosis** (Barnes 2005:137–138). If a pathogen that usually is considered zoonotic in humans develops the ability to be transmitted from person to person, it is no longer a zoonosis.

The number of propagules produced is related to the mode of transmission. Airborne pathogens may release millions of propagules to increase the chances of successful transmission. If the microorganism uses a specific vector, then fewer propagules are produced. Parasites relying on insects or airborne seeds for dispersal, for example, produce fewer propagules than do airborne parasites without a vector. Instead of relying on numerical superiority, other species reduce dispersal risks by having a stage in their life cycle during which most or all individuals are inert.

Some parasitic organisms are confined to specific hosts or vectors but others use more than one vector and may infect a variety of organisms. The plague bacillus

(*Yersinia pestis*) is transmitted by fleas that use black rats (*Rattus rattus*) as hosts but the bacillus also uses brown or Norway rats (*Rattus norvegicus*) and other wild rodents, as well as becoming airborne (Barnes 2005:240–241, 247). More than 200 flea species can transmit plague bacteria (Barnes 2005:241).

Examples of more complex cycles are found in many organisms. *Plasmodium falciparum*, the protist responsible for malaria, needs both human and mosquito hosts (members of the genus *Anopheles*) to complete its life cycle (Brusca and Brusca 2003:149). In Africa, yellow fever is caused by a virus (RNA Flavivirus) that primarily is passed to primates by the mosquito *Aedes aegypti*. Historically, the mosquito *A. aegypti* acquired it from the mosquito *Aedes africanus*, whose primary hosts are wild monkeys (Barnes 2005:300–303). When *A. aegypti* brought the yellow fever virus to the Americas, the virus infected the indigenous *Haemagogus* mosquito and Central and South American monkeys. The virus is not harmful to African monkeys, but it causes serious illness in some American monkeys.

Some diseases are acute and kill the host relatively quickly; others are chronic. **Acute diseases** kill large numbers of individuals but are difficult to identify in the archaeological record using traditional studies of skeletal and dental morphology because infected individuals die quickly. When death is sudden, skeletal and dental systems do not have time to develop anomalies that might indicate the presence of a disease (Waldron 2009:84). A parasite that causes acute diseases creates a crisis for itself because it needs to find a new host to continue its life cycle; therefore, relatively large, dense host populations are required. Acute diseases are often spread as **epidemics** (large-scale, sporadic illnesses that leave survivors immune). With **chronic diseases** the infected host lives for an extended period of time. An immune response may result in the pathogen's death rather than the death of the host. Chronic diseases are progressive diseases of long duration and are more likely to be recorded in skeletal and dental remains because the infected host lives with the disease for years. Chronic diseases are often **endemic** (continually present in a specific region). Endemic diseases do not require large, dense host and vector populations. Many acute diseases are associated with urbanization, irrigation, and farming, whereas many endemic diseases are characteristic of smaller, more dispersed populations.

General Field and Laboratory Considerations

It is unlikely that viruses, prokaryotes, protists, and fungi will be observed using common field and laboratory techniques, but they can be found in soil or pinch samples collected from contexts that might contain cysts, spores, hyphae, and similar evidence. The likelihood that remains of these organisms will be recovered is higher in palaeofeces, gut contents of well-preserved hosts, such as mummies and bog bodies, and in materials recovered from stable anoxic, frozen, or very dry settings. Their study relies on recovering hard tissues, antigens, cultures, and genetic evidence. The most direct evidence is derived from anatomical and morphological features of calcareous, siliceous, phosphatic, or organic (e.g., chitin) remains of

dinoflagellates, diatoms, nannofossils, radiolaria, foraminifera, and fungi. Many of these organisms are microscopic, thus great care must be exercised to recover them, and to avoid contamination with modern members of these same groups.

Immunological studies, particularly when combined with other microbiological studies and archaeogenetics, provide direct evidence of pathogens (e.g., Bianucci et al. 2009; Mitchell et al. 2008). **Antigens**, generally proteins or **glycoproteins** (proteins associated with a sugar residue; Thain and Hickman 2004:309), elicit an immune response in the host and the production of antibodies. The presence of an antibody indirectly suggests exposure to the pathogen. **Cultures** are organisms grown in a nutrient medium such as **agar**, a gel obtained from seaweed. Direct culturing grows thousands or millions of individuals. A pure (**axenic**) culture grows one organism in an environment free of other organisms. **Mixed cultures** are composed of two or more kinds of organisms. Organisms are usually grown as colonies, rather than as individuals. Viruses and rickettsias require a **tissue culture** (living host medium). Increasingly many microorganisms are identified through **archaeogenetics** (biomolecular or genetic applications to archaeological materials) and **biomarkers** (organic compounds linked to specific organisms; Gaines et al. 2009). Archaeological evidence for viral and bacterial infections is sought in DNA and RNA extracted from skeletal and dental materials (Aufderheide et al. 2004; Waldron 2009:82), though not always successfully (e.g., Hunnius et al. 2007).

Indirect evidence is useful though it may be ambiguous and cannot be used with the same confidence as direct identification of the organism. For example, identification of a specific vector provides indirect evidence for the presence of parasites associated with it. When remains of the plague-bearing black rat are found in archaeological deposits, or when an outbreak of plague is recorded in artistic, historical, or similar sources, the existence of the plague bacillus may be inferred. One of the reasons Bianucci et al. (2009) sought evidence of plague in human burials from Poitiers and La Chaize-le-Vicomte (France) is that lime was found with the burials, a mortuary practice associated with plague victims. In some cases, human skeletal remains bear evidence of non-specific infections associated with specific microorganisms (e.g., osteomyelitis with *Staphylococcus aureus*, *E. coli*, and *Salmonella typhi*) or characteristic of specific diseases (e.g., some treponemal infections, leprosy, tuberculosis; Bendrey et al. 2008; Larsen 1997:83–84; Rubini and Zaio 2009; Waldron 2009:83–117).

Viruses

Viruses are transported by air, water, and animal vectors (Barnes 2005:16–18). They parasitize all organisms, including bacteria and protists. Chickenpox (*Herpes* spp.), poliomyelitis (RNA Enterovirus), rubella (*Rubivirus*), and colds (rhinoviruses) are all caused by viruses (Barnes 2005). Some viral diseases, such as rabies (RNA Rhabdovirus) and influenza, infect both people and animals that live in close proximity to people (Barnes 2005:345). In other cases, human viruses infect other

animals. The airborne viruses (RNA Morbillivirus) that cause rinderpest in cattle, distemper in dogs, and measles in people are very similar and have a common ancestor (Barnes 2005:139, 191–193). Horses (*Equus caballus*) are natural reservoirs for rhinoviruses; likewise, mumps in people and Newcastle disease in domestic poultry are similar (Barnes 2005:193, 199).

Viruses themselves are difficult to identify in archaeological contexts. Most vertebrates respond at the cellular and molecular level to infection, and may die (or recover) before skeletal and dental systems respond to the infection. Although DNA and RNA analyses of archaeological materials provide direct evidence of viral diseases heretofore unavailable, the presence of most viruses generally continues to be inferred from indirect evidence (e.g., Barnes 2005:193). For example, three mummified bodies of individuals who died in Egypt ca. 1570–1085 BCE have lesions and other pathologies symptomatic of smallpox (Barnes 2005:227). Human skeletons from Corinth (Greece) bear signs of asymmetry suggesting that some limbs were paralyzed, which may be evidence of polio in the thirteenth century CE (Barnes 2005:360; Waldron 2009:109).

Viral infections had major demographic and historical consequences after CE 1492 (e.g., Crosby 1986). An epidemic of smallpox (*Variola virus*) raged in Mexico City after 1519 just as the Aztecs defended themselves from the Spanish invasion led by Hernando Cortés (McNeill 1976:183). Most Spaniards were immune to the disease, having survived it in their youth. The native population declined rapidly after the conquest. By 1568, the population of central Mexico was an estimated three million, about a tenth of its pre-Hispanic size. The disease progressed for another 50 years (McNeill 1976:180). The human population reached an estimated low of 1.6 million by 1620 and did not begin to recover for another 30 years, remaining low into the eighteenth century. It is unlikely that such a rapid population decline can be attributed entirely to warfare and smallpox, but these certainly were among the causes. The psychological implications of a disease that primarily killed native peoples and left Europeans unharmed were significant (e.g., Crosby 1986:250).

Bacteria

Detecting bacteria in archaeological deposits relies on cultures of species that can survive in a dormant state for long periods and on archaeogenetics (e.g., Kolman et al. 1999; Padden et al. 2000; Taylor et al. 2000; Zink et al. 2001). Otherwise, like viruses, they are inferred indirectly from vectors or hosts, or from pathologies observed in plant and animal remains. Some bacteria become part of the archaeological record through subsequent site formation processes and were not members of the original biota (e.g., Rollo et al. 2007). Some pathogenic bacteria may survive in dust, dirt, and occupational debris for a long time and still be capable of infecting new hosts. Bacterial DNA has been recovered from **dental calculus** (hardened accumulation of material at the base of teeth) adhering to the roots of incisors of human burials dated to between 4,000 and 5,000 years ago (Preus et al. 2011).

Pathogenic bacteria cause diseases as diverse as bubonic plague, anthrax (*B. anthracis*), botulism (*Clostridium botulinum*), cholera (*Vibrio cholerae*), diphtheria (Corynebacteria), whooping cough or pertussis (*Bordetella pertussis*), syphilis (*Treponema pallidum*), gonorrhea (*Neisseria gonorrhoeae*), dysentery (*Shigella dysenteriae*), leprosy *(Mycobacterium leprae*, also known as Hansen's disease), tuberculosis (*Mycobacterium tuberculosis* and *Mycobacterium bovis*), a form of pneumonia (*Haemophilus pneumoniae*), and tetanus (*Clostridium tetani*). The diseases associated with these and other bacteria bear a variety of vernacular names and produce a host of different symptoms. Yaws, for example, is a non-venereal form of treponemal infection (Barnes 2005:204). Treponemas and *Staphylococcus aureus* are among several infectious agents associated with osteomyelitis (e.g., Okumura and Eggers 2005). *Salmonella* cause both salmonella outbreaks and typhoid fever (Barnes 2005:287–291). Other staphylococcal and streptococcal bacteria are associated with impetigo, blood poisoning, food poisoning, strep throat, rheumatic fever, scarlet fever, childbed fever, and bacterial pneumonia (Barnes 2005:367–375). Some rickettsiae infect fleas that in turn infect wild rodents and other wild mammals (Barnes 2005:253). When rickettsiae are transmitted from rodents to people via fleas, they may cause illness. *Rickettsia* spp. causes a wild flea-borne typhus, for example. Rocky Mountain spotted fever is associated with a tick-borne rickettsia; other rickettsiae diseases are transmitted by mites and chiggers (Barnes 2005:262–267).

In some cases, people are not the preferred hosts or vectors, but may become hosts inadvertently. Bacteria responsible for cholera, for example, prefer saline waters for growth (Barnes 2005:280–281). These bacteria eat chitin, a constituent of the external skeleton of crustaceans such as crabs. When people eat undercooked or raw fish and shellfish, they consume these bacteria, which produce diarrhea, fecal contamination of local waters, and further contamination of fish, shellfish, drinking water, and foods rinsed with that water. This bacterium tolerates fresh water despite its preference for salt water and can remain dormant for years.

Domestic animals also serve as vectors for bacteria. One such relationship exists among *Toxoplasmosis gondii*, rodents, domestic cats (*Felis catus*), and people (Barnes 2005:141–142). Likewise, typhus can be transmitted by cats. Strains of the bacterium that cause tuberculosis are transmitted from voles (a small rodent) to cattle, and thence to people (Barnes 2005:159). The voles are not harmed, but both cattle and people become ill.

Some bacterial diseases leave evidence of their presence in skeletal remains. Tuberculosis produces lesions on human vertebrae and fingers (Larsen 1997:99–103; Ortner 2001; Waldron 2009:95). Lesions associated with tuberculosis indicate that the disease was present at two sites in southwestern Italy by 4000–3520 BCE, as were domestic cattle (Barnes 2005:168). Records written after 2000 BCE describe the disease in Asia. Skeletal remains throughout the Americas bear signs of the disease and tuberculosis DNA has been identified in a human vertebra from Chile dated to CE 1000 (Barnes 2005:169; Larsen 1997:100). Leprosy can leave skeletal evidence, particularly deformities in the skeletal elements of the face, hands, and feet (Larsen 1997:104–106). It is likely leprosy evolved in Africa and reached India

by ca. 2000 BCE when the Indus Civilization, Mesopotamia, and Egypt were part of a large trade network involving people, goods, and diseases (Robbins et al. 2009). It was present in northern Africa by the fourth century CE and in western Micronesia by the ninth century CE (Barnes 2005:181). Documentary evidence and DNA from skeletons reinforce the interpretation of some pathologies as leprosy. Some treponemal infections produce characteristic deformities in the skeletal system (Barnes 2005:216–217; Larsen 1997:93–99; Waldron 2009:105–108). In many cases, it is difficult to ascribe a specific cause to a pathology in an archaeological specimen because there may be concurrent conditions or the pathology cannot be conclusively attributed to a specific disease (e.g., Buckley and Tayles 2003).

An excellent example of a bacterium identified indirectly through its vector is the plague bacillus *Y. pestis*, whose presence is inferred from the presence of susceptible rodents. This bacillus normally uses fleas as vectors and rodents as hosts, only occasionally infecting humans. It has a stable pattern of infection and recovery in most wild rodents; but black and Norway rats generally die from the disease (Barnes 2005:241–242). The bacterium may be lethal when it infects a previously unexposed (**naive**) rodent population, or a human population. On the basis of historical accounts, it is estimated that nearly a third of the European human population died between CE 1346 and 1350 as a result of the bubonic plague caused by *Y. pestis* (McNeill 1976:147). Even if this mortality estimate is too high, this is clearly a lethal organism for people. Plague continues to be endemic in rodents.

Some bacteria, of course, do not cause disease but do provide insights into other aspects of the past. For example, magnetic bacteria may be used to date environmental change (Linford et al. 2005). The combined presence of dyer's woad (*Isatis tinctoria*), other dye-producing plants, and endospores of the indigo-reducing bacterium (*Clostridium isatidis*) suggests to Padden et al. (2000) that some tenth-century CE Anglo-Scandinavian deposits at York (UK) were waste from Viking dye vats. Other bacteria play important roles in nitrogen recycling. They are particularly active in nitrogen fixation in the roots of leguminous plants (e.g., alfalfa [*Medicago sativa*], clovers [*Trifolium*], peanuts [*Arachis hypogaea*]; Thain and Hickman 2004:490–491). Others are important as sources of antibiotics. A commensal bacterium, *Staphylococcus epidermis*, lives on our skin. Half of the contents of our colon and a quarter of our feces by weight may be bacteria, a relationship that is vital to our survival (Krogh 2009:401). One of these bacteria, *E. coli*, lives in both human and cattle digestive systems. When people ingest *E. coli* from cattle, however, people sicken (Barnes 2005:38, 295–297).

The Protists

Many protists, though not all, are aquatic and offer important details about aquatic environments because they are sensitive to salinity, water depth, temperature, and similar variables. Protists with hard tissues are more likely to be found in the archaeological record. These include organic-walled dinoflagellate cysts, siliceous diatoms and

radiolarians, and calcareous foraminifera and nannofossils (coccoliths, nannoliths; e.g., Traverse 2008:72; Wilkinson et al. 2008). Strictly marine forms become part of the archaeological record through marine sediments, as might happen, for example, when the clay or temper used in tile or ceramic vessels are from deposits with a marine history. Testate amoebae are among the most abundant protists in peat and are good indicators of the hydrology of such contexts because of their sensitivity to moisture (Barber and Langdon 2001). Some protists are responsible for diseases; for example, amoebic dysentery is caused by *E. histolytica* and *G. intestinalis* is associated with nausea, diarrhea, and vomiting when contaminated water is consumed (Campbell et al. 2008:580–581; Krogh 2009:409, 411).

Dinoflagellates

Dinoflagellates are distinguished from other protists by their cell coverings (**thecae**) and flagella. Dinoflagellates occupy a variety of aquatic settings, though they are more typical of marine waters than of brackish or fresh waters (Steidinger and Tangen 1996). Sediments of marine origin should contain a more abundant and diverse array of dinoflagellates than those of freshwater origin (Traverse 2008:541). Dinoflagellates may change appearance as they advance through their life cycle (Steidinger and Tangen 1996:411–416). During the mobile part of their life cycle, the cell walls of dinoflagellates are reinforced by organic plates composed of cellulose (Krogh 2009:502; Steidinger and Tangen 1996:388; Traverse 2008:333). During non-mobile parts of their life cycles, some dinoflagellate cysts (**dinocysts**) become thick walled and contain **dinosporin**, a durable substance similar to sporopollenin (Traverse 2008:327–345, 698). Some cysts contain calcium carbonate and these are less resistant to acidic conditions. Cysts may be identified to the level of genus or even attributed to a specific epithet (Traverse 2008:53). Some dinoflagellates produce neurotoxins and cause red tides that kill fish and make some fish and shellfish toxic (Campbell et al. 2008:582–583; Steidinger and Tangen 1996:389–390).

Diatoms

Although the remains of other algal groups are found in archaeological deposits (e.g., Cronberg 1986; Guilizzoni et al. 2002), diatoms are among those most frequently studied. These protists live in nearly all habitats that are at least occasionally wet (Stoermer and Smol 1999a:3). Species composition is related to sunlight (needed for photosynthesis), oxygen levels, temperature, pH, salinity, nutrients, and mineral content. These ecologically sensitive aquatic species are characteristic of the specific environmental conditions and sedimentary processes that prevailed when the sediment formed. The siliceous cell walls of diatom cells are generally

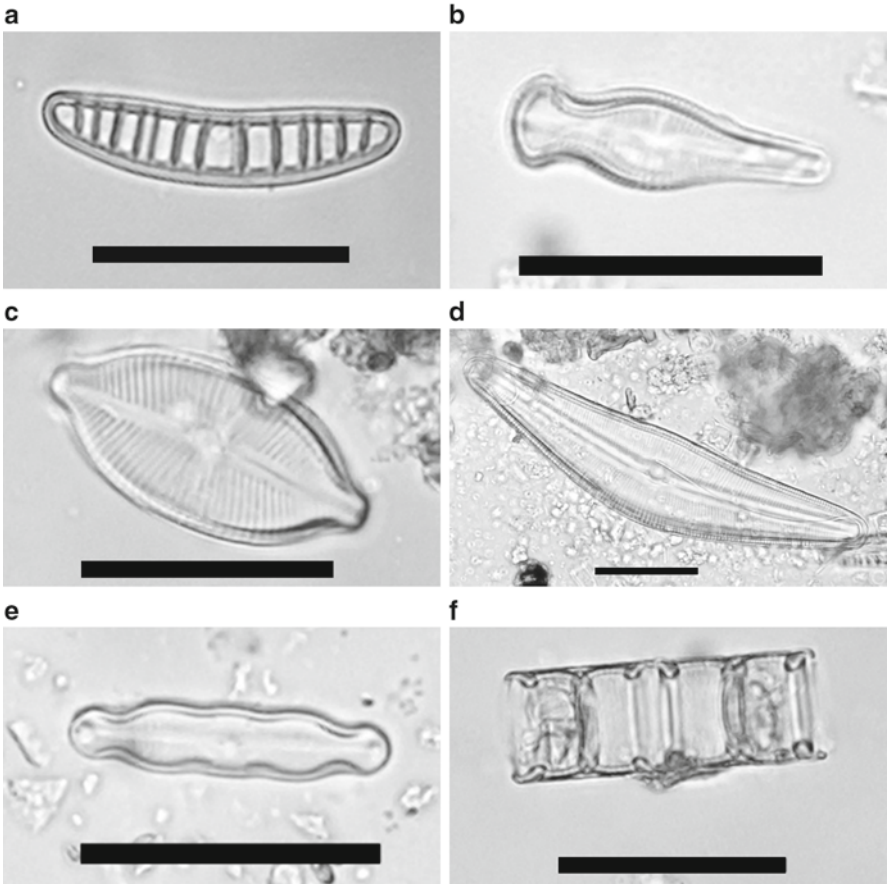

Fig. 6.3 Photomicrographs of diatom species recovered from a Viking Age farmstead in the Mosfell Valley (Iceland): (**a**) *Eipthemia* sp.; (**b**) *Gomphonema truncatum*; (**c**) *Navicula decussis*; (**d**) *Cymbella* sp.; (**e**) *Pinnularia mesolepta*.; and (**f**) *Melosira varians*. Scale is 100 μm. From Bathurst et al. (2010:2927) and used by courtesy of the authors and Elsevier

well preserved and, under favorable conditions, form massive diatomaceous deposits. Many of these formerly lacustrine and marine deposits are now terrestrial land forms and are mined for industrial applications as filtering agents, abrasives, and insulation. A **biofilm** is a concentration of diatoms in the upper 2 mm of sediments (Stoermer and Smol 1999b:452).

Diatoms absorb silica compounds from water to achieve many unique shapes (Fig. 6.3; Bathurst et al. 2010:2927; Branch et al. 2005:78; Hasle and Syvertsen 1996:7, 10; Trombold and Israde-Alcantara 2005). Silica forms cell walls (**frustules**) that are divided into two siliceous cases (**valves**) and may be connected by a girdle or band (**cingulum**). The upper **epivalve** (or **epitheca**) and the lower **hypovalve** (or **hypotheca**) overlap and are highly sculptured. The frustules of **centric**

diatoms are radially symmetrical and those of **pennate diatoms** are bilaterally symmetrical (Brusca and Brusca 2003:154; Hasle and Syvertsen 1996:24). Some pennate diatoms are flagellated, some have processes and struts, and others have a longitudinal groove (**raphe**) between the two valves.

Due to their environmental sensitivity, diatoms are key indicators of water quality and habitat types (Battarbee 1986; Faegri et al. 1989:203–205). The presence of similar diatom species in clays found over a large broad area can establish a shared regional depositional history. Correlations between a sequence of marine and freshwater diatoms and other depositional attributes can characterize flooding intensity and indicate changes in estuarine environments or river water quality, for example (e.g., Juggins and Cameron 1999). The valves of diatoms from brackish waters are thicker than those from fresh or marine waters because brackish water forms must resist a greater range in salinity and pH (Battarbee 1986). High pH values, however, may dissolve diatom valves, fragment specimens, and completely remove poorly silicified ones. In deposits containing both allochthonous and autochthonous materials, local diatoms may be distinguished from non-local ones because the local organisms may be represented by fewer broken specimens compared with non-local taxa.

Diatoms are present in archaeological materials for many reasons (Juggins and Cameron 1999). Diatomaceous earth is an important component of some archaeological materials, such as clays used in bricks, tiles, and ceramics, though the valves do not survive if the clay is fired at temperatures above ca. 1,400°C (Matiskainen and Alhonen 1984). The diatom content of clay may indicate the source of the clay. To use this relationship to provenance ceramic objects, it is important to know the origins of both the clay and the final product. The object may be locally made from non-local clays. This implies trade in raw materials rather than in finished products, or the finished product itself was imported. Imported clays and objects, though important as evidence for trade networks, indicate environmental conditions at the clay source, not where the objects were made or discarded. The presence of diatoms in non-aquatic settings, such as in soils from farming terraces, may be evidence of a flood or of intentional irrigation (Trombold and Israde-Alcantara 2005). Diatoms also become part of the archaeological site because they were transported there by wind and animals, including people (Hunt et al. 2007).

Unless the sample is from a ceramic vessel, tile, or similar object, the field sampling method used for diatomaceous sediments is similar to that for other sediment samples, with care taken to minimize contamination among strata. The silica of diatoms is destroyed by pollen extraction methods, but they can be extracted using laboratory methods modified for siliceous materials discussed in more detail in Chap. 9 (e.g., Battarbee 1986; Matiskainen and Alhonen 1984; Traverse 2008:2).

Diatoms are identified on the basis of size (5–2,000 μm), shape, surface morphology, and ornamentation of the frustule (Hasle and Syvertsen 1996:14–22). They are sampled for identification using a modification of the standard count approach used in other studies of small materials: identifying until a predetermined total count per preparation is reached. Often this number is 200; because diatoms usually are part of studies focused on pollen or phytoliths, the predetermined count may refer to the number of pollen grains and phytoliths and not to diatoms specifically.

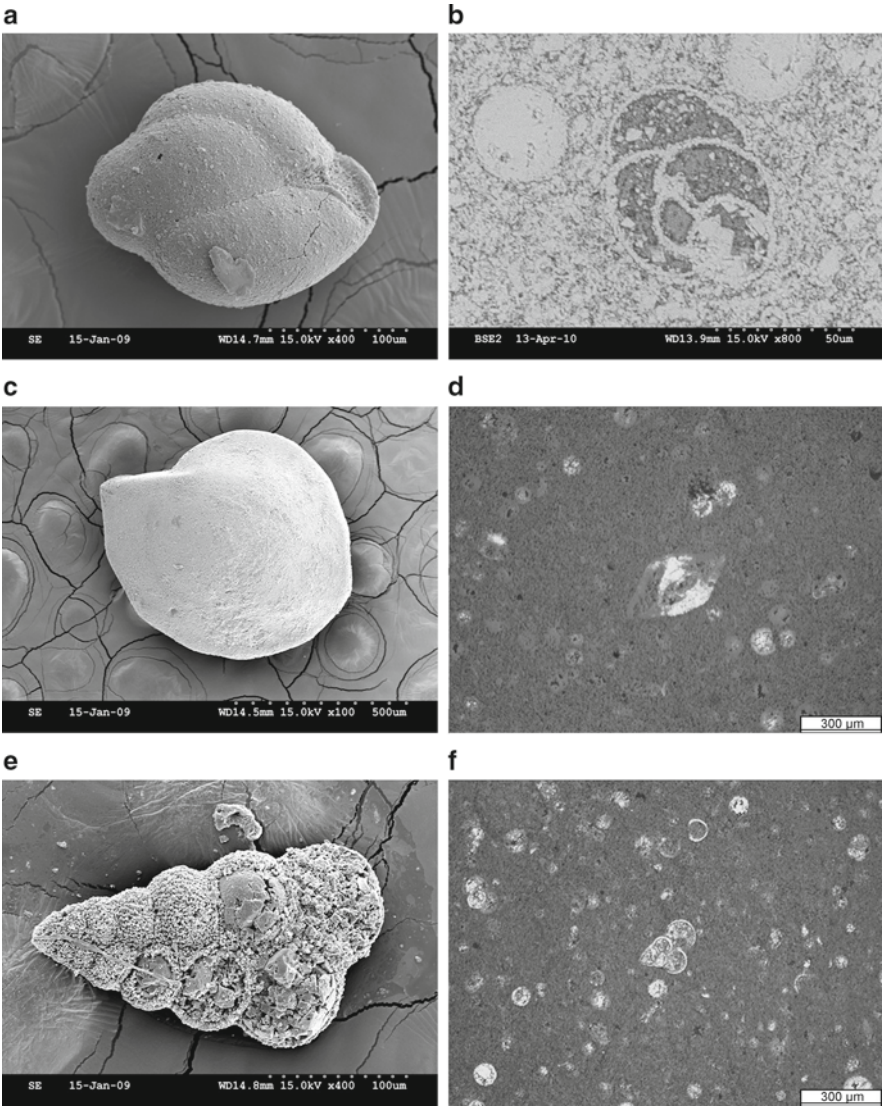

Fig. 6.4 Examples of foraminifera in chalk tesserae from the Vine Street excavation in Leicester (UK) comparing intact foraminifera and their appearance in thin sections: (**a**) *Praebulimina reussi*; (**b**) *Praebulimina* sp. thin section; (**c**) *Lenticulina rotula*; (**d**) *Lenticulina rotula* thin section; (**e**) *Heterohelix reussi*; and (**f**) *Heterohelix reussi* thin section. Identifications by Ian Wilkinson and images by Alison Tasker. Used by permission of Alison Tasker

Foraminifera

The internal tests of foraminifera are usually made of calcite, though sometimes of chitin, silica, or other materials (Fig. 6.4; Branch et al. 2005:87; Brusca and Brusca 2003:166; Campbell et al. 2008:589; Traverse 2008:686). Some forams cement

sand- and silt-sized grains together to make **agglutinated tests**. Their pseudopodia extend through pores (singular: **foramen**; plural: foramina) in their shells. Each species has narrowly defined marine habitat preferences (e.g., marine, brackish, estuarine, coastal, littoral, reef). These preferences reflect qualities such as food availability, predation, substrate, depth, light penetration, water temperature, and salinity. They frequently are used to trace environmental histories.

Many site formation processes affect foraminifera. Because the tests of most species are composed of calcium carbonate, they are unlikely to be found in contexts that are heavily weathered, acidic, redeposited, or contain much gypsum or limonite. They are introduced into archaeological sites by a number of processes. For example, they may be transported to the site as stomach contents in vertebrate and invertebrate prey species or in the scats of sea birds and marine mammals (Rosendahl et al. 2007). They may be deposited by tides and storm surges or incorporated into archaeological strata from earlier deposits. Rosendahl et al. (2007) use foraminifera to distinguish between natural and cultural depositional events, finding that coastal deposits of shell accumulating through non-anthropogenic processes have much higher densities of foraminifera than do ones that accumulated through cultural processes.

Foraminifera are larger than many of the organisms reviewed in this chapter (100 μm–1 mm). Some tests may be recovered simply by field inspection using a hand lens, though this will bias the sample toward larger species and specimens. Soil samples and fine-meshed sieves should be used for a more controlled recovery of foraminifera (Rosendahl et al. 2007). If water is used during screening, it should be fresh to avoid contaminating archaeological materials with the remains of present-day marine organisms. It may be necessary to use relatively large samples to obtain adequate quantities of foraminifera. The structure and composition of tests, the shape and position of apertures and foramina, chamber development, and sculpturing are used for identification; these are often species specific (Sen Gupta 1999). In many cases, however, the surviving material is **indurated** (hardened) so that the specimen can only be examined in thin section, which can appear quite different from the intact organism (Fig. 6.4).

Fungi

Fungi are significant sources of information about environments and cultures (e.g., Seaward et al. 1976; van Geel et al. 2003). They live in a wide variety of habitats, especially compost and dung, and may be detected in most archaeological soil samples. They are especially common in plant litter in which temperatures in excess of 30°C are reached either by microbial activity or by sunlight. Fungal spores provide direct evidence for plant diseases and indirect evidence for host plants. Spores of the wheat rust fungus (*P. graminis*), for example, were found in a coffin in the Great Barrow at Bishop's Waltham (Hampshire, UK; Ashbee 1957; Dimbleby 1978:121), indirect evidence that the coffin was lined with diseased wheat straw.

Fungi release large quantities of spores, some of which disperse widely. *P. graminis* may yield 25 million spores per square meter; the giant puffball (*Calvatia*) may produce 7–10^{12} spores (Gregory 1961:39). Spores are dispersed passively by gravity, air, and rain, as well as actively by other mechanisms (Gregory 1961:39–56). Fungal spores may be vertically transported high into the upper atmosphere and over great distances; wind-borne *P. graminis* spores may travel as far as 300–970 km (Gregory 1961:185, 270). Spores are transported within the soil by physical and biological processes. Fungi can live as much as half a meter below the surface, though their numbers decline as nutrient levels decline. High numbers of spores are encountered where plants were processed or stored. Archaeological samples processed for fungi also may contain remains of algae, ferns, mosses, worms, and insects.

Fungal spores, fruiting bodies, and hyphae may survive deposition depending on the amount of chitin each contains (Faegri et al. 1989:203; Traverse 2008:73, 401–411). Identification is based on the presence, shape, location, number, the size of pores and septa, or the presence of bristles (e.g., van Geel et al. 2003). If the reproductive cycle is complex, a single species may produce several different types of spores during its life cycle. Small (<10 μm), spherical conidia of some fungi may look like starch grains (Haslam 2006). Fungal hyphae have been found in wood charcoal; hyphae penetrate the wood as part of the decay process and are incorporated in the charcoal (Fig. 6.5; Marguerie and Hunot 2007; Moskal-del Hoyo et al. 2010:2109). This relationship may enable researchers to determine if fallen, decaying wood was used as fuel and to distinguish among other wood uses. Despite being a common affliction, most fungal infections leave little evidence in animal skeletons (Waldron 2009:107, 111).

The presence of fecal matter can be inferred indirectly from fungal spores because some coprophilous fungi (e.g., *Cercophora, Chaetomium, Coniochaeta, Sporormiella*) are closely associated with feces and other decaying matter. An increase in fungal taxa commonly associated with herbivore dung, a decline in tree pollen, and an increase in wood charcoal, for example, may independently be evidence of deforestation. When all three lines of evidence are found together, they may verify the occurrence of disturbance events, particularly woodland fires. Fires would open forested areas to grasses and offer new feeding opportunities to herbivorous animals and fungi alike (e.g., Innes and Blackford 2003). A similar association between coprophilous fungi and the dung of megafauna in North America highlights an apparent association between megafaunal extinctions, peak rates of vegetation change, and fire regimes between 14,800 and 13,700 years ago; in addition to documenting the existence of plant communities with no modern analogs (Gill et al. 2009).

Edible fungi no doubt figured prominently in the lives of many people, though it is rare for archaeological evidence of this to survive. In some places today, only the mushrooms *Boletus edulis* and *Tricholoma* are eaten, whereas in other locations a far greater range is consumed, from massive beefsteak fungi (*Fistulina hepatica*) to little chanterelles (*Cantharellus cibarius*). The spectacular *Amanita caesarea* has a long, celebrated history (e.g., Rolfe and Rolfe 1974:168).

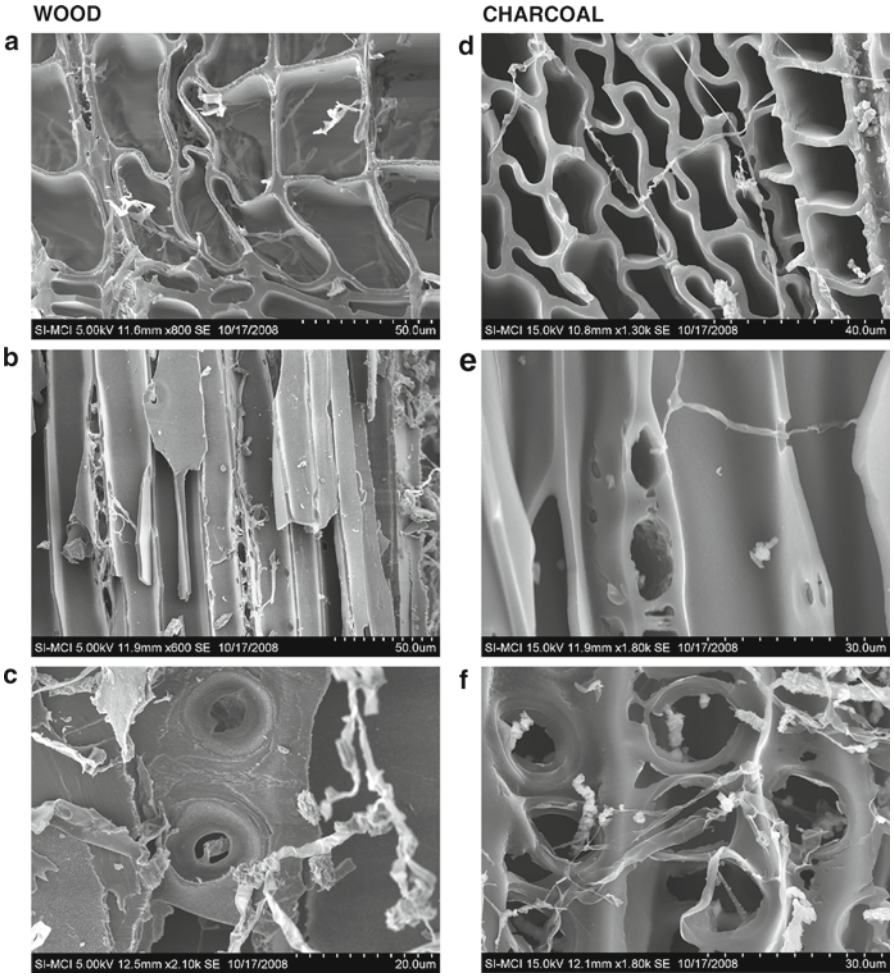

Fig. 6.5 Wood (**a–c**) and charcoal (**d–f**) fragments of hemlock (*Tsuga* sp.) with brown-rot fungi: (**a**, **d**), transverse sections; (**b**, **e**), longitudinal tangential sections; (**c**, **f**), longitudinal radial sections. From Moskal-del Hoyo et al. (2010:2109) and used by courtesy of the authors and Elsevier

Fungi have many other uses (Money 2007; Rolfe and Rolfe 1974). The fly agaric (*Amanita muscaria*) is a source of hallucinogenic materials. The bracket fungus *Fomes fomentarius* is known as tinder fungus because it smolders for a long time and can be fanned into a flame. Tinder fungus recovered from Star Carr (Yorkshire, UK; Clark 1954:18) is interpreted as evidence of such a use. Seaward et al. (1976; Seaward and Williams 1976; Watling and Seaward 1976) report finding puffballs (*Bovista nigrescens*, *Calvatia utriformis*) in deposits from Vindolanda (Northumberland, UK), Skara Brae (Orkney, UK), and other sites. The quantity of puffballs recovered suggests they were economically important, but it is unlikely

they were eaten because the fruiting bodies were fully mature. Watling (1975; Watling and Seaward 1976) suggests they were used to block up drafty holes, to smoke out bees, as a styptic, or as tinder (Grieve 1971).

The leaf-like or shrub-like undifferentiated vegetative and reproductive structures (singular: **thallus**; plural: thalli) of some long-lived lichens grow very slowly but at a constant rate. This characteristic permits archaeologists to calibrate age with size, enabling them to date ancient structures, land forms, and events using lichens (Zhu and Yu 2007).

Applications

Environmental archaeologists document changes in wetland systems to associate them with broader aspects of environmental and cultural sequences (e.g., Mudie et al. 2007; Ryan et al. 2003). Gearey and Caseldine (2006; Caseldine and Gearey 2005) look at **humification determinations** (the degree of peat decay), peat stratigraphy, testate amoebae (Protozoa: Rhizopoda), macrobotanical remains, and pollen to correlate hydrology and human use of a Holocene **mire** (fenland, lowland bog) known as the Derryville Bog (Derryville, County Tipperary, Ireland). The bog contains numerous causeways (trackways, hurdles), platforms, mounds, and cemeteries constructed between 1315 BC and AD 900. Gearey and Caseldine (2006) find a strong correlation between the hydrology of the mire, testate amoebae, and human activity. Testate amoebae in profiles from the bog show that the water table rose and fell twice (Caseldine and Gearey 2005). This interpretation is supported by other lines of evidence, such as fluctuations in *Sphagnum cuspidatum*, a moss typical of bogs. Caseldine and Gearey (2005) suggest that some environmental changes, such as those in Derryville Bog, may be responses to local processes internal to the system rather than to externally driven forces such as climate change.

Protists and other small organisms embedded in stone and other materials obtained from distant sources may be distinguished from local materials, thereby suggesting sources of raw materials and finished products and indicating trade routes and other economic or political ties. Wilkinson et al. (2008) use this relationship in their study of foraminifera, nannofossils, and ostracods (crustaceans) in the **tesserae** (small stones used to construct mosaics) of Roman mosaics from Calleva Atrebatum (Silchester, UK). Calleva Atrebatum was occupied from the first to the fourth centuries AD. The nannofossils in these tiles are severely altered by recrystallization, a diagenetic process. None of organisms in the tesserae are characteristic of chalk deposits near Calleva Atrebatum but they are similar to those found at the Norden Roman site (Dorset, UK), 100 km southwest. Wilkinson et al. (2008) interpret the foraminifera and other aspects of the tiles as evidence that chalk in the tiles is from deposits located elsewhere in southern England. By way of contrast, a similar examination of tesserae from the Brading Roman Villa on the Isle of Wright found that the raw material for these tesserae were from an outcrop just north of the villa (Tasker et al. 2011). Such work provides evidence for trade in raw materials

within Roman Britain as well as use of local resources, and offers a way to investigate sources of stones used in mosaics throughout the Roman Empire.

Uses of algae are difficult to document in the archaeological record; however, evidence for algae use may be found in special finds, such as masticated cuds (Dillehay et al. 2008). Algae are identified on the basis of cellular structure, morphology, and color. Soft remains of ten species of algae were recovered from Monte Verde II (Chile). Several of these were partially burned. The layers containing seaweed were deposited ca. 14,220–13,980 calendar years BP. At that time, Monte Verde was approximately 90 km from a sandy coast, 15 km from a rocky one, and 120 m above sea level. The presence of three marine, two estuarine, and one terrestrial shoreline algal species indicates that considerable effort was expended to obtain these materials from several coastal habitats. Additionally, a stone artifact had seaweed embedded in a working edge. The authors interpret these findings as evidence that algae were used as food and medicines. In other contexts, seaweed was used as fuel and fodder and its presence testifies to contact between coastal and inland locations (Sveinbjarnardóttir et al. 2007).

Diseases play important roles in human history, not only because they afflict human populations but also because of close ties among diseases, people, and domesticated plants and animals. Evidence for human responses to bacterial infections is found in some unexpected places. Bendrey et al. (2008) report on evidence for bacterial infections found in male horse skeletons from two Iron Age (ca. 300 BC to AD 100) sites in southern England. The horses were between ca. 7 and 10 years of age when they died and their skeletons show evidence of bacterial osteomyelitis. A nearly complete horse skeleton was found in a pit at Viables Farm (Hampshire, UK). This horse was accompanied by two human females, two sheep, two cattle (*Bos taurus*), and a second, incomplete horse skeleton. This combination of human remains and domestic animals suggests a ritual burial. The more complete horse skeleton had signs of post-mortem carnivore gnawing and natural disarticulation, both of which indicate delayed burial. In contrast, a horse from Downlands (Kent, UK) appears to have been buried as rubbish. All four of the Downlands horse's legs were broken soon after death, apparently to make the carcass fit into the pit. Both horses were sick when they died and their skeletons had extensive pathological changes. Pathologies on the ribs and vertebrae are consistent with a blood-borne bacterial disease resulting in osteomyelitis. A number of bacteria cause such infections in adult horses. *Mycobacterium bovis* causes tuberculosis in cattle and horses, as well as people. Cancer, the bacterium *Arcanobacterium pyogenes*, brucellosis (*Brucella abortus*), and fungi such as *Aspergillus* produce similar lesions, however. To determine the cause of death for the Viables Farm horse, the skeleton was sampled for a biomolecular study. Unfortunately, samples were negative for equine and bacterial DNA, indicating that genetic material did not survive diagenesis. The authors suggest that the sacrifice of a diseased animal instead of a healthy one at Viables Farm was a pragmatic choice and that the Downlands animal was culled in an effort to control a contagious disease.

Archaeogenetic and modern genetic analysis clarifies many of the migration routes followed as people dispersed from Africa. Moodley et al. (2009) argue that

genetic isolation and the resulting **founder effect** (the effect of the restricted gene pool represented within a new population) produced bacterial strains characteristic of each dispersal route. Their study focuses on the genotype and phylogenetic distributions of a modern human bacterial parasite, *Helicobacter pylori*, which today is associated with chronic peptic ulcers (Barnes 2005:380). The authors cultivated bacterial isolates from Taiwan, Australia, Melanesia, and Polynesia. They found evidence for two waves of migration into the Pacific: one to New Guinea and Australia and the second through Melanesia to Polynesia, each accompanied by distinct populations of *H. pylori*.

Summary

Even though we may not be able to see many of these organisms, their roles in human life are critical at many levels, outweighing their diminutive size. Our knowledge of the complex environmental and cultural processes in which microorganisms are involved has expanded greatly over the past few years due to advances on many fronts. Improved methods should encourage field and laboratory studies that seek them out instead of waiting for them to be observed incidentally in conjunction with some other study. No longer should their size dissuade us from their study. The vital roles of these organisms in environments, ecosystems, and human life highlight the importance of integrated, multi-proxy inquires that combine several lines of evidence to verify and elaborate upon interpretations based on single-proxy studies.

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Chapter 7
Bryophytes and Vascular Plants

Plants offer archaeological insights into a broad array of environmental and cultural phenomena. Demographic attributes, activity patterns, technologies, divisions of labor, exchange networks, and political institutions are associated with plant use, particularly when significant commitments are made to cultivating domestic plants for goods and services, not least for food. Uses of plants extend far beyond their nutritional value and many studies focus on these non-dietary uses. They are important components in tools, fabrics, drugs, dyes, and many other products, as well as construction materials for many kinds of structures. Plants reflect waste and water management practices, with implications for sanitation, pest control, and the health of people, plants, and animals. Some methods used to manage waste and water, as well as wild and domestic plants, significantly altered landscapes. Resulting changes in the structure and composition of ecological communities (e.g., forests transformed into grasslands) had further consequences for plant and animal use as well as other aspects of cultural life.

An important aspect of plant use is the cycle of seasonal productivity associated with many plants and the products used by people (e.g., seeds, oils, fibers). **Perennial plants** live more than 1 year, which distinguishes them from **annual plants** that live a single year. People merge these and other aspects of plants' seasonal and annual cycles of productivity with other aspects of daily life in many ways. They may alter catchment areas used, the location, function, and size of sites, diet, and resource composition in response to seasonal plant productivity, for example. They may store plant products or manage wild or domestic plants to ensure that valued resources are available when needed. Plants have such significant roles in human affairs that many aspects of both routine and ritual life are designed to enhance their productivity, often equating human fertility with plant fertility and linking social calendars to plant reproduction cycles.

Plants are important sources of information about the timing and sequence of domestication and related innovations. Much of the research into the causes and consequences of domestication focuses on the merits of wild and domestic plants in terms of risk management, nutrition, labor, cultivation methods (e.g., weeding,

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irrigation, ploughing, terracing), harvesting methods and schedules, and processing techniques. Research into the stimuli, processes, and consequences of plant domestication raises general questions about sources of cultural innovations and whether specific innovations were stimulated by internal cultural dynamics or by external forces. If by external forces, were innovations such as plant domestication introduced indirectly via trade or by the expansion of farming populations into new areas, merging with or displacing non-farming residents? Many anthropological theories presume that domestication is associated with demographic attributes (e.g., population size, population density), residential patterns (e.g., sedentism, mobility), economic organization (e.g., hunting and gathering, horticulture, agriculture, pastoralism), and political institutions (e.g., bands, tribes, chiefdoms, states).

Archaeological plant remains are divided informally into macrobotanical and microbotanical categories, based primarily on whether the material can be seen without magnification. **Macrobotanical remains** are understood to be relatively large; they include many of the larger seeds, fruits, roots, and woods. The use of low-power microscopy usually is enough for their study, but high-powered examination of whole structures (such as those of mosses) or sections (such as those of wood) may be required. **Microbotanical remains** include spores, pollen, phytoliths, and starch grains, all of which need high-power microscopy for their study. This distinction is common in the literature and useful at a broad level, but it has no taxonomic or anatomical validity and often fails to capture the diversity of ways plant remains appear in archaeological samples. Size, among other attributes, influences how botanical samples are collected in the field and processed in the laboratory. Macrobotanical and microbotanical remains sometimes are studied in different laboratories because of the distinct methods, comparative collections, and skills required to study them.

This chapter begins with an overview of nomenclature for all plants, but the focus is on seeds and fruits, regardless of size. Wood, wood charcoal, stems, fibers, leaves, and roots are reviewed in Chap. 8 and microbotanical remains in Chap. 9. Another way to characterize the next three chapters is that Chap. 7 reviews female reproductive cells and structures; Chap. 8 reviews woody and non-woody support tissues and underground storage organs; and Chap. 9 focuses on spores, male reproductive cells and structures, and non-reproductive materials such as phytoliths and starch grains.

Nomenclature

Plants are multicellular, eukaryotic organisms the vast majority of them photosynthetic autotrophs. They are divided into non-vascular (Bryophytes) and vascular (Pteridophytes, Gymnosperms, Magnoliophyta [or Angiosperm]) groups (Table 7.1; Campbell et al. 2008:605). Most **non-vascular plants** lack internal water- and food-conducting vessels, true leaves, stems, or roots, whereas **vascular plants** have

Table 7.1 Classification of some plants[a]

Category	Examples
Bryophytes	Non-vascular plants
Hepaticophyta	Liverworts
Anthocerotophyta	Hornworts
Bryophyta	Mosses, *Sphagnum*
Tracheobionta	Vascular plants
Pteridophytes	Seedless vascular plants
Equisetophyta	Horsetails
Lycopodiophyta	Club mosses, *Lycopodium*, *Selaginella*
Psilophyta	Whisk ferns
Pteridophyta	Ferns, *Polypodium*, *Pteridium*
Gymnosperms	"Naked" seed-bearing vascular plants
Ginkgophyta	Ginkgopsida, *Ginkgo biloba*
Cycadophyta	Cycadopsida, cycads
Gnetophyta	Gnetophytes, gnetae
Coniferophyta	Conifers, pines
Magnoliophyta	Angiosperms, flowering vascular plants
Liliopsida	Monocotyledonae, palms, lilies, grasses, orchids
Magnoliopsida	Most flowering plants (formerly Dicotyledonae)
	Basal angiosperms, water lilies, Nymphaeaceae
	Magnoliidae, *Cinnamomum*, *Magnolia*
	Eudicots, "true" dicotyledons, most angiosperms

[a]Following Campbell et al. (2008:605, 614, 622–623, 630–631, Appendix E) and Krogh (2009:438)

these attributes. The cell walls of plants generally contain cellulose, which provides strength under tension (Krogh 2009:502). **Lignin** (a strengthening and stiffening polymer) in the fibers of some higher plants resists compression; wood may contain as much as 50% lignin (Krogh 2009:502; Leng 2006:298). In some plants, the **epidermis** (outer cell layer) of leaves and other parts of the plant are coated with an external layer (**cuticle**), which may contain **cutin** (a waxy compound; Thain and Hickman 2004:184–185), among other substances. The cuticle may be interrupted by **stomata** (singular: stoma) and **lenticels**, both of which control gas exchange and water loss by evaporation (Campbell et al. 2008:754; Gifford and Foster 1989:34; Krogh 2009:480–482; Thain and Hickman 2004:403, 669–671). These aspects of plants are discussed in more detail in Chap. 8 because they are more significant in the identification of woods, stems, fibers, leaves, and similar plant remains than they are in the identification of seeds and fruits.

Plants generally alternate a **gametophytic generation** (haploid, single set of chromosomes) with a **sporophytic generation** (diploid, two sets of chromosomes; Campbell et al. 2008:602). The gametophytic generation produces **gametes** (eggs, sperm). **Pollen grains** are male reproductive cells that contain only sperm and must fertilize an egg for the reproductive cycle to continue, whereas plant **spores** develop into new individuals without fusing with another cell (Chap. 9).

Bryophytes

Bryophytes have very specific habitat preferences as well as a number of uses, many of which are now served by other materials (Seaward and Williams 1976). Bryophytes do not produce pollen, but they do produce large numbers of spores that are released irregularly (Campbell et al. 2008:606–610). Bryophyte spores generally are protected by very little sporopollenin and, consequently, have little potential for survival. The spores of peat mosses (*Sphagnum*), however, are exceptional because they contain sufficient sporopollenin to produce a record that extends back at least 150 million years (Traverse 2008:80). Bryophytes are most abundant in moist places because they do not have true root or vascular systems and require ready access to water, which they absorb over the whole plant surface. Some grow in other conditions, however. *Sphagnum* grows in bogs where acidic conditions and low oxygen levels permit extensive deposits of organic matter to accumulate. Very large moss deposits, in the form of peat, may be mined for fuel, building material, and horticultural applications.

Bryophytes include liverworts, hornworts, and mosses (Campbell et al. 2008:608). Liverworts (Hepaticophyta) are differentiated into a spore-producing organ (singular: **capsule** or **sporangium**; plural: sporangia), **seta** (a stalk), and foot (Fig. 7.1a; Shackley 1981:65). The reproductive system of hornworts (Anthocerotophyta) is differentiated into a capsule and a basal foot, with a **meristem** (zone of active growth) between the capsule and foot (Fig. 7.1b). The capsule increases in length as the meristem divides. Mature mosses (Bryophyta) have a capsule, seta, and foot, but growth occurs at the **apex** (tip), not at a meristem (Fig. 7.1c). Some bryophytes are epiphytes.

Vascular Plants

Vascular plants have internal vessels (xylem, phloem) that serve many functions, including transport of materials. Vascular tissues are elaborated upon in Chap. 8 because of their importance in the identification of woods and fibers. Vascular plants include **ferns** (pteridophytes, seedless vascular plants), **gymnosperms** (vascular plants with seeds that are not enclosed in an ovary, i.e., "naked"), and Magnoliophyta or **angiosperms** (vascular plants with seeds enclosed in an ovary, i.e., "covered").

Seedless vascular plants have true roots and lignified vascular tissues but do not produce seeds (Campbell et al. 2008:610–612, 614). They bear clusters of leaves or fronds specialized for spore production (**sporophylls**). Lines, dots (singular: **sorus**; plural: sori), or club-shaped cones of sporangia form on the underside of the sporophylls (Fig. 7.2; Jones and Luchsinger 1986:262; McVaugh and Pyron 1951:75). Spores are protected by sporopollenin. Seedless vascular plants are most common in damp habitats because their gametophyte generation requires a film of water for fertilization.

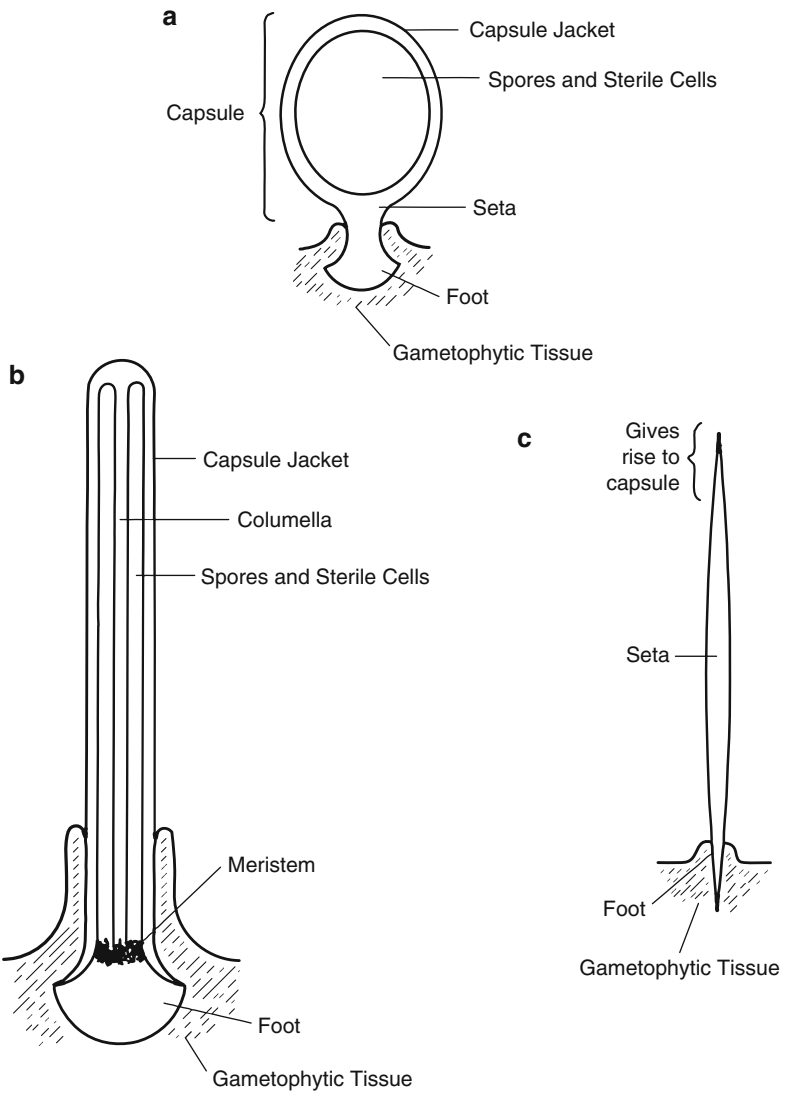

Fig. 7.1 Morphology of bryophytes: (**a**) liverwort; (**b**) hornwort; and (**c**) moss. These show the short-lived multicellular sporophytic generation, which remains attached to the multicellular long-lived gametophytic generation. From Shackley (1981:65)

Gymnosperms and angiosperms are vascular plants that produce seeds. A female gametophyte produces an egg cell (singular: **ovum**; plural: ova) in an **ovule** (an immature seed) located within an **ovary** (a structure containing one or more ovules and which sometimes develops into the fruit; Fig. 7.3; Jones and Luchsinger 1986:232–234). After fertilization, the egg develops into an embryo and the ovule

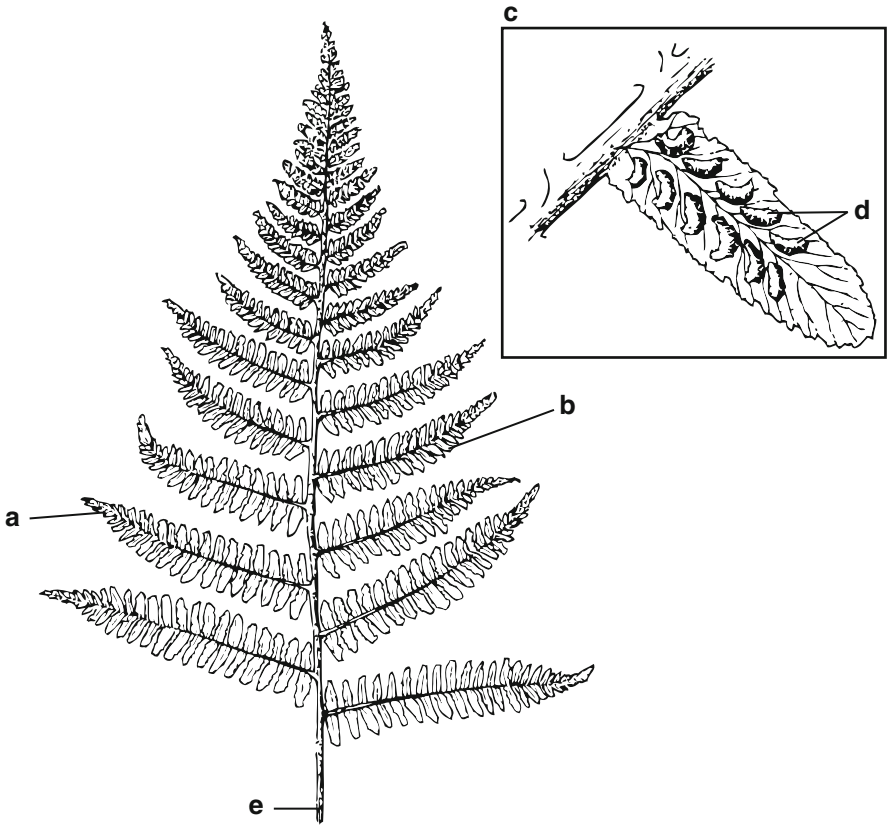

Fig. 7.2 Frond of a common ladyfern (*Athyrium filix-femina*): (**a**) pinna; (**b**) pinnule; (**c**) enlarged pinnule; (**d**) sori; and (**e**) rachis. From McVaugh and Pyron (1951:75) and used by courtesy of The University of Georgia Press

ripens into a **seed** (Campbell et al. 2008:618–620, 802; Harris and Harris 2001:105; Jones and Luchsinger 1986:233). The covering of the ovule (**integument**) develops into a seed coat or **testa** (Fig. 7.4; plural: testae; Gifford and Foster 1989:329; Harris and Harris 2001:59, 78, 105, 196). The stalk of the ovule (**funicle**) leaves a scar (**hilum**) on the seed. Some seeds bear evidence of **pollination** (the transfer of pollen grains to ovules) as a **pollination scar** or **micropyle** where the pollen tube penetrates the ovum (Harris and Harris 2001:68; Pearsall 2000:135; Thain and Hickman 2004:446, 560).

Seeds are complex, multicellular reproductive structures containing an embryonic plant, sometimes a food supply (**endosperm**), and a testa (Fig. 7.4). The embryonic plant consists of one or two embryonic seed leaves (**cotyledons**) and an embryonic rootlet (**radicle**). Seeds may have spines, bristles, and hairs to aid in dispersal and that are useful in identifying archaeological specimens. The term "seed" often is applied to materials that more accurately should be referred to as

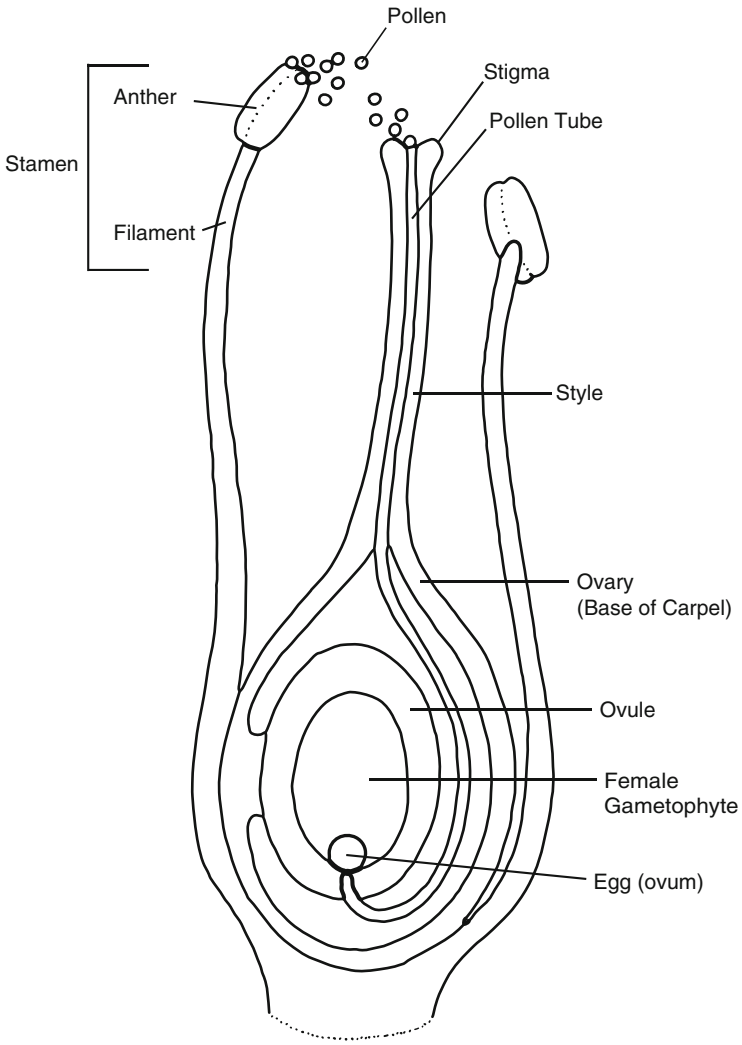

Fig. 7.3 Stylized version of an angiosperm reproductive structure with a single carpel (simple pistil)

fruits (mature, ripened angiosperm ovaries, and other structures attached to them; Harris and Harris 2001:49). One solution is to refer to them as propagules or **disseminules**, which reflects their function as dispersive reproductive structures released from parent organisms to give rise to new ones (Thain and Hickman 2004:579).

Gymnosperms (e.g., conifers such as pines [*Pinus*]) are seed-bearing plants that do not have ovaries, that is, they do not protect seeds within fruits. Instead, ovules and seeds develop on the surface of sporophylls, which form densely packed structures

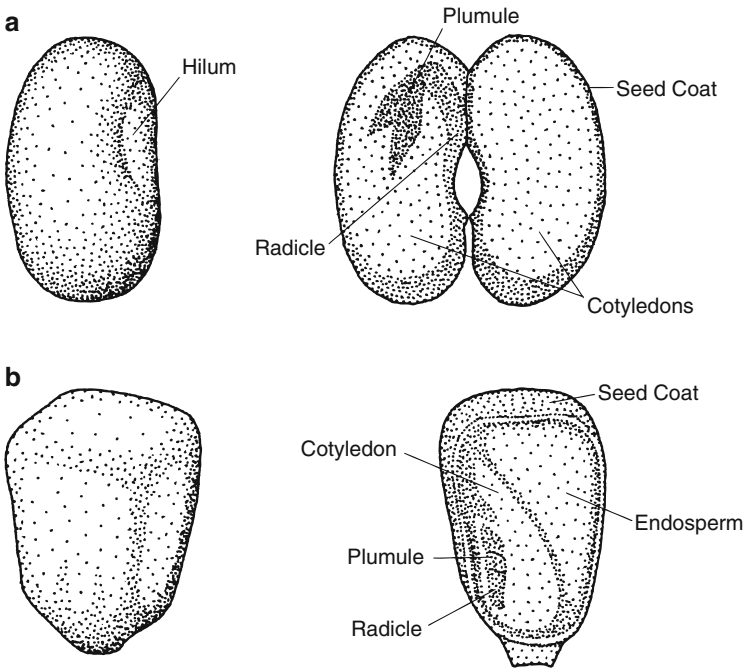

Fig. 7.4 Comparison of seed structures: (**a**) dicotyledon, common bean (*Phaseolus*); and (**b**) monocotyledon, maize (*Zea mays*)

known as cones (Campbell et al. 2008:621; Jones and Luchsinger 1986:284). The names "conifer" and "coniferous" are derived from the Latin *conus*, cone, and *ferre*, to carry (Campbell et al. 2008:623).

Magnoliophyta or angiosperms (flowering plants) include **monocotyledons** (e.g., grasses), **basal angiosperms** (amborella, water lilies), and **eudicots** (e.g., trees, shrubs), though the relationships among these groups is under revision as DNA studies clarify their shared ancestry (Campbell et al. 2008:630–631; Krogh 2009:438). Monocotyledons once were contrasted with **dicotyledons** (trees, shrubs) based on a number of distinctive features; however, DNA analysis has shown that the evolutionary history of dicotyledons is far more complex than previously thought. Most of the plants formerly known as dicotyledons are referred to as eudicots or "true" dicotyledons, though some are variously referred to as basal angiosperms and other terms. The distinction between monocots and dicots, however, remains useful in many archaeological applications. As with all such classifications, no single character falls exclusively in one category or the other.

The reproductive systems of angiosperms are known as flowers, thus their designation as "flowering plants." An **inflorescence** is a mode of flowering associated with specific arrangements of flowers on an **axis** (the main stem of growth; Gifford and Foster 1989:551–554; Harris and Harris 2001:59). **Sepals** are the outer, typically

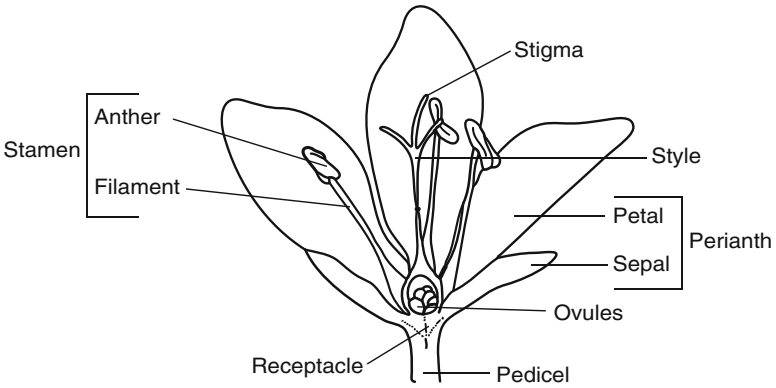

Fig. 7.5 Parts of a generalized angiosperm flower with male and female reproductive parts

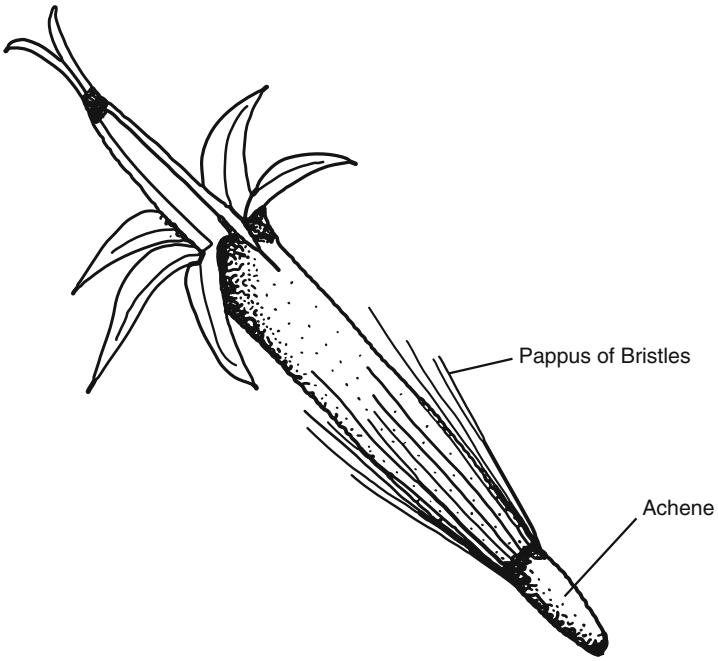

Fig. 7.6 Pappus composed of bristles. From Harris and Harris (2001:80) and used by courtesy of the authors. Drawn by Melinda Woolf Harris

leaf-like, structures at the base of the flower, collectively known as the **calyx** (Fig. 7.5; Gifford and Foster 1989:523; Jones and Luchsinger 1986:233). In sunflowers and asters (Compositae [Asteraceae]), the calyx is modified into a **pappus** consisting of awns, scales, or bristles (Fig. 7.6; Harris and Harris 2001:80). **Petals** are the

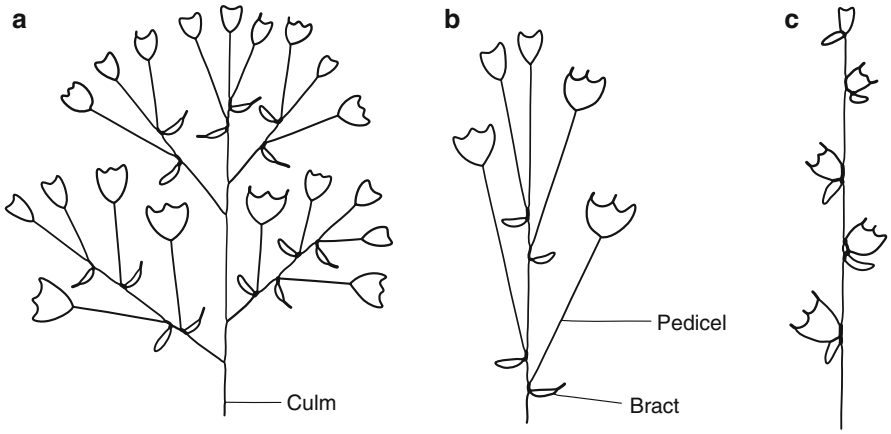

Fig. 7.7 Some major types of inflorescences: (**a**) panicle; (**b**) raceme; and (**c**) spike. From Jones and Luchsinger (1986:235) and used by courtesy of the McGraw-Hill Companies

often-colorful part of the flower, collectively called the **corolla**. The corolla and calyx jointly are referred to as the **perianth**.

Inflorescences of domesticated grasses (Gramineae [Poaceae]) are borne at the top of a **culm** (upright hollow stem; Harris and Harris 2001:33) and take many forms (Harris and Harris 2001:47, 51, 73, 79, 81, 96, 47, 51, 110–111; Jones and Luchsinger 1986:235–236, 437). Inflorescences of some domestic grasses are arranged as spikes (e.g., wheat [*Triticum*], barley [*Hordeum*]); spreading panicles (e.g., oats [*Avena*]); spike-like panicles (e.g., foxtail millet [*Setaria*]); or as panicles of spike-like racemes with the flowers on pedicels (e.g., barnyard millet [*Echinochloa*]; Renfrew 1973:31, 220–225). **Panicles** (Fig. 7.7a) are branched, compound inflorescences and **racemes** are inflorescences with flowers arranged along the main axis on **pedicels** (stalks of individual flowers or grass spikelets; Fig. 7.7b) or spikes. **Spikes** have a single axis and flowers that do not have pedicels (Fig. 7.7c). The central axis of an inflorescence (singular: **rachis**; plural: rachises) may be segmented at nodes where **spikelets** (secondary spikes) or branches originate (Renfrew 1973:31). The axis of each spikelet is a small rachis known as a **rachilla** (Fig. 7.8; Jones and Luchsinger 1986:437). Each spikelet consists of a pair of outer bracts or casings (**glumes**) that hold one or more **florets** (individual flowers in a dense cluster) in place (Harris and Harris 2001:47).

Some grass leaves are modified to such an extent that they are not recognizable as leaves. **Bracts** (reduced or modified leaf structures) are found in the inflorescence or subtending a flower (Fig. 7.7b; Harris and Harris 2001:18; Jones and Luchsinger 1986:230, 235). The first and second glumes (bracts) contain florets, each subtended by outer (**lemma**) and inner (**palea**) bracts, for example (Fig. 7.8; Harris and Harris 2001:64, 79; Jones and Luchsinger 1986:437). In some cases, narrow, bristle-like projections (**awns**) are associated with the lemma. A maize (*Zea mays*) cob is an expanded grass inflorescence and a maize cupule is a modified, cup-shaped rachis.

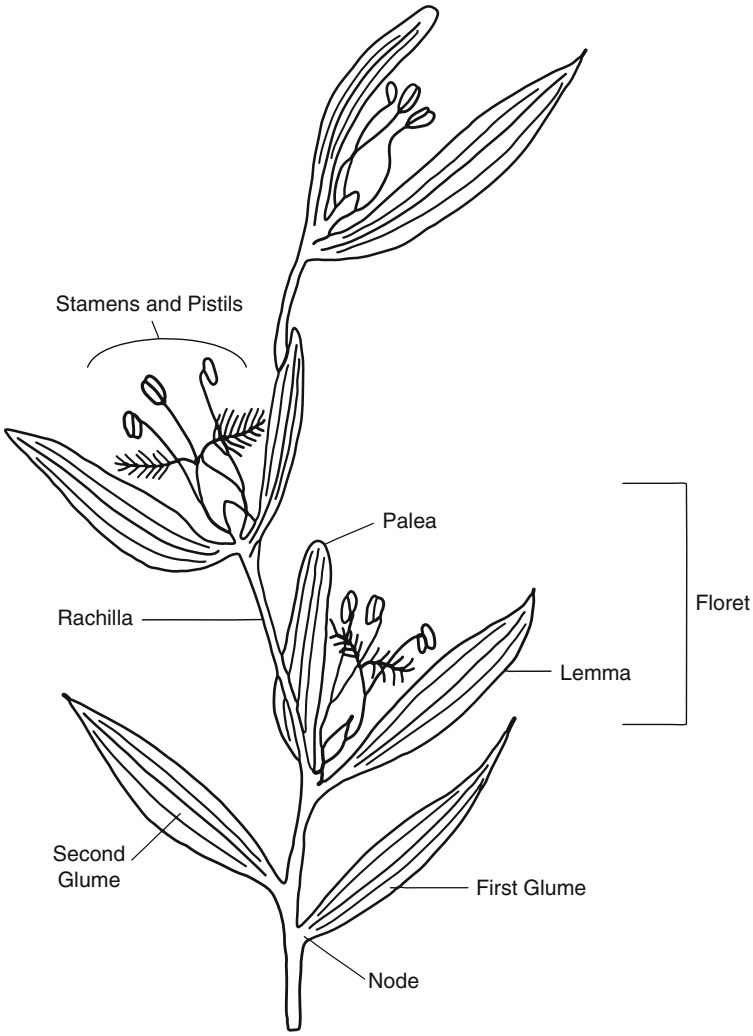

Fig. 7.8 Grass (Gramineae [Poaceae]) spikelet. From Jones and Luchsinger (1986:437) and used by courtesy of the McGraw-Hill Companies

These features are not restricted to grasses; some are found in sedges (Cyperaceae) and rushes (Juncaceae), for example (Harris and Harris 2001:33, 96).

A brittle rachis permits ripened wild grains to be dispersed by wind or by animal vectors. While this kind of dispersal is important for the survival of wild plants, it is undesirable in domestic ones. One of the signs of domestication is that the rachis becomes less brittle, ensuring that the grain remains attached to the stalk until harvested. **Hulled** or **glume** grains have **kernels** (i.e., fruits) that are tightly encased in the glumes. Other grains are termed "**naked**," indicating the glumes are fragile

and fall free of the **chaff** (dry bracts at the base of the fruit) during threshing. Free-threshing forms have a tough rachis but glumes that are less tightly enclosed. Hulled forms require more processing to remove the glumes than do free-threshing grains and provide different returns for that effort.

Figure 7.5 (Jones and Luchsinger 1986:233–234) is a simple diagram of a stylized angiosperm flower with male reproductive parts (**stamen**) and female reproductive parts, though there are many variations on this theme. Female reproductive structures consist of a simple pistil (**carpel**) or a **compound pistil** (two or more carpels fused into a single unit; Gifford and Foster 1989:523; Harris and Harris 2001:52). A carpel encases one or more angiosperm seeds and comprises an ovary (the expanded base containing ovules), a **stigma** (the portion of the carpel that receives pollen; plural: stigmata), and a **style** (a stalk that connects the stigma to the ovary). The ovary is protected by an outer wall that becomes the thickened wall of the developing fruit (**pericarp**). Another way to describe seeds is that they develop within ovaries after eggs inside ovules are fertilized. Carpels vary in terms of type, number, position of the ovary, form of the style, attachment of the ovules, and ovule type (Harris and Harris 2001:195–200). The **tassels** in maize are the stamens and **silks** are the styles and stigmata. "**Germ**" refers to the embryo and "**bran**" refers to the pericarp.

All angiosperm seeds develop within a fruit, that is, within the mature ovary of a flowering plant (Krogh 2009:523); many of the items known vernacularly as seeds, grains, and nuts are technically fruits (Harris and Harris 2001:49, 205–206; Jones and Luchsinger 1986:246–247). A fruit consists of a ripened pistil, including the carpel wall that encloses developing seeds. The form of the fruit reflects the structure of the ovary from which it develops and the ways in which the pericarp differentiates as the fruit ripens. The pericarp is divided into external (**epicarp**, **exocarp**), medial (**mesocarp**), and internal (**endocarp**) layers. The pericarp may be soft and fleshy, hard and dry, or a combination of these, as in stone fruits such as plums (*Prunus*). Other features important for analysis are whether the fruit opens upon maturity to disperse its seeds (**dehiscent**), or does not (**indehiscent**), and the number of seeds contained within the fruit.

Fruits have many different forms (Fig. 7.9; Campbell et al. 2008:810; Harris and Harris 2001:49, 200–206; Jones and Luchsinger 1986:246–247). Some of the basic features used in the identification and analysis of fruits are introduced in the following paragraphs, though many other characteristics are used in practice. Harris and Harris (2001) provide an illustrated glossary to plant identification terminology that is recommended for further reading.

Jones and Luchsinger (1986:248–249) define the following five fruit types: (1) dry, indehiscent, and one-seeded; (2) dry, dehiscent, with many seeds; (3) fleshy, derived from a single flower; (4) derived from a single or compound ovary and **accessory structures** (parts of the fruit derived from non-ovarian tissues); and (5) derived from the fusion of many separate carpels of a single flower (**aggregate**), or of several fruits of separate flowers (**multiple**).

Among the dry, indehiscent, one-seeded fruits are achenes, schizocarps, utricles, nuts, and caryopses. An **achene** forms from a single carpel in which the seed coat

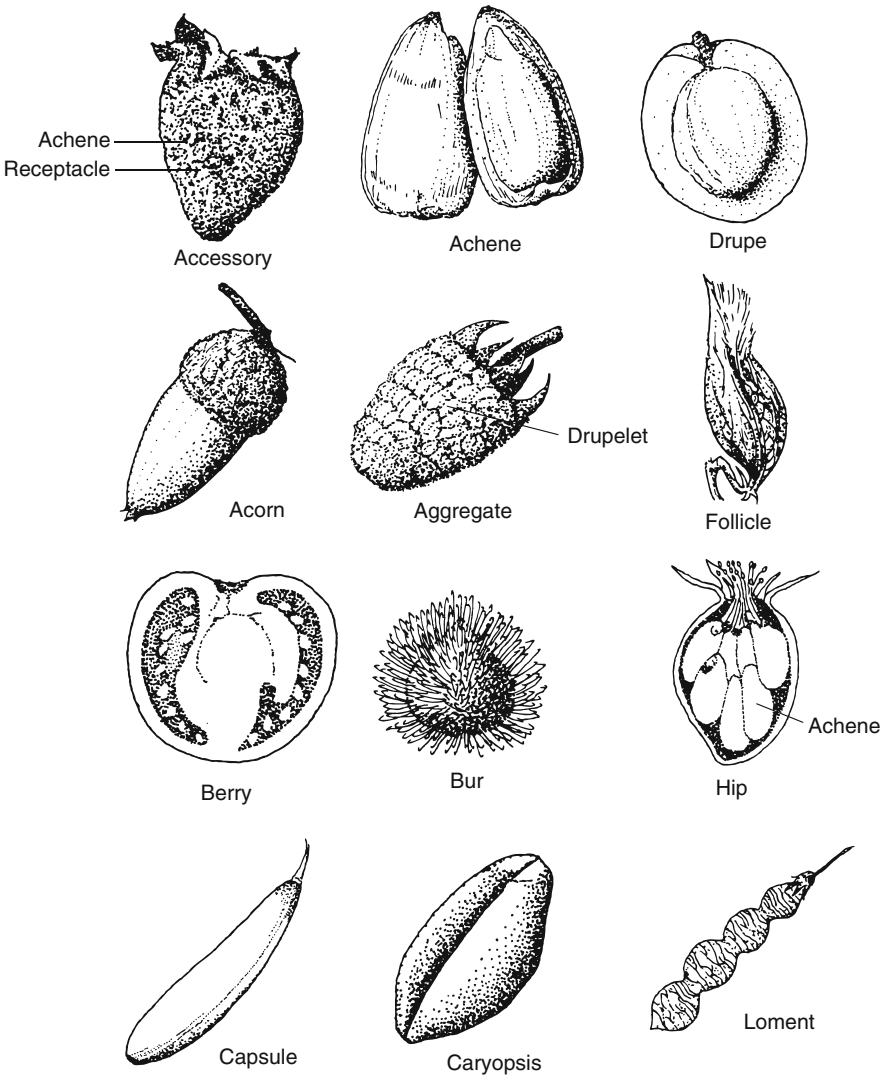

Fig. 7.9 Types of fruits. From Harris and Harris (2001:205–206) and used by courtesy of the authors. Drawn by Melinda Woolf Harris

does not adhere to the pericarp (e.g., sunflower [*Helianthus annuus*]; Harris and Harris 2001:4; Jones and Luchsinger 1986:248; Thain and Hickman 2004:4). A **samara** is winged achene (e.g., ash [*Fraxinus*]; Jones and Luchsinger 1986:248). A **schizocarp** is a fruit that splits into two **mericarps**, or partial fruits (e.g., carrot/parsley [Umbelliferae (Apiaceae)]; Harris and Harris 2001:68, 104; Jones and Luchsinger 1986:248, 387; Thain and Hickman 2004:440, 637). Some schizocarps

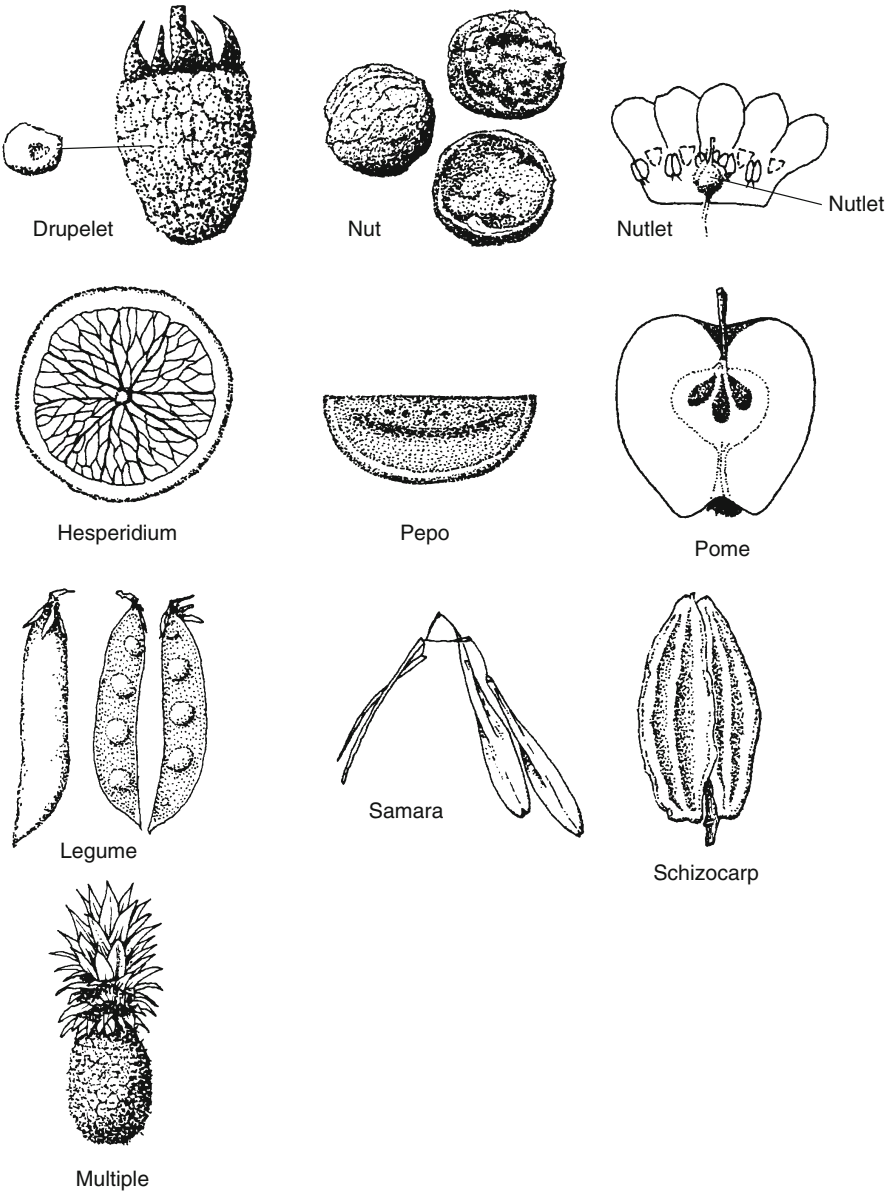

Fig. 7.9 (Continued)

are winged (e.g., maple [*Acer*]), consisting of two samaras. **Utricles** have a thin, bladdery, inflated wall (e.g., some pigweeds [Amaranthaceae]).

Nuts are dry, indehiscent, one-seeded fruits with hard, woody coats (e.g., oak [*Quercus*]; Jones and Luchsinger 1986:248). The nut shell is a hard pericarp and the

nut meat is the seed containing an embryo. A tough outer covering (**husk**) may be present (e.g., walnut [*Juglans*], pecan [*Carya*]). Although nuts are fruits and contain seeds (the meat), they are distinguished from other fruits because their hard pericarps may survive in the archaeological record long after the seed is consumed. The fact that nuts usually do not open at maturity means that people must either extract the seed from the heavy, inedible portion in the field or transport the entire structure to a processing area. The inedible coverings often dominate the botanical spectrum at archaeological sites, leaving the impression that nuts were the primary dietary item.

In botanical terminology, if not in English vernacular usage, a grain is a **caryopsis** (plural: caryopses), a dry, indehiscent, single-seeded fruit in which the pericarp is fused to the seed (Harris and Harris 2001:202; Jones and Luchsinger 1986:248, 437). When a grain matures, it separates along the junction (**abscission line**) between adjacent fruits, forming an **abscission scar**. The grains with which we are most familiar are the economically important monocotyledons classified as grasses. Fruits of grasses are generally caryopses, though some may be nuts, utricles, or berries (see below, this chapter). If they produce starchy seeds that are cultivated as a crop, these may be referred to in the vernacular as **cereals**, a term broadly applied to maize, rice [*Oryza sativa*], wheat, oats, barley, and sorghum (*Sorghum bicolor*; Thain and Hickman 2004:128–129). In much of the archaeological literature, "grain" refers broadly to many seeds and fruits that may not be, strictly speaking, caryopses.

Capsules and legumes are dry, dehiscent fruits with many seeds. **Capsules** originate from two or more carpels (e.g., cotton [*Gossypium*], Harris and Harris 2001:21; Jones and Luchsinger 1986:248). **Legumes** or **pulses** (Leguminosae [Fabaceae]) are characterized by a single carpel that contains multiple seeds and splits along two sutures. The dry, dehiscent fruits of legumes may be termed **pods**. Legumes are particularly important because they are involved in nitrogen fixation; their cultivation enriches the soil in which they are grown. Legumes include alfalfa (*Medicago sativa*), peanuts (*Arachis hypogaea*), horse beans (*Vicia faba*), chickpeas (*Cicer*), lentils (*Lens* [*esculenta*] *culinaris*), soybeans (*Glycine max*), garden peas (*Pisum sativum*), common beans (*Phaseolus vulgaris*), and trees such as acacia (*Acacia*) and algarrobo or mesquite (*Prosopis*).

Fleshy fruits derived from single flowers include drupes, berries, and pepo types (Harris and Harris 2001:15, 40; Jones and Luchsinger 1986:249). A **drupe** is an indehiscent fruit with a fleshy mesocarp and a hard, woody endocarp surrounding, usually, a single seed (e.g., almonds, plums, peaches, and cherries [*Prunus*]; coconut [*Cocos nucifera*]). The seed may be known as a stone or pit. **Berries** develop from a single pistil, have fleshy pericarps, one or more seeds, often lack a pit or core, and each seed is surrounded by a hardened testa. Berries include tomatoes (*Solanum* [*Lycopersicon*] *lycopersicum*), grapes (*Vitis vinifera*), and dates (*Phoenix dactylifera*). The **pepo** form is a fleshy, indehiscent, many-seeded fruit with a tough rind (e.g., watermelons [*Citrullus*], bottle gourds [*Lagenaria siceraria*]).

Fruits derived from a single or compound ovary and accessory structures are known as **hips** (e.g., rose [*Rosa*]) and **pomes** (e.g., apples [*Malus*]). These may

Table 7.2 Differences between monocotyledons and dicotyledons

Monocotyledons	Dicotyledons
Embryo with single cotyledon	Embryo with two cotyledons
Flower parts in multiples of three	Flower parts in multiples of four or five
Narrow leaves	Broad leaves
Major leaf veins parallel	Major leaf veins reticulated
Stem vascular tissue scattered	Stem vascular tissue forms a ring
Fibrous root system	Taproot system
Roots are adventitious	Roots develop from radicle
Secondary growth absent	Secondary growth often present
Pollen with single furrow or pore	Pollen with three furrows or pores
Examples: wheat, rice, bananas	Examples: oaks, cacti, sunflowers

develop from the point at which the carpels, stamens, and other flower parts attach to the stem (**receptacle**; Fig. 7.5) instead of the pistil. Fruits developing from the receptacle, or from the calyx, are known as **pseudocarps** (false fruits; Harris and Harris 2001:93).

Fruits that form from many separate carpels of a single flower, or the fusion of several fruits of separate flowers, are known as aggregate fruits and multiple fruits (Jones and Luchsinger 1986:249). An aggregate fruit is a cluster of small fruits produced by a single flower (e.g., raspberries [*Rubus idaeus*]). Despite their vernacular names, blackberries (*Rubus fruticosus*) and raspberries are not berries; they are **drupelets**, aggregations of small drupes. A multiple fruit develops from the ovaries of several, tightly clustered flowers (e.g., pineapple [*Ananas comosus*], figs [*Ficus carica*]; Harris and Harris 2001:204).

Angiosperm seeds are described and identified in archaeology by details of their surviving structures (Fig. 7.4; Campbell et al. 2008:631, 808; Krogh 2009:501). An important difference is whether the seed has a single cotyledon (i.e., a monocotyledon) or two cotyledons (i.e., a dicotyledon; Table 7.2; Pearsall 2000:135–136).

Many economically important plants are monocotyledons (e.g., vanilla [*Vanilla planifolia*], century plants [*Yucca*], palms [Arecaceae], lilies [Liliaceae], grasses such as sugar cane [*Saccharum officinarum*], maize, wheat, rice). The endosperm of monocotyledon seeds may be very large as this is the principle food storage area for these seeds (Campbell et al. 2008:807; Krogh 2009:501). Dicotyledons include plants with **woody growth habits** (trees, shrubs) and **herbaceous growth habits** (non-woody, e.g., sunflowers, tomatoes). The endosperm of some dicotyledon seeds may be smaller than in monocotyledons because cotyledons are the primary storage locations for dicotyledons instead of the endosperm (e.g., Pearsall 2000:134).

Asexual reproduction should not be confused with **vegetative reproduction**, in which a new plant develops from a portion of the original plant and is identical to the original one. Succulents known as life plants (*Kalanchöe*) produce small, vegetative, rooted plants that fall off and grow into new adult plants (Jones and Luchsinger 1986:352). Quaking aspens (*Populus tremuloides*) reproduce vegetatively by producing shoots or suckers from their roots. Many plant husbandry

techniques use vegetative reproduction instead of seeds. The capacity for vegetative reproduction is a critical characteristic of many roots and tubers that are now dietary staples (Hather 1994), though some, such as sweet potatoes (*Ipomoea batatas*), reproduce both vegetatively and sexually. Vegetative reproduction is one of several reasons that evidence for root crops is rare in archaeological deposits.

Although the term "vegetative" refers to non-floral parts of a plant (Harris and Harris 2001:132), the English vernacular term "vegetable" is not a scientific classification. In common use, "vegetable" distinguishes between forms known vernacularly as seeds, fruits, nuts, and grains and edible soft materials such as leaves, stems, and roots. Thus, some "vegetables" are, in fact, non-reproductive plant parts, such as leaves and stems (e.g., Marshall 2001), but many "vegetables" are not vegetative. Some of the fruits called vegetables are rare in archaeological sites because their seeds are so small or soft that they are consumed with the fruit itself, such as those of domesticated squashes (*Cucurbita*) and fresh green or runner beans (e.g., *Phaseolus vulgaris*). These have little or no chance of surviving site formation processes unless deposited in permanent dry, cold, or wet locations, or preserved by mineral replacement. Some vegetables are considered more flavorful if eaten before the plant "goes to seed," such as okra (*Abelmoschus esculentus*).

Mechanisms of Seed Dispersal

Dispersal of seeds and fruits relies primarily on wind, water, and animals. Some plants do not disperse seeds and fruits far from the parent plant. Most plants, however, distribute them some distance away to avoid competition and to maximize reproductive success. Methods of dispersal are reflected in features of specific seeds and fruits. Some have structures that facilitate transportation by wind or water, such as wings, fluffy hairs, and other aerodynamic or hydrodynamic properties. Seeds and fruits dispersed by animal vectors may have spines or sticky substances that enable them to become attached to passing animals. Others offer attractive flavors, odors, and colors that encourage animals to eat them. The ingested seeds pass unharmed through the vector's digestive tract and are excreted, perhaps many kilometers away. Some characteristics are designed to attract specific vectors. Many domestic plants have limited ability to disperse seeds without human intervention because awns and hairs are reduced or the rachis is less brittle.

Site Formation Processes and Field Considerations

Site formation processes and recovery methods are reviewed in Chaps. 2 and 3, but some details specific to plants are summarized here. For most plant materials to survive, consumption by aerobic organisms must be inhibited. The shape and size of all plant remains are altered if they are charred, desiccated, or waterlogged, but

plant remains may not survive unless subjected to these processes. Processes that affect the survival potential of plant remains influence the recovery of plant remains representing different environmental and cultural features. These can produce widely differing representations of plants in study assemblages, which means that a plant's significance cannot be judged entirely on the basis of its numerical abundance. Analysis must take these factors into account (Pearsall 2000:139–140).

Site Formation Processes

Bryophytes, in archaeological settings almost always mosses, and seedless vascular plants are best preserved in anoxic, waterlogged conditions and consequently are infrequently recovered from the most common archaeological deposits. Most tissues of bryophytes do not contain lignin and their spores usually are not protected by sporopollenin; thus, their survival generally is doubtful. Water loss in some bryophytes, however, is controlled by a cuticle and some bryophyte tissues contain silica, both of which may enhance the survival potential in some cases (Piperno 2006:15; Thain and Hickman 2004:184). Ferns produce spores that are protected by sporopollenin and may strengthen their tissues with silica; they also have true roots and lignified vascular tissue. Such seedless vascular plants are more likely to survive site formation processes than are those that lack these structures.

Seeds and fruits of gymnosperms and angiosperms are preserved primarily by four processes: carbonization, deposition in anoxic conditions, desiccation, and mineral replacement (McCobb et al. 2001). Whole fruits are rarely recovered from archaeological sites; more typically inedible fruit parts, usually in a charred state, are found. Carbonization is the most common form of preservation. It is seldom random and may be the result of accidental (e.g., during food preparation) or deliberate burning (e.g., used as a fuel). For this reason, carbonized materials may not be representative of the overall environmental and cultural spheres. Seeds that are heated slowly while being protected from direct contact with flames are reduced to elemental carbon but retain many of their original characteristics. The surviving material is inedible, which restricts further destruction primarily to abiotic rather than biotic processes. Grains that are parched before they are threshed or winnowed are more likely to be carbonized accidentally than are seeds and fruits that are not heated (Helbaek 1952). Even carbonized plant remains are adversely affected by alkaline depositional environments, however (Braadbaart et al. 2009).

Dennell (1976) suggests that the roles of plants can be gauged by considering sample composition, economic status, behavioral context within the site, and archaeological context. He proposes that considering plants within a continuum of crop-processing activities can distinguish between potential plant resources and those actually used, and indicate the relative importance of those actually used. A processing continuum for a grain might include threshing, winnowing, roasting, pounding, sieving, parching, sorting, milling, and storing. At each stage in this chain, different parts of the plant may be lost or discarded in different locations and be subjected thereafter to different site formation processes. Dennell (1976) demonstrates

the importance of food processing techniques in studies of early Neolithic settlements at Chevdar and Kazanluk (Bulgaria), occupied between 5300 and 4700 BC. Chevdar was destroyed by fire so that plant materials were recovered in situ from floors and ovens, whereas the Kazanluk remains primarily are from middens, including residue from cleaning and processing crops. He evaluates the plants recovered from these sites in terms of the steps required to produce each collection. This enables him to distinguish between actual plant resources and potential ones by determining which plants were processed and which were not. This approach allows him to assess site formation processes that affect the representation of plants in the assemblages.

Other characteristics affect interpretations. Some fruits may be small with many, delicate seeds (e.g., figs, tomatoes). These seeds may be less sturdy than those of fruits that protect a single large seed with a strong outer coat (e.g., some drupes, nuts). Large-seeded fruits may dominate the collection because of their durability, even though they may have been less frequently eaten, compared with the smaller seeds. In terms of processing, transportation, storage, and consumption, nuts usually involve choices very different from those required for fleshy fruits, if only because nuts usually are heavier and more bulky. Fruits that are eaten may be common but plant parts used in dyes and fermented beverages may be rare. Many herbs and spices are harvested before they produce seeds, or only vegetative parts are used, leaving little evidence of their use at the archaeological site.

Sometimes seeds and fruits survive without carbonization. This usually occurs in damp, anoxic conditions, desiccated ones, or at high altitudes. Jiang et al. (2007) report finding uncarbonized fruits of common gromwell (*Lithospermum officinale*), a perennial herb whose fruits have hard pericarps, glued to the exterior walls of wooden tubs from Xinjiang (China). The fruits form triangular patterns around the lips of two tubs and are well preserved with no distortions. Xinjiang is a very dry site, which enhanced the preservation of these rare finds. Such uses may have been common in the past, but the extent rarely can be assessed.

Evidence for plant use may be indirect (Dimbleby 1978:95). Ceramic vessels may be crafted in the form of a particular plant (e.g., Bonavia et al. 2004) or the plant may be depicted in decorative motifs (Zizumbo-Villarreal et al. 2009). Evidence of plants, or specific plant parts, may be preserved in corroded metal or as impressions in clay or plaster (e.g., Renfrew 1973:15–16). Impressions are most plentiful when clay was modeled in the same area where plants were processed, so that stray plant materials could be incorporated into the damp clay. Imprints of the matting upon which the unfired vessel sat, as well as leaf, twig, and grain inclusions may be recorded in the clay. Plant material may be added to clay as temper, improving the firing quality and other properties of the ceramic vessel (e.g., Lippi et al. 2011). Such inclusions generally burn out when the vessel is fired, but may leave detailed images of their original forms. Just as clay shrinks during firing, plant impressions shrink as the clay is fired (Renfrew 1973:16). If temper is used to document the presence of a plant, the location where the object was manufactured must be established because that is where the plant was used, not where the vessel entered the archaeological record. Pottery and other fired clay materials should be sorted and cleaned with caution so as to preserve this fragile evidence.

Field Considerations

Field recovery methods are discussed in detail in Chap. 3, but mosses require special mention. Although mosses are reported from several archaeological deposits (e.g., Seaward and Williams 1976), these accounts probably do not represent the frequency with which these plants were used. Excavators may not see these small, delicate materials or be using sampling strategies able to recover them. Moss fragments, for example, may be less than 20 mm long (Dickson 1973). Mosses often are sampled in stratigraphic columns, but they may be encountered in all sorts of waterlogged contexts. Large deposits of mosses should always be sampled. With better recovery and handling, larger fragments and intact specimens could be recovered, improving the chances of identification. As with all environmental materials, care should be taken in storing samples in the field, in transferring samples to the laboratory, and in the laboratory itself. In particular, measures to avoid moisture (or drying if the samples are from damp contexts), inhibit decay organisms, and limit mechanical damage are important.

Laboratory Procedures

Seeds and fruits are identified using reference collections and illustrated keys. Some commercial firms produce sets of seeds of common plants for teaching purposes. Many museums have herbaria that are useful for reference and may permit samples to be taken to establish comparative collections specifically for use in archaeobotanical studies (Pearsall 2000:127–128). In many cases, voucher specimens of contemporary vegetation found near archaeological sites are collected and donated to herbaria following standardized protocols (Bridson and Forman 1998; Metsger and Byers 1999; Pearsall 2000:120–128). Because much of the plant material recovered from archaeological sites is charred, some portion of the reference collection must be burned as well (Pearsall 2000:128–133). Additional specimens may be prepared as wet specimens, anticipating that waterlogged samples might be encountered either during the current study or in a future one. Some reference materials may be thin sectioned or whole specimens (e.g., moss fragments, small seeds) mounted on slides.

Although many aspects of plants can be observed without magnification, in most cases at least low-level magnification is needed. Some applications require much higher magnification or the use of a scanning electron microscope (SEM). In such cases, the materials may be stabilized in an embedding medium, sectioned, and/or mounted on slides. Each type of plant material has its own requirements when it comes to such preparations (e.g., Pearsall 2000:170–177). The following discussion often presumes preparation and magnification but the procedures involved are beyond the scope of this volume.

Processing

Many of the initial processing steps are similar to those practiced in all environmental archaeology laboratories, modified to conform to standards prevailing in each discipline, the specific needs of the materials being studied, and local facilities. As a general rule, the first step is to record all of the contextual information provided by the field staff onto laboratory forms (Pearsall 2000:100). Archaeological field notes and laboratory records, including maps, stratigraphic profiles, summaries of soil and sediment analyses, and preliminary, functional interpretations of contexts are very helpful in preparing lab records and in correcting errors that slip into the record-keeping process subsequently. It is essential to maintain, transfer, and update these records throughout the study as well as during the curation of the archaeological materials.

Selecting samples to study requires communication between field and laboratory staff. If samples are too large or numerous for the time or funds available, it will be necessary to chose which samples to study. This selection could begin by deciding which archaeological samples are from locations or contain information germane to the research questions. It should not be assumed that field samples are appropriate units for analysis. In this, as in all other aspects of environmental archaeology, it is best to organize field samples into those representing specific time periods, functions, activity areas, and other cultural behaviors instead of assuming each field sample bag represents a significant cultural event or a closed context. Further subsamples may be taken following procedures described in Chap. 5.

Once the lab records are prepared and the field samples selected for study, further processing begins. This may begin with sieving the materials if this was not done previously. Samples recovered in screens and those recovered by flotation may be approached in different ways. In part this reflects disparities in the sizes of the remains in screened and floated materials. Screened materials are usually larger in size and can be sorted by hand. Pearsall (2000:102) recommends that flotation samples be separated into two or more fractions using graded geological sieves. One fraction, for example, could be materials captured in a 2.0 mm sieve and the other fraction could be materials smaller than 2.0 mm. More sieve sizes could be used to yield fractions containing specimens that fall into larger or smaller size categories. The materials within each fraction share a similar size, which resolves some of the depth of field issues that arise when materials of different sizes are examined under a microscope and makes it less tiring and more efficient for the person carrying out the sorting. Each fraction should be weighed or its volume recorded.

The contents of each fraction likely will be handled differently following the research questions guiding the work and the nature of the materials in each fraction. All of the charred material in the ≥2.0 mm fraction may be identified, including not only seeds but also wood charcoal, tubers, nut shell fragments, and other botanical materials (Pearsall 2000:102). In contrast, the contents of the <2.0 mm fraction may be less thoroughly examined. Perhaps only charred seeds or special materials of

particular importance to the research question (e.g., portions of squash rind, maize cupules) will be identified from the <2.0 mm fraction, leaving behind small flecks of wood charcoal that may be both abundant and taxonomically unidentifiable (though see Moskal-del Hoyo et al. 2010). These procedures may be altered if other materials from these same samples will be studied, though often these other studies use soil samples specifically taken for those applications.

Identification

After selecting the samples or subsamples, and removing any obvious modern materials from them, the remaining materials will be identified to the lowest taxonomic level consistent with accuracy (Pearsall 2000:100). Two of the more difficult aspects of identification are judging what cannot be identified and distinguishing between modern and archaeological materials (Pearsall 2000:110). These skills are developed only through practice and access to experienced mentors. There is no substitute for devoting years to handling both archaeological and modern materials, a caution that applies to all organic remains.

Specimens may be sorted initially by size, shape, and surface sculpturing based on characteristics that experience shows have diagnostic value for attributing a specimen to a taxon. Many archaeological specimens are so fragmented that diagnostic features are missing or too damaged for identification. The size and shape of the specimen, number of cotyledons, the placement and relative size of embryo and endosperm, the presence of sutures, and characteristics of the hilum are diagnostic features, as are the presence and location of attachment and pollination scars. Other distinguishing traits pertain to the seed coat, such as color (in uncharred seeds), texture, and surface features. Seed coats may be smooth, or have ridges, grooves, or other patterns. Identification also relies on the thickness, texture, and other characteristics of the outermost surviving layer (Pearsall 2000:142–144; see Adams et al. 1999 for morphological features of maize). Charring alters many of these attributes (Pearsall 2000:139–140). At the end of the identification process, a list of taxa attributed to various taxonomic groups is developed with a list of parts identified for each, counts, and weights, as appropriate.

Measurements of key features (**morphometric data**) provide additional information needed for identification and analysis. Morphometric data are used in some cases to attribute specimens to taxonomic categories; and an increase in size is one of the primary characteristics distinguishing wild from domestic forms (Fig. 7.10; Smith 1995:73). Willcox (2004) identifies other sources of morphometric variation, including environmental conditions, genetic variability, and crop processing. He concludes that changes in the grain size of barley, emmer (*Triticum dicoccon*), and two-grained einkorn (*Triticum boeoticum* ssp. *thauodar*) at two tenth-millennium BP (non-cal) sites in the Euphrates Valley are due to genetic changes at the population level and not to phenotypic variation. Herbig and Maier (2011) measure flax [*Linum usitatissimum*] seeds to determine if flax was grown in southwest Germany for oil

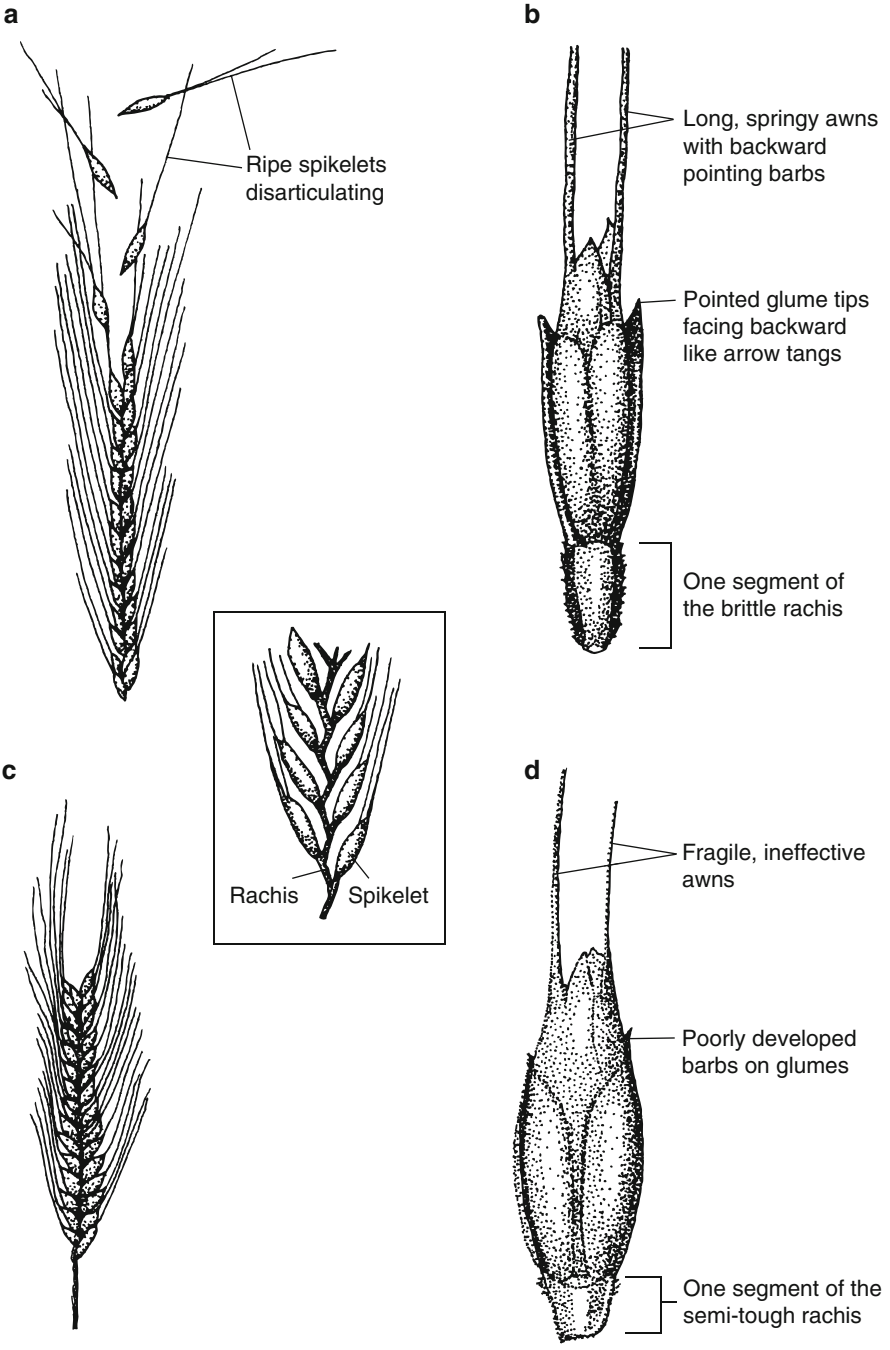

Fig. 7.10 Wild and domesticated forms of einkorn wheat (*Triticum monococcum*): (**a**) wild form, a ripe ear in the process of shattering; (**b**) wild form, a single disarticulated spikelet; (**c**) domestic form, a fully ripe ear; and (**d**) domestic form, a single spikelet from a threshed ear. Insert shows the position of a rachis and spikelet. Note difference in size in the wild and domestic spikelets. From Smith (1995:73) and used by courtesy of Bruce D. Smith

or for fiber. Measurements should conform to published standards; if idiosyncratic measurements are used, thorough descriptions should accompany specimens into publication and curation. Standard measurements include the length of a seed along its main axis, its thickness, and its width or depth. For archaeological specimens that are charred, the length may have shrunk and the breadth and thickness may have increased compared with uncharred reference materials.

Analytical Procedures

Taxonomic attribution, parts represented, counts, weights, and measurements are primary, descriptive data that meet standards for a basic study. For interpretations of environments and cultures, however, additional data are required. Such secondary data are derivative and more subjective than primary data. They are interpretations of direct observations developed using methods that rely upon additional steps to explore specific research questions. This is not to say that the process of attributing an archaeological specimen to a taxonomic category is not, in itself, an interpretation of the observed characteristics, but identification usually is based on anatomical and morphological attributes intrinsic to archaeological and comparative materials, whereas secondary data are removed from the actual observations. Secondary data constitute estimates, whereas identifications, at least in principle, should be more reliable.

Research questions structure approaches to secondary data, specifically how data are quantified and presented. The most basic presentation of primary data is a simple list or roster of the materials found in the study assemblage. Such lists document the presence of a particular plant, group of plants, or plant part in the study assemblage (Pearsall 1988, 2000:212–216). Taxa in the list may be organized by plant part (e.g., seed, wood), function (e.g., fuel, dye, funeral offering), habitat (e.g., wetland, domestic, alpine), or season of availability (e.g., cold, wet, austral summer). Although listing by plant part is descriptive, attributing a usage, habitat, or season of availability to the identified materials is an interpretive, derivative step. Thus, the transition from observation to interpretation is fundamental to further study.

Most secondary data are quantified using a variety of techniques. Some of these are developed for specific applications by individual researchers, but others are widely used. Among the most frequently used are ratios, ubiquity, diversity, and food values derived from counts, weights, and measurements. All of these have strengths and weaknesses and are subject to detailed, critical evaluations (e.g., Pearsall 2000:192–224). The most common techniques are summarized here. The literature should be consulted to become familiar with the assumptions and biases fundamental to each and to investigate more sophisticated quantitative approaches.

Perhaps not so obvious in the literature is the underlying knowledge that skilled researchers draw upon when deciding how far to take their analyses and which quantification techniques to use, if any. Familiarity with the biological, ecological, taphonomic, and recovery aspects intrinsic to the specimens, as well as with the primary data from which secondary data are derived, profoundly influences the procedures followed by experienced environmental archaeologists. This is particularly

the case with quantification. Pearsall (2000:192–193) recommends "…(1) do not use any statistical technique you do not fully understand, (2) begin with simple tabulations and then apply more complex techniques, and (3) do not use approaches that require more rigor than the data are capable of sustaining."

Specimen counts and weights are the primary data most frequently recorded in addition to the taxon and plant part represented (Pearsall 2000:194–206; Popper 1988). The number of taxa may be compared to the number of remains (Fig. 7.11; Figueiral et al. 2010:144). The count or weight is quantified for each taxon, for specific material types (e.g., seeds, wood charcoal, fibers, other plant materials), for specific contexts, or for the site as a whole. The decision of whether or what to count and weigh is based on the research question. In deciding whether, what, and how to quantify, the analyst might anticipate future questions that may require primary data not needed in the original study.

Miller (1988) distinguishes between: (1) ratios that estimate proportions, percentages, and density; and (2) comparison ratios. A **ratio** is a proportion or share of one observation relative to another one, written as a quotient of one observation divided by the other. Ratios are relative rather than absolute measures of abundance and generally use counts, weights, or volume as numerators and denominators.

In ratios that estimate proportions and percentages, the material in the numerator is a subset of the material included in the denominator. For example, the ratio of seeds identified as blackberry in a sample of all seeds is estimated by the following: 10 blackberry seeds/20 total seeds, yielding a ratio of 0.50. This ratio may be converted to a **percentage** by multiplying the ratio by 100; so a ratio of 0.50 would be converted to 50% blackberry seeds. In Fig. 7.11a, Figueiral et al. (2010:144) present the results of their study of waterlogged and charred plant materials as percentages of the number of remains (NR) in several ecological and economic groups. They conclude from this and other evidence that cultivated fruits, especially grapes grown locally for wine production, were important in the Roman economy of southern France. As the percentage of one taxon increases, the percentages of other taxa decrease because percentages must total to 100%. Percentages can only be used when the numerator and the denominator are the same, such as when dividing a specific seed type by all seeds to obtain a percentage of, for example, cultivated fruits among all seeds and fruits.

In other cases, the numerator and denominator are different in some way. **Comparison ratios** are ones in which materials in the numerator are excluded from the denominator (e.g., a seed to wood charcoal ratio; Miller 1988). These ratios compare two different items. The results often are used to assess the effects of preservation on materials, using wood charcoal as the denominator (e.g., seed:charcoal, nutshell:charcoal). This approach can identify different activity areas. It is permissible to compare counts to weights, so one might find a comparison ratio of seed count to nutshell weight. A **density ratio** or **concentration index** is derived using numerators and denominators that are mutually exclusive; such as the number of seeds per volume of sediment (e.g., 20 seeds/L; Fig. 7.12, Herbig 2009:1282).

Another application assesses the ubiquity, presence (**percentage presence**), or frequency of a particular plant, group of plants, or tissue type in the archaeological collection (Pearsall 2000:212–216; Popper 1988). **Ubiquity** refers to the number of

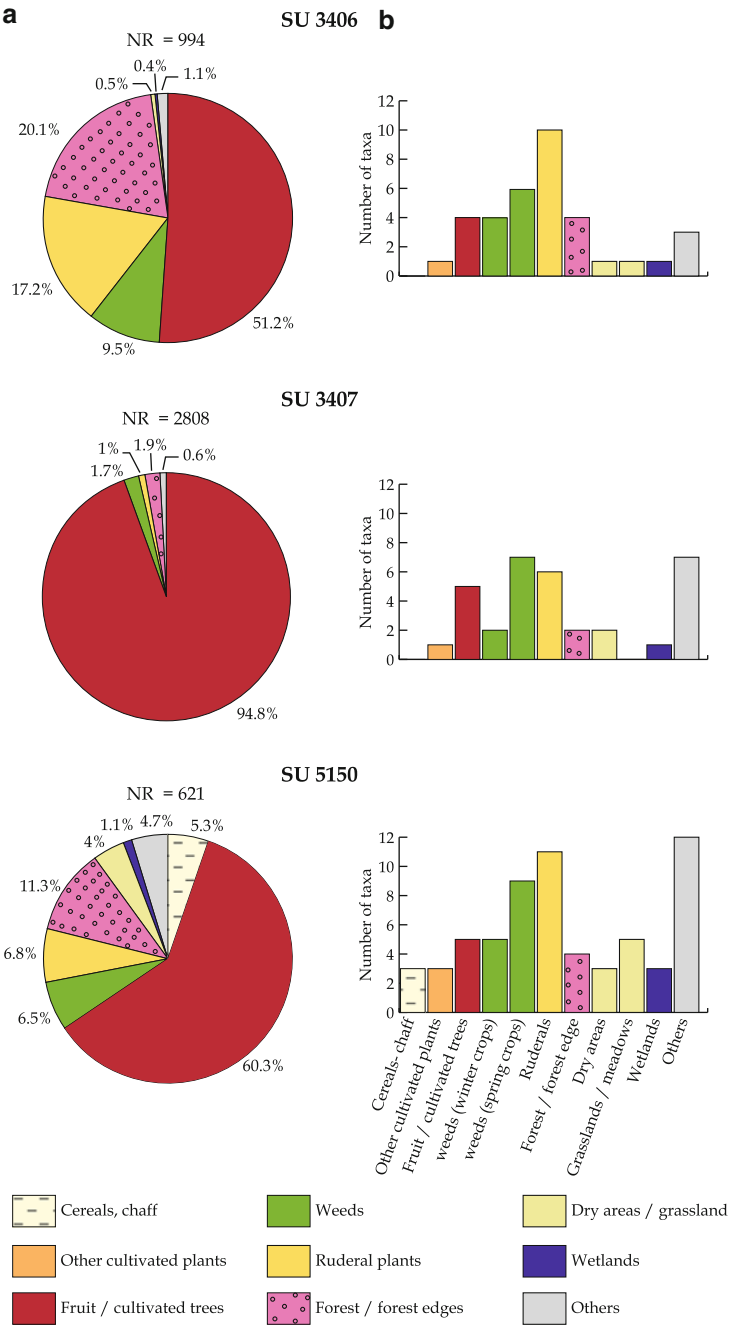

Fig. 7.11 Main ecological and economical groups of waterlogged seeds and fruits in three stratigraphic units (SU) from Gasquinoy (France): (**a**) proportions of number of remains (NR); and (**b**) number of taxa in each group. From Figueiral et al. (2010:144) and used by courtesy of the authors and Elsevier

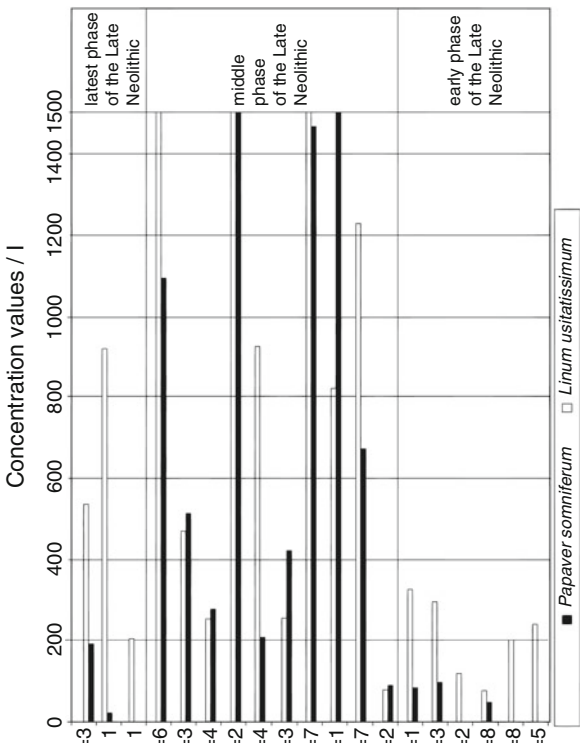

Fig. 7.12 Concentration values per liter (L) of sediment for oil (poppy, *Papaver somniferum*) and fiber (flax, *Linum usitatissimum*) plants at Lake Constance (Germany). Sites are in ascending chronological order; *n* = number of samples. From Herbig (2009:1282) and used by courtesy of the author and Elsevier

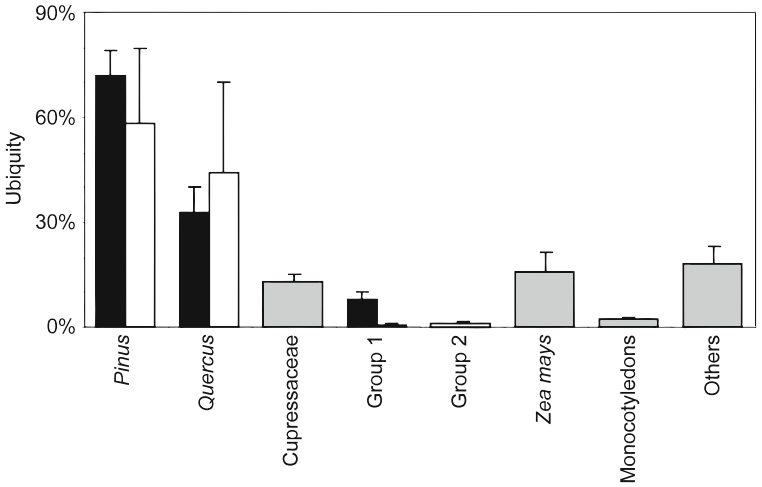

Fig. 7.13 Differences in ubiquity among taxa in different contexts in the Teotihuacan Valley, Mexico. Pine (*Pinus*), oak (*Quercus*), and Group 1 (taxa present during all periods or during at least four of them) show significant differences between floors, fills, and hearths (*black bars*) and other contexts (*white bars*). *Gray bars* indicate taxa that show no significant variation among contexts, including cypress (Cupressaceae), Group 2 (taxa present in at least two of the periods), maize (*Zea mays*), monocotyledons, and other taxa (present in a single sample or that could not be attributed to a genus). Intervals correspond to standard errors. From Adriano-Morán and McClung de Tapia (2008:2933) and used by courtesy of the authors and Elsevier

samples in which a taxon, economic grouping, or plant part is present. It measures how many samples contain the taxon, for example, based on the observation that a taxon is present (or not) in each sample. This frequency score is converted to a percentage by dividing the number of samples in which the taxon is present by the number of samples considered (Fig. 7.13; Adriano-Morán and McClung de Tapia 2008:2933). The scores for one taxon indicate the frequency with which that taxon is found in samples from the site and can be evaluated independently of the scores of other taxa. Ubiquity does not provide information about the abundance of that taxon compared with other taxa; a taxon may be represented by a single specimen in every sample, being, therefore, a highly ubiquitous taxon present in very small quantities.

Richness, diversity, and equitability are measures of the number of taxa present in a sample and the abundance of each (Pearsall 2000:209–212; Popper 1988). Interpretations based on these measures, other than richness, are far more common in studies of animal remains and are discussed in Chap. 11.

Estimating food value for plants, and for fungi, requires deciding which taxa were used as food and which were not (Miller 1988; Pearsall 2000:206–209). Many organisms have multiple uses and human nutrition may or may not be among these uses. Some are accidental inclusions, others are commensal, some are used to make other products, used as animal fodder and bedding, and others may be emblems of social cohesion, or be purely decorative. Some organisms are brought to the site unintentionally along with the preferred plant materials and are discarded without being used at all.

If it seems probable that the plant was used as food, which parts of the plant were used? In the first place, many of the plant parts recovered are specifically those portions that are inedible (e.g., nut shells); the edible portion having been consumed long ago. We are, therefore, interpreting food value specifically from portions that likely had no food value. Some plants have several edible portions, each with different nutritional values. What was the food value of the specific edible plant part, bearing in mind that the edible parts likely are not present? What do we mean by food value? This can be measured as calories, carbohydrates, proteins, lipids, vitamins, or minerals; fiber content also is relevant to digestion. In some cases, the primary use may be as a spice (e.g., black pepper [*Piper nigrum*]) or an oil (e.g., flax or linseed oil [*L. usitatissimum*]). The nutritional value of a specific plant tissue may change as it matures. Should estimates of nutritional value be derived from count, weight, or some other aspect of the materials? The nutritional literature is based on weight and to do otherwise with archaeological materials would result in further analytical distance from the original observations.

Due to difficulties posed by these and similar questions, estimating nutritional value for plants is uncommon, which is just one of the factors complicating efforts to merge plant and animal data into a holistic dietary synthesis. When nutritional values are examined, however, they can be an important part of a study (e.g., Marr et al. 2007).

Plant Domestication

Domestication is important because of its role in the evolution of human societies and landscapes. Theories about stimuli for domestication, the timing of domestication, the process by which people and domestic organisms came to rely upon each other, and the consequences of this relationship to the domestic forms, to people, and to environments are fundamental to many anthropological interpretations and the foci of many long-lived debates (e.g., Cunniff et al. 2010; Fuller et al. 2007; Harris 2007; Schulting 2010; Vrydaghs and Denham 2007). Evidence for domestication is present in the archaeological record throughout the Holocene, depending on the location of the site and the plant involved. It is traditional to consider domestication in terms of developmental stages, though, in practice, most evidence indicates that "stages" as firm steps in a universal, irreversible, evolutionary trajectory did not exist.

Explanations for the origins of plant domestication are too numerous to discuss here, but they range from human population pressure to social stimuli to environmental change. Among the environmental hypotheses is that an increase in atmospheric CO_2 concentrations at the end of the last glacial period was a precondition for plant domestication, stimulating higher plant productivity and enabling people to rely on just a few plant taxa. To test this hypothesis, Cunnifff et al. (2010) experimentally grew C_3 and C_4 cereals under conditions that controlled CO_2, water, photoperiod, and temperature. They conclude that atmospheric conditions at the end of the Pleistocene might have limited the productivity of crop progenitors, but does not

explain why plant domestication occurred, why it occurred in some places and not in others, or why some plants were domesticated and not others.

Much of the evidence for domestication is indirect. Terraces, sunken fields, drainage ditches, storage facilities, tools, increased human population size or density, larger, more numerous, and more complex communities, changes in human biomechanics and health, complex social and political institutions, fertility rituals, and reduced residential mobility, among other phenomena, may be evidence for plant domestication. Some of these attributes (e.g., villages occupied by sedentary populations, monumental architecture, ceramic traditions) are found among people who did not have domestic food sources. Nonetheless, if a number of these phenomena are found together at several contemporaneous sites within a region, it is likely that domestic plants did meet at least some economic needs of the human population. Linguistic affiliations and human genetic characteristics may suggest reliance on domestic resources.

A basic characteristic of domestication is a change in phytogeography as a taxon is transported beyond the wild population's presumed preferred habitat. This preferred habitat is the area within which *wild* members of a given species characteristically are found today. Much research focuses on associating these presumed preferred habits with hypothetical centers of domestication or origin. Centers of domestication were thought to be associated with centers of diversity, where an abundance of wild taxa closely related to domestic forms occurs today. The original definition of centers of origin assumed that domestication of each organism occurred only once, in a single place, and that similarities of morphology, disease resistance, fertility of hybrids, and other traits shared by domestic and wild forms would identify such centers (e.g., Vavilov 1992). Tracking the dispersal of domestic stock from such locations is critical to tracing historical trajectories of environments and cultures.

The underlying assumption of this ecological analogy was that environments and the biogeographical distribution of wild species today are unchanged from those in the past (Harris 2007). Such analogies were plausible when the Holocene was considered climatologically stable, but they are suspect in the face of evidence for environmental changes during the Holocene. This assumption also fails to take into consideration clinal variations within species and their responses to phenomena other than domestication, such as diseases and ecological processes (e.g., succession, predation). Much of the wild diversity in some hypothesized centers of origin appears to be due to formerly domestic forms that have become wild (**feral**) after escaping from fields of domestic crops.

Domestication of many organisms occurred more than once and in more than one place and range expansions may be responses to environmental change and ecological processes in addition to cultural interactions. Dispersals of wild and domestic forms from hypothetical centers of origin, or of domestication, may have been facilitated by historical changes, human population movements, or mediated through formal and informal exchange networks among communities in different regions. Any of these phenomena may have produced the reproductive isolation and phenotypic changes required for archaeological evidence of domestication to become manifest (Vrydaghs and Denham 2007).

Most studies of domestic plants focus on seeds and fruits because other important plant portions, such as leaves and stems, are less likely to be carbonized or survive carbonization. Although carbonization is desirable because it enables seeds and fruits to survive, charring affects some attributes that distinguish between wild and domestic forms, such as the size, shape, proportion, and external morphology (Renfrew 1973:11–14). Because leaves, stems, and roots tend to be rare, much less is known about the cultivation history of leaf and root crops compared with crops represented by seeds and fruits.

Although the search for centers of domestication has lost much of its original intent, research continues to assess the timing, mechanisms, and consequences of the biogeographical expansion of domestic forms from one or more presumed original sources into other regions (e.g., Barton et al. 2009; Bonavia et al. 2004; Doebley et al. 2006; Erickson et al. 2005; Marr et al. 2007; Speller et al. 2010). The continued search for such centers derives from the comparative basis of this research: it is necessary to compare the habits, habitats, phenotypes, and genotypes of wild progenitors with those of transitional and fully domestic forms, which requires knowing which ancient wild populations were ancestral to early domestic ones. These comparisons enable researchers to assess spatial, temporal, and cultural aspects of domestication. This presumes that the wild progenitors and origins are known and wild populations are still extant, though, in fact, in many cases the wild progenitors are extinct or uncertain.

Direct lines of evidence for domestication derive primarily from seed and fruit sizes, anatomical properties, and genomes that differ from those of wild progenitors. The seeds and fruits of domestic plants usually are larger, and anatomically different compared with those of closely related or ancestral wild relatives (Fig. 7.10). They may have fewer, though larger, fruits or grains per plant, the central stem may be dominant compared with side stems, reproduction may be closely synchronized, seeds may lose dormancy, photoperiod sensitivity may change, and bitter substances may be lost. Even after considerable periods of human management, however, some plants, as well as animals, show little or no morphological evidence of domestication (Vrydaghs and Denham 2007).

An important consequence of domestication is that the cycle whereby wild seeds of some important crops mature and disperse is interrupted; that is, seed heads of domestic plants are non-shattering and seeds remain attached to stalks awaiting harvest. In wild grains, rachises are brittle and thin so that seeds can break away from the parent plant when seeds ripen. One line of evidence for domestication in grains is that the rachis is no longer brittle, all of the grain ripens more or less at the same time, and the ripe grain remains on the stalk until harvested. In addition, seeds and fruits may lose other properties that aid natural dispersal. Changes may occur in awns, barbs on glumes, and other structures that enable seeds to penetrate surface litter, and become embedded in the ground. Although an increase in grain size appears before non-shattering forms in wheat, barley, and rice, in the case of pearl millet (*Pennisetum glaucum*), non-shattering attributes precede the increase in grain size (Manning et al. 2011).

These phenotypic changes in seeds, fruits, and other plant remains are manifestations of underlying genetic modifications, some of which may be subtle or slow to emerge (e.g., Doebley et al. 2006; Zheng et al. 2009). On the other hand, **polyploidy** (having more than two sets of chromosomes; Chap. 13) is a common condition in domestic plants, often a consequence of hybridization (Jones and Luchsinger 1986:177–179; Thain and Hickman 2004:565). Studying polyploid hybrids requires identifying several different genetic sources that contributed to the domestic form in a complex, multistage process involving either a single ancestral species (**autopolyploid**) or multiple ancestral species (**allopolyploid**). This may separate a potential domestic plant from its wild progenitors within a single generation because polyploids often must be self-pollinating. Some of our most important crops are polyploids, including bananas (*Musa*), tobacco (*Nicotiana tabacum*), white potatoes (*Solanum tuberosum*), and bread wheat (*Triticum aestivum*).

Plant domestication produces **cultivars**, forms originating under cultivation (Harris and Harris 2001:33). Cowan and Watson (1992:4) distinguish between **cultigens**, wild plant species tolerated or encouraged by people, and **domesticates**, plants dependent upon human agency (i.e., genetically altered from the wild form) to emphasize that a continuum of genetic, phenotypic, and behavioral transformations occur in both plants and people as wild taxa become domestic ones. Early stages in this transition are understandably difficult to observe, particularly if they are expressed in characteristics that seldom leave archaeological evidence, such as color, chemical composition, growth habits, or the timing of seed maturation. The combination of multiple lines of evidence is important for defining early stages in this process. These include deforestation, an increase in weed pollen or crop pests, the presence of farming terraces and harvesting tools, a change in isotope ratios, and an increase in plant remains from non-indigenous taxa. Genetics and stable isotope biochemistry may pinpoint early stages and indicate which resources were significant in the economy during the transition, the role of wild and domestic plants during the transition, and intermediate phenotypic changes (e.g., Barton et al. 2009).

Direct anatomical evidence for domestication may be rare for the early stages of domestication. Initially, members of the wild plant population, potential ancestors to domestic forms, are separated from other members of the wild population by human agency. As the wild population and the domestic one became increasingly separated from each other, some genetic and phenotypic changes would emerge due to **genetic drift** (random sampling errors in gene frequencies within the population), founder effect, and human choice. Preventing interbreeding, leading to reproductive isolation from wild progenitors, is generally achieved beyond the natural range of the wild progenitor, raising again the question of origins. This separation of populations reduces diversity throughout the domestic genome, creating what is known as a **bottleneck**. Mutations within both the wild and domestic populations might further increase differences between the two groups.

Patterns of genetic differentiation within a single species are influenced by environmental and ecological processes that influence dispersal, isolation, and recolonization. For phenotypic changes to be common in archaeological materials, changes

in the frequency of genes governing seed and fruit anatomy in domestic forms must become abundant, even dominant, in the "domestic" population beyond those that might normally occur. At some point, morphological traits become fixed in the population, meaning that the genetic trait has replaced all others in the population. As genetic changes become fixed, further distinctions can be made between early and later stages on this continuum. Identifying the timing, sequence, and types of genetic changes clarifies the origins of domestic forms and the timing of domestication.

It is unwise to conclude that a domesticated form was raised at a specific site based entirely on its presence at the site. In their study of grape production in China, for example, Jiang et al. (2009) conclude that grape pips could be transported over long distances in raisins and are not necessarily evidence of local grape cultivation. They argue, however, that the presence of grape vine stems is direct evidence that the plant was cultivated nearby as it is unlikely that stems would be transported very far from the production center.

It is not known to what extent people consciously selected preferred traits or whether the traits that people came to value arose through unconscious selection (Emshwiller 2006). In some cases, the characteristics we now value in a crop are secondary features that arose during or after domestication. Thus, the fleshy fruit that we associate with squashes emerged as a consequence of domestication; the wild fruit is not fleshy and squashes originally may have been used primarily for their seeds. Likewise, some varieties of flax may have been domesticated for oily seeds rather than for fiber (Herbig and Maier 2011) and papyrus (*Cyperus papyrus*) was used initially to make bread (Trager 1970:16).

Applications

Palaeofeces may contain a variety of organic materials, including intestinal parasites, seeds and fruits, pollen, starch grains, epidermal tissues, insects, hairs, and vertebrate remains. They provide direct evidence of substances consumed within several days or less, indicating the season in which a meal was ingested and, by extension, when the site was occupied. This, in turn, can suggest a site's role in the annual cycle and residential patterns in terms of annual and seasonal fluctuations in resources. Riley (2008) explores seasonality, dietary breadth, and habitat exploitation using seeds found in palaeofeces recovered from Hinds Cave (Texas, USA). The cave was used by people throughout the Holocene. It had been argued that the cave was occupied only during the late summer and early fall as part of a seasonal round that followed resources north as the summer progressed and then south for the winter (Sobolik 2008). Riley (2008) argues that warm-season palaeofeces should contain a high diversity of plants, particularly warm-season seeds and fruits. Cold-season palaeofeces should contain a limited array of plants, and these should be taxa available throughout the year. The dietary staples at the site were desert succulents: sotol (*Dasylirion*), lechuguilla (*Agave lechuguilla*), and prickly pear (*Opuntia*). Prickly pear **tunas** are seasonal, seed-bearing fruits whereas **nopales** are **cladodes**

Table 7.3 Characteristics of grape (*Vitis vinifera*) remains collected from three modern grape processing methods[a]

Method	Frequency
Pressing vat	
Pressed skins, occasionally with attached pips	Numerous
Peduncles, rachis, lateral and pedicels	Numerous
Pips	Numerous
Immature whole grapes (6×7 mm)	Sparse
Sieving basket	
Pips	Numerous
Pressed skins	Numerous
Pedicels	Numerous
Immature whole grapes (3×2 mm)	Sparse
Plastic storage container	
Pips, occasionally with attached skin	Numerous
Pressed skins	Very few
Pedicels	Very few

[a]Modified from Margaritis and Jones (2006:791)

(thick, fleshy, pad-like stems) available throughout the year. A wide range of other plants is represented in the palaeofeces. Riley (2008) concludes that Hinds Cave was occupied intermittently throughout the year instead of during a single season and that people used resources from multiple habitats. This flexibility and a broad-spectrum strategy enabled people to reduce the costs of large-scale mobility.

Most fleshy fruits decompose rapidly if not consumed or processed relatively quickly. Some are dried, but fermentation transforms fruits into a liquid with a high alcohol content that can be stored for months, even years. Grapes can be consumed in fresh, dried (i.e., raisins), or fermented form. Margaritis and Jones (2006) combine archaeological evidence from a farmstead at Komboloi (Pieria Southern Macedonia, Greece) with ethnohistoric accounts, ethnographic observations, and charring experiments to define criteria that might distinguish among products of three processing methods (Table 7.3; Margaritis and Jones 2006:791). Komboloi was occupied from the second half of the fourth century to the early third century BC. The authors observed present-day non-mechanical processing methods used to make raisins and wine, noting which plant remains were present at each stage and when in each sequence plant remains were likely to be charred. Temperature, time, moisture content, and oxygen exposure all influence the condition and identity of organic residues (e.g., pips, stalks, skins) that might be preserved or destroyed by different treatments. Margaritis and Jones (2006) conclude that their criteria enable residues from grapes pressed for wine to be distinguished from those of fresh grapes and raisins, but discriminating between grapes and raisins is more problematic. Margaritis and Jones (2006) interpret grape remains from Komboloi as primarily by-products of wine production, with some evidence for raisins and limited use of fresh grapes.

Often seeds and fruits are analyzed for economic information and pollen for environmental information, a dichotomy encouraged by field protocols that collect

seeds from contexts within the site and pollen from off-site locations. The recovery of seeds, fruits, and pollen from the same Middle Bronze Age (3150 ± 40 BP, 3270 ± 50 BP) clay-lined storage pit or silo at San Lorenzo a Greve (Florence, Italy) enables Lippi et al. (2009) to combine these lines of evidence. The pit was 1.8 m deep and contained the remains of two ladders. Numerous wooden fragments in the upper level of the fill, mostly of elm (*Ulmus*), suggest the pit was covered. Two fill layers were distinguished, each containing a mixture of seeds, fruits, and pollen from cultivated, wild, and weedy plants, but low seed and fruit concentrations. The seeds and fruits are from plants that produce small quantities of pollen whereas much of the pollen is from plants rarely represented by seeds and fruits. About half of the plant taxa in the pit are represented only by pollen, a third by pollen in addition to seeds and fruits, and a few taxa only by seeds and fruits. After considering the possibility that pollen was introduced into the pit by wind, rain, or trampling, the authors conclude that both foodstuffs and fodder were stored in the pit: seeds and fruits representing foodstuffs and pollen representing stored leaf and twig fodder.

Bryophytes and bracken fern recovered from the Roman fort of Vindolanda (Northumberland, UK) demonstrate how these overlooked plants can illuminate environmental conditions and suggest cultural activities. The most abundant moss (55% of the bryophytic material analyzed up to 1976) in samples from Vindolanda was *Hylocomium splendens* (Seaward 1976; Seaward and Williams 1976). *H. splendens* is present in such quantity at Vindolanda that Seaward and Williams (1976) suggest it had a cultural use, perhaps as bedding or to fill gaps in interwoven partition walls. Many other bryophyte taxa are present (Seaward and Williams 1976). These include *Acrocladium cuspidatum* (now known as *Calliergonella cuspidata*), usually found on clay soils in moist habitats in contrast to *H. splendens*, which prefers acid and peaty soils amongst grass and heather; *Brachythecium rutabulum*, which lives in moist grassland or woodland; *Pleurozium schreberi*, an associate of *H. splendens*; *Rhytidiadelphus squarrosus*, an associate of *B. rutabulum* and *P. schreberi*; *Mnium undulatum*, which prefers humus-rich soils in woodlands; and *Thuidium tamariscinum*, characteristic of both woodland and open situations and an associate of the other taxa. The combination of mosses from grasslands, heathlands, and woodlands documents the ecological complexity near Vindolanda. Much of the deposit consists of bracken fern (*Pteridium*). At least 1 ha of bracken fern would be required to cover the 30 m^2 excavated, leading Seaward (1976) to conclude that harvesting bracken was a major community activity. This same area contained over 200,000 stable fly (*Stomoxys calcitrans*) **puparia** (casings that protect transitional insect larvae [singular: **pupa**; plural: pupae]). It seems likely that these rooms contain primarily animal bedding, though the area may have been used to store bracken, to tan and work leather, and to accumulate domestic rubbish. Mosses and ferns might have been used for packing and caulking.

A critical aspect of all human endeavors is the amount of time and energy expended on the acquisition, processing, and care of resources balanced against the return for the cost involved. Many researchers explore the processes and consequences of plant domestication in these terms: why did people domesticate plants and why did they domesticate the specific suite of plants familiar to us today?

These are pertinent questions for early stages, when wild plants contributed substantially to the diet and before the plants and their cultivators were committed to domestication. Abbo et al. (2008a, b) follow a long-established experimental tradition in environmental archaeology by assessing the potential yield and return for effort of modern wild populations of small-seeded plants that eventually became part of a Near Eastern crop tradition that combined legumes with cereals. The authors report on their harvests of wild lentils (*Lens orientalis*, *Lens odemensis*) and chickpeas (*Cicer judaicum*) in Israel (Abbo et al. 2008b). Although patches of wild lentils may be very dense today, stands of wild chickpeas are small and patchy. Compared with controlled productivity experiments using wild wheat and barley, the productivity of both wild legumes is low, below 100 g of seeds per hour of collection. Abbo et al. (2008b) question the role of these small-seeded legumes as targeted or staple foods prior to domestication, adding that several site formation processes might be responsible for the presence of small-seeded legumes in many archaeological sites (e.g., Weiss et al. 2008). This might account for their presence at the site without meaning that they had been collected. Elsewhere, Abbo et al. (2008a) report similar low yields for wild peas (*Pisum*). The authors query whether the abundance of plant taxa in archaeological collections should be evidence of the taxa's economic roles (Abbo et al. 2008b). These studies raise the possibility that yield was not a prime reason for domesticating these legumes.

In a study of crop plants recovered from settlements occupied between 4000 and 2400 cal BC around Lake Constance and in Upper Swabia (Germany), Herbig (2009) finds evidence for dynamic and complex communication systems, mobility, exchange systems, and site functions. The study documents a progressive change in cereals cultivated in the region. The cereals are from 260 samples from 30 sites associated with lakes and mires. Most of the cereals are preserved because they were deposited under wet conditions; carbonized materials are common at only one site. Cereals include naked barley (*Hordeum vulgare* ssp. *nudum*), emmer (*T. dicoccon*), einkorn (*Triticum monococcum*), and a tetraploid naked wheat (*Triticum durum* Desf./*turgidum*). (**Tetraploid** refers to four sets of chromosomes [4*n*]; Chap. 13). Seeds from oil and fiber plants are present, including opium poppy (*Papaver somniferum*) and flax (Herbig and Maier 2011), as are small quantities of other crops. Herbig (2009) reports that tetraploid naked wheat and einkorn are the dominant wheat species in the early part of the sequence, but emmer wheat becomes progressively more abundant. By the end of the sequence, the concentration of naked wheat is very low. Barley is consistently present and more common than any of the hulled wheat taxa. Poppy and flax seeds are present in considerable quantities and increase over time in collections from Upper Swabia as well as in collections from Lake Constance (Fig. 7.12). Although these changes in husbandry regimes may be due to changes in climate, soil quality, or aspects of culture history, they seem more clearly to suggest influences from neighboring regions. Herbig (2009) hypothesizes that sites in Upper Swabia were part of a complex residential network involving settlement dimorphism, with some sites occupied only during the growing season to process oil and fiber crops. Some of the Lake Constance sites, however, probably were occupied continuously for 50–60 years.

Summary

Strategies in plant use had far-reaching consequences for landscapes, cultural institutions, and human health. Seeds and fruits, however, do not provide the full range of environmental and cultural information that can be gleaned from plants. Other plant parts offer additional insights into landscapes, cultural institutions, plant use, and health. In the next chapter, the contributions of wood, wood charcoal, stems, fibers, leaves, and roots are reviewed.

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Chapter 8
Wood, Wood Charcoal, Stems, Fibers, Leaves, and Roots

That plants have many uses other than food is particularly obvious when wood, wood charcoal, stems, fibers, leaves, and roots are considered. Although some of this diverse group of plant materials are used as foods, beverages, drugs, and animal fodder, others are important in structures, fabrics, bedding, tools, firewood, and as ingredients in multi-faceted manufacturing processes. Some are used in ornaments, statuary, and other decorative or symbolic objects, many of which are associated with social structures, belief systems, and rituals.

Ecological and functional aspects of wood anatomy expand upon cultural uses of plants, the appearance of earlier environments, and environmental changes. Trees are environmentally sensitive and document local and regional distributions of individual taxa, broader woodland compositions, vegetational histories, climatological patterns, and trade routes. Episodic growth suggests ecological and climatological patterns through time, as well as the human impact on managed and unmanaged forests. Fire regimes are important ecosystem processes; and changes in those regimes might be attributed to changes in forest tree composition, climate, or human activity, among other explanations (e.g., Ohlson et al. 2011). Episodic growth patterns are fundamental to dendroarchaeology, which uses the patterns to establish local and regional calendars and document environmental changes.

The properties and uses of raw materials, such as wood and fibers, often are closely matched, introducing an element of bias into the archaeological record as people select materials they consider best for each purpose and ignore ones that might be more common but may not be considered as suitable. Forests and woodlands may be managed to sustain such valued resources; or they may be cleared for settlements, fields, pastures, and roads. This can lead to deforestation, erosion, changes in drainage patterns, and habitat loss. Some organisms will not be able to live in the new landscape; others will thrive in the newly patchy, scrubby habitats and open landscapes. Often fire was used to manage pastures, woodlands, and farmlands, leaving evidence in the form of charred stems, leaves, and roots. Burned wood also may be debris left from fuel, trash disposal, funerary rituals, wildfires, or razed villages.

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The primary subjects of this chapter are wood and wood charcoal. Technically, **wood** is the secondary xylem of woody plants constituting the major permanent tissue of stems and roots (Gifford and Foster 1989:511). Archaeologists, however, often use the term for any woody plant material that is not burned. Although the term "charcoal" may be used to refer to any burned organic material (i.e., bone charcoal), in plants, **charcoal** refers to what is produced when wood and other plant tissues are reduced to elemental carbon by burning. Charcoal is chemically inert and not subject to microbial attack; thus it has good preservation potential in contexts where uncarbonized materials do not survive. Sometimes burned wood is referred to as **wood charcoal** to distinguish between burned wood and carbonized seeds, fruits, nut shells, and non-woody roots. When the wood's structure persists in wood charcoal, it may suggest some ways in which the wood was used or aid in assessing the role of fire in creating and maintaining plant communities.

This chapter also considers stems, fibers, leaves, and root, which generally are rare in archaeological assemblages. Sometimes their presence is documented in pottery, bricks, plaster, and floors, or in deposits where decomposition is slowed. When preservation permits, they may be abundant and are valuable sources of knowledge about environments, construction and manufacturing techniques, and plant products other than seeds and fruits (e.g., Chandler-Ezell et al. 2006; Purdy 1988).

Nomenclature

Plants have three tissue systems (Campbell et al. 2008:742–744; Gifford and Foster 1989:34). The **vascular tissue system** conducts water and nutrients, provides support, and stores food. The **dermal tissue system** consists of the outermost cellular layers, which provide protection and a mechanism for gas exchange. The **fundamental** or **ground tissue system** is located between the dermal tissues and the vascular tissues (Campbell et al. 2008:742) and is involved in metabolic functions, photosynthesis, storage, and secretion. These categories are not mutually exclusive. The cellular composition and arrangement of these systems variously distinguish between young and mature woods, woody and non-woody materials, gymnosperms and angiosperms, and monocotyledons and dicotyledons (Gifford and Foster 1989:511–518; Krogh 2009:501).

Vascular tissues include phloem and xylem (Fig. 8.1; Campbell et al. 2008:745–746, 750; Krogh 2009:487, 506). **Phloem** consists of living cells arranged more or less as elongated, interlocking tubes through which photosynthetic and other metabolic products pass (Thain and Hickman 2004:539). **Xylem** is the primarily non-living portion of the transport system and consists of mineral/water-conducting, supportive, and storage cells (Thain and Hickman 2004:745). When a xylem cell reaches maturity, its cellulose wall is reinforced with lignin and the cell dies.

Xylem includes tracheids and vessel elements (Fig. 8.1). **Tracheids** conduct water and provide support by means of long, thin, hollow cells with tapered ends (Campbell et al. 2008:745; Thain and Hickman 2004:703). **Vessel elements**

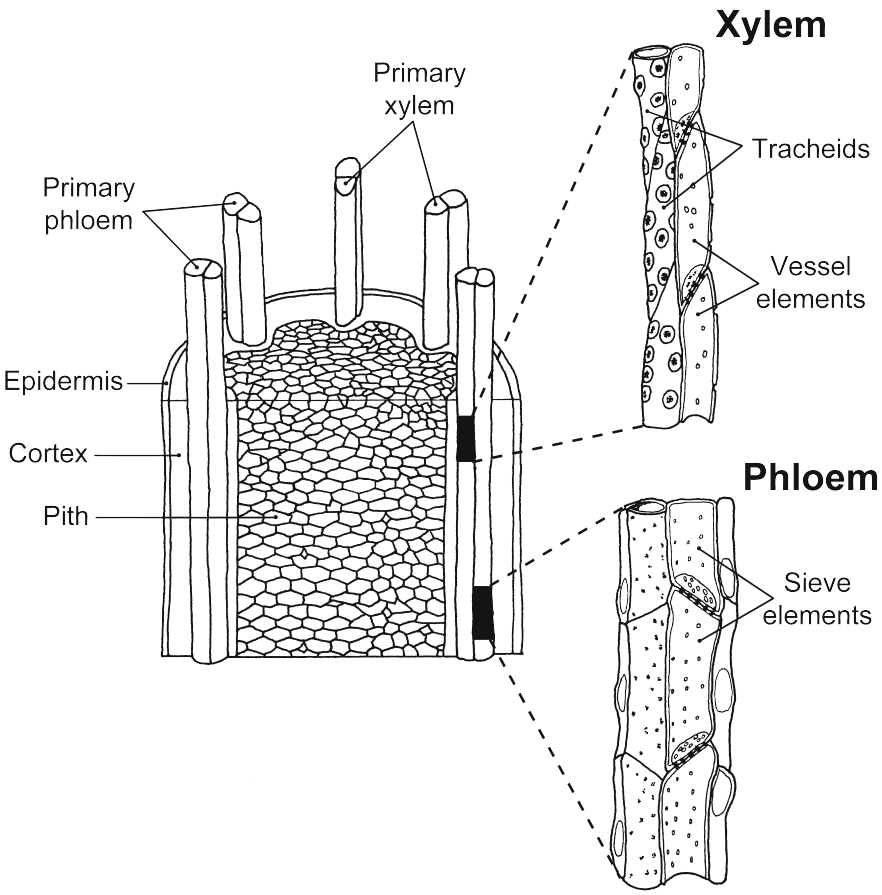

Fig. 8.1 A stylized vascular bundle showing the location of primary xylem, primary phloem, and other features. Modified from Campbell et al. (2008:746, 750) and Krogh (2009:487, 506)

commonly are shorter, wider, and less tapered than tracheids. The ends of vessel elements are perforated so that when individual elements are arranged end-to-end, they form continuous tubes or "vessels" through which water and dissolved minerals flow (Campbell et al. 2008:745; Thain and Hickman 2004:733). When a slice of wood is viewed in transverse section, the ends of vessel elements appear as circular holes or **pores** (Figs 6.5 and 8.2; Moskal-del Hoyo et al. 2010:2109; Pearsall 2000:145). The walls of tracheids and vessel elements have **pits** that allow for inter-cellular fluid conduction. The size and number of vessels are related to water transport and may provide evidence for the amount of moisture available to the plant, observations important for reconstructing environments and tracking environmental changes (e.g., Marconetto 2010). Gymnosperms rely exclusively on tracheids; this distinguishes them from angiosperms, which have both tracheids and vessel elements.

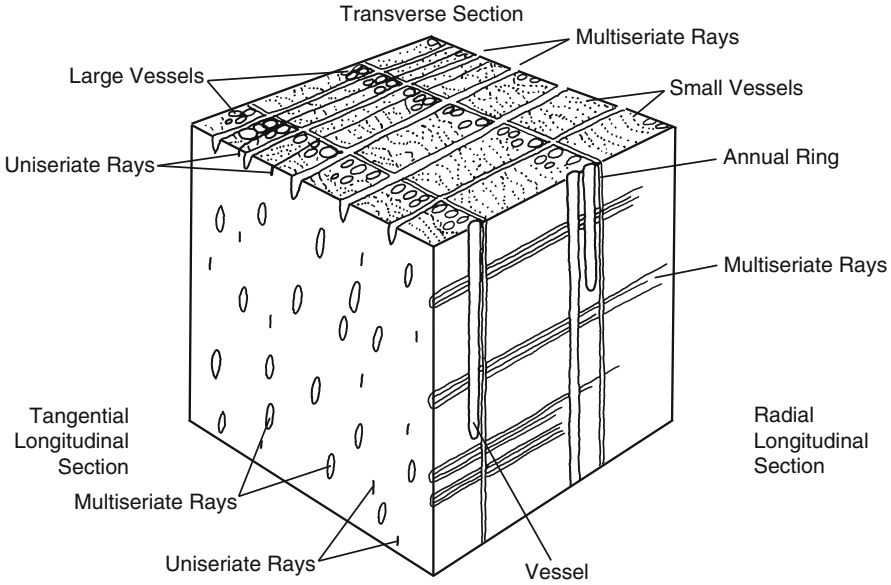

Fig. 8.2 Transverse, tangential longitudinal, and radial longitudinal sections of a typical hardwood. From Pearsall (2000:145) and used by courtesy of the author and Left Coast Press

Distinctions between young and mature plant tissues are based on plant growth and development. Plants generally grow throughout their lives (**indeterminate growth**). They are able to do this because of embryonic tissues in meristems (Campbell et al. 2008:746). **Meristem cells** retain the capacity for cell division, in contrast to **permanent cells**, which usually no longer divide. **Apical meristems** are actively dividing zones at the tips of roots and at the ends of shoots. They produce **primary phloem** and **xylem** during **primary growth**. **Lateral meristems** give rise to **secondary phloem** and **xylem**, among other features, during **secondary growth** (Fig. 8.3; Campbell et al. 2008:752; Krogh 2009:511). Primary growth is associated with increases in length and secondary growth results in a progressive thickening of roots and stems. The term "wood" should be applied only to the secondary xylem of woody plants (Pearsall 2000:144), though sometimes it refers to all secondarily thickened plant tissues.

Primary and secondary growth may occur at the same time. Primary growth is more typical of the youngest parts of the plant and secondary growth is more typical of the older parts. Non-woody, herbaceous plants have only primary growth characteristics and woody plants (e.g., trees, woody shrubs) have characteristics of both primary and secondary growth (Krogh 2009:509). Gymnosperms and many eudicot species have characteristics of secondary growth, but secondary growth is rare in monocotyledons (Table 7.2; Campbell et al. 2008:751).

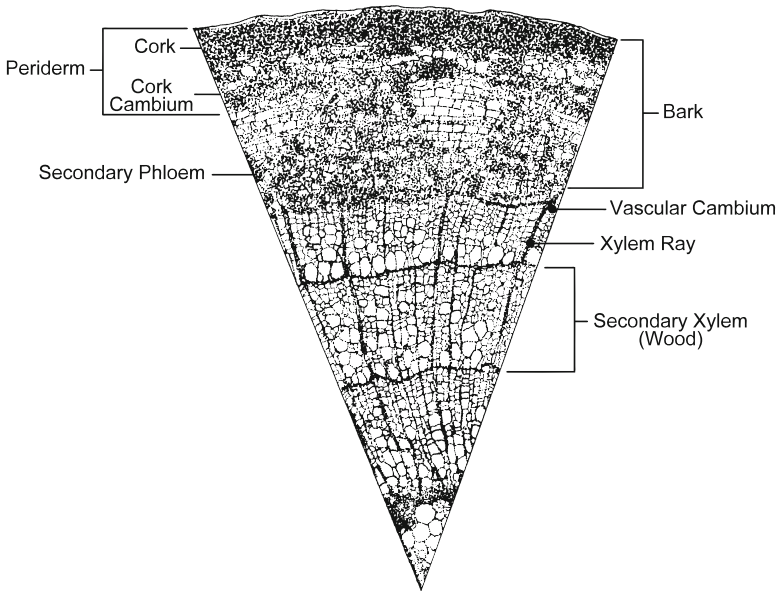

Fig. 8.3 Wood (secondary xylem) and its relationship to other aspects of a 3-year-old stem. Modified from Campbell et al. (2008:752) and Krogh (2009:511)

The dermal system includes epidermis in non-woody plants and the **periderm** (cork cambium and its products) in woody plants (Fig. 8.3; Campbell et al. 2008:742, 752–754). The **epidermis** consists of the thin layer of outermost cells in non-woody plant tissues, such as leaves, young stems, and roots (Harris and Harris 2001:42). During secondary growth in woody plants, the thin epidermis of primary growth is replaced with several layers of living and non-living outer tissues collectively known as **bark**. Bark consists of the outermost layers of a woody stem external to vascular cambium (Harris and Harris 2001:140). **Vascular cambium** is a thin layer of actively dividing cells located between primary xylem and primary phloem; it produces secondary xylem (wood) to the inside and secondary phloem to the outside (Harris and Harris 2001:140; Thain and Hickman 2004:729). Bark includes the secondary phloem as well as cork cambium and cork. **Cork cambium** is a product of secondary phloem and produces a protective outer layer of cork cells (Krogh 2009:511). Repeated growth of cork cambium gives rise to radiating rows of primarily cork cells (Thain and Hickman 2004:175). Cork and cork cambium jointly constitute the periderm, the protective coat that replaces the epidermis during secondary growth (Campbell et al. 2008:742, 754). As successive layers of secondary tissue accumulate and the plant increases in diameter, the accumulating girth is traversed by radial strips or **rays**. As the plant grows, new rays connect the center of the branch with its outer surface. Rays store and transport carbohydrates produced by photosynthesis.

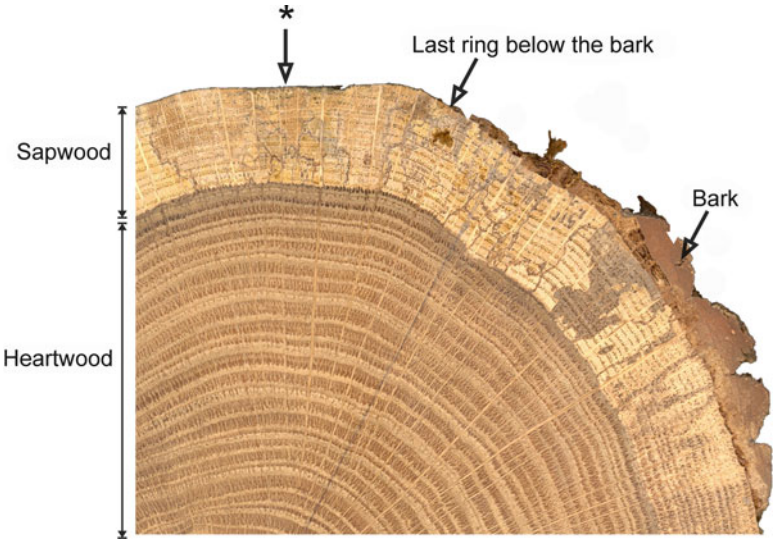

Fig. 8.4 Cross-section of an oak (*Quercus*) beam showing heartwood, sapwood, and bark. An estimated two rings are missing at the location marked with *asterisk*. From Haneca et al. (2009:4) and used by courtesy of the authors and Elsevier

Sapwood is secondary xylem that continues to transport fluids (**sap**) and **heartwood** is secondary xylem that is no longer functional (Fig. 8.4; Campbell et al. 2008:754; Haneca et al. 2009:4; Harris and Harris 2001:53, 102; Krogh 2009:512). Sapwood is, therefore, the newer part of a woody stem located around the periphery of the wood cylinder (**cone**). Heartwood is the innermost wood and is a repository for tannins, gums, resins, oils, and lignin. These stored products give heartwood a distinctive dark color compared with the lighter colored, outer wood whose xylem still conducts sap.

Secondary growth generally occurs periodically in response to temperature, sunlight, rainfall, nutrients, and pests. This episodic growth habit produces concentric bands (**growth increments**) of secondary xylem and phloem in some taxa and in some locations (Figs. 8.3 and 8.4; Haneca et al. 2009:4; Krogh 2009:510). Xylem bands may consist of two parts in a mature plant: wider bands of thin-walled, large-diameter tracheids alternating with narrower bands of thick-walled, small-diameter tracheids with correspondingly smaller cavities (singular: **lumen**; plural: lumina) within each cell. A narrow band of tracheids may mark the beginning and end of growth during a cycle, perhaps distinguishing between early and late wood. Droughts and other episodes of physiological stress are recorded in these growth patterns; plants grow more in some years than in others.

The tendency is to think of episodic growth as a response to alternating seasons of heat and cold or dry and wet; but it actually occurs during periods of optimal growing conditions, when growth may be rapid. These alternate with periods of less satisfactory growing conditions during which growth is slow or the plant is dormant.

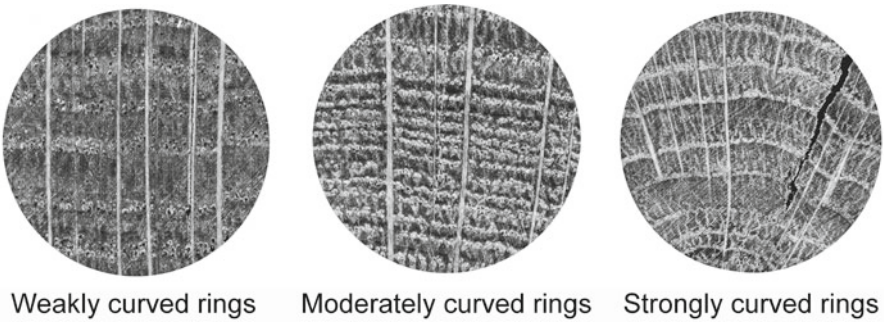

Fig. 8.5 Weakly, moderately, and strongly curved rings. From Marguerie and Hunot (2007:1421) and used by courtesy of the authors and Elsevier

Some growth bands are intra-annual and others form in response to stimuli that are not seasonal or annual, characteristics shared by most episodic growth habits that produce increments in other organisms. Periods of optimal and non-optimal growing conditions do tend to conform to seasons, though not as universally as once thought. Thus, a pair of fast growth and slow growth bands may be interpreted as evidence for growing conditions over a year. A pair of such bands may be termed an **annulus** (plural: annuli) or **annual ring**. The temperature, moisture, and other variables that define seasons are themselves ranges around means and rarely as punctual as either farmers or archaeologists would wish.

Wood grows in response to biomechanical forces. **Tension** occurs when branches lean or droop and **compression** occurs as branches bear weight. One side of a branch may be under tension and the other side under compression. The tree may add extra wood to sustain this stress, producing **reaction wood**. Responses to biomechanical stresses may be seen in the curvature of growth rings and the angle of the rays relative to that curvature (Fig. 8.5; Marguerie and Hunot 2007:1421). Weak curvatures are seen in wood from trunks and strong curvatures in branches (Marguerie and Hunot 2007). Eccentric growth and other characteristics may provide additional evidence for the conditions of growth and the choice of woods.

Fundamental or ground tissue lies beneath the dermal system and surrounds the vascular system (Campbell et al. 2008:751). Ground tissue may contain parenchyma, collenchyma, and sclerenchyma cells (Catling and Grayson 1998:21; Gifford and Foster 1989:35–37).

Parenchyma cells are undifferentiated living cells of various sizes and shapes located between dermal and vascular tissues. They perform most of the metabolic and storage functions of the plant (Campbell et al. 2008:744; Gifford and Foster 1989:37–38; Thain and Hickman 2004:523). They generally have thin, soft walls. Rays are mainly parenchyma cells, as is the fleshy tissue of most fruits. Lenticels are raised, lens-shaped patches of parenchymatous tissue on the surface of young, woody stems and the surfaces of some fruits (Harris and Harris 2001:64; Jones and Luchsinger 1986:219; Thain and Hickman 2004:403).

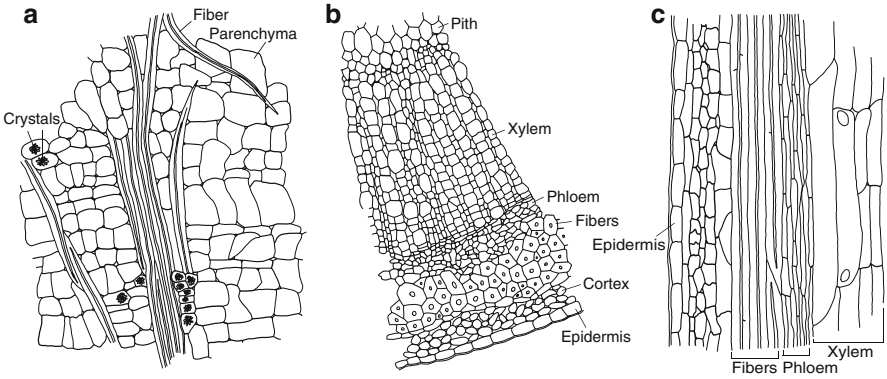

Fig. 8.6 Location of elongated fiber cells (sclerenchyma cells) and crystals: (**a**) tangential longitudinal section (TLS) of a hemp (*Cannabis sativa*) stem showing location of fibers, crystal inclusions, and parenchyma cells; (**b**) transverse section of a flax stem (*Linum usitatissimum*) showing location of fibers; and (**c**) longitudinal section of flax stem showing location of fibers. From Catling and Grayson (1998:14, 15, 21)

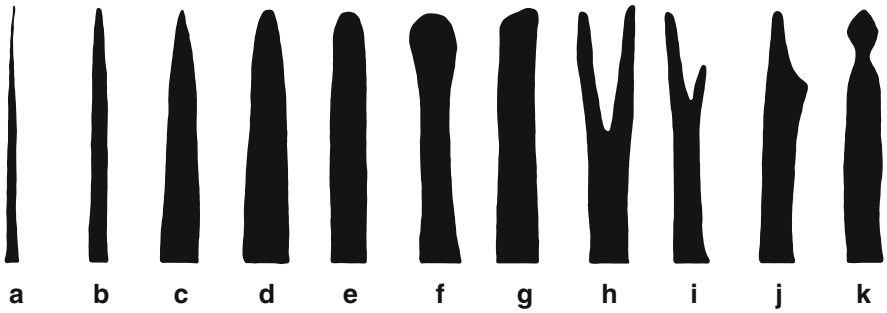

Fig. 8.7 Various fiber cell end shapes: (**a**) tapering and pointed; (**b**) tapering and rounded; (**c**) pointed; (**d**) bluntly pointed; (**e**) rounded; (**f**) spatulate; (**g**) square; (**h**) bifurcated; (**i**) unequally bifurcated; (**j**) scimitar-like; and (**k**) constricted. From Catling and Grayson (1998:2)

Collenchyma cells are living cells that lack secondary walls and lignin (Campbell et al. 2008:744; Gifford and Foster 1989:35, 38). Their walls are irregularly thick (Krogh 2009:505). They support parts of the plant that are still growing and provide flexibility.

Sclerenchyma cells provide mechanical support, rigidity, fluid transport, hardness, and defense against herbivory (Campbell et al. 2008:744, 751; Krogh 2009:502; Pearsall 2000:148–149; Thain and Hickman 2004:638). They are thick-walled, lignified cells that often die upon maturity (Gifford and Foster 1989:38). Tracheids and vessel elements are types of sclerenchyma cells, as are fiber cells and sclereids. **Fiber cells** are long, slender, tapered cells with ends of diverse shapes (Figs. 8.6 and 8.7; Catling and Grayson 1998:2, 14, 15, 21; Gifford and Foster 1989:38). **Sclereids** are shorter fiber cells with irregular shapes that occur as clusters or as isolated cells (Gifford and Foster 1989:37). Sclereids reinforce bark,

nut shells, and some fruits. They are responsible for the gritty texture of pears (*Pyrus communis*), for example.

Primary growth typically produces arrangements of xylem and phloem that distinguish monocotyledons from dicotyledons (Table 7.2). Primary xylem and phloem are arranged in **vascular bundles**, with xylem internal to phloem. Generally, vascular bundles in monocotyledons are scattered irregularly throughout the stem. In dicotyledons, vascular bundles are arranged in a circular pattern, forming rings. This circular pattern defines the center of the stem, the **pith** (spongy, parenchyma tissue located in the center of the branch, twig, or stem and internal to the vascular region), and the **cortex** (an outer layer of parenchyma tissue located between vascular bundles and the epidermis; Thain and Hickman 2004:177).

A leaf generally consists of a flattened **blade** on a stalk (**petiole**) that joins the stem at a **node** (place on the stem from which leaves or branches originate; Fig. 8.8; Harris and Harris 2001:141; Jones and Luchsinger 1986:222–223). Leaves of gymnosperms often are needle-shaped. Angiosperm leaves have many different shapes, such as smooth, lobed, or toothed (Harris and Harris 2001:148–164). Surfaces may be plain, or have scales, pits, apertures, hairs, thorns, waxes, channels, textures, facets, fenestrations, and other characteristics (Harris and Harris 2001:164–172). Likewise, leaves differ in their **leaf base** (the part of the blade nearest the point of attachment), the **apex** (the tip of the leaf), **venation** (the pattern of veins on the leaf), attachments, the number of leaves per node, and other features. Succulents (e.g., cactus [Cactaceae]) are distinguished from other plants because they store water in their leaves, stems, or roots, giving them a fleshy, juicy appearance or texture. The leaves of monocotyledons usually are long and slender, with their veins running parallel to the long axis (Table 7.2; e.g., a blade of grass [Gramineae (Poaceae)]). Grasses and some other monocotyledons do not have petioles (Campbell et al. 2008:741; Harris and Harris 2001:84). The leaves of dicotyledons (e.g., oak [*Quercus*]) often are broad and the veins are strongly branched in a number of different patterns. Stomata primarily form on leaves and are protected by **guard cells** (Harris and Harris 2001:114). Generally, stomata and guard cells are arranged in rows parallel with the long axis of the leaf in monocotyledons and are scattered across the leaf in dicotyledons (Thain and Hickman 2004:670). Leaf structures distinguish among plants from damp or aquatic habitats (**hydrophytic**), habitats with average moisture (**mesophytic**), and arid habitats (**xerophytic**).

Plants have other traits that reflect different growth habits, environments, and cultural uses. Monocotyledons are mostly herbaceous, many are annuals and lack a persistent above-ground woody stem. Most have only primary growth, though palms are monocotyledons with secondary growth (Table 7.2). Some dicotyledons are herbaceous, but many are perennials and have secondary, woody growth. Most gymnosperms are **evergreens**; their leaves persist throughout the year. Many perennial angiosperms in the temperate zone are **deciduous**; their leaves are replaced on a seasonal schedule each year. Often gymnosperms are referred to as **softwoods** and angiosperms as **hardwoods**, reflecting chemical, physiological, and structural differences between these two broad groups that aid in the identification of wood and wood charcoal.

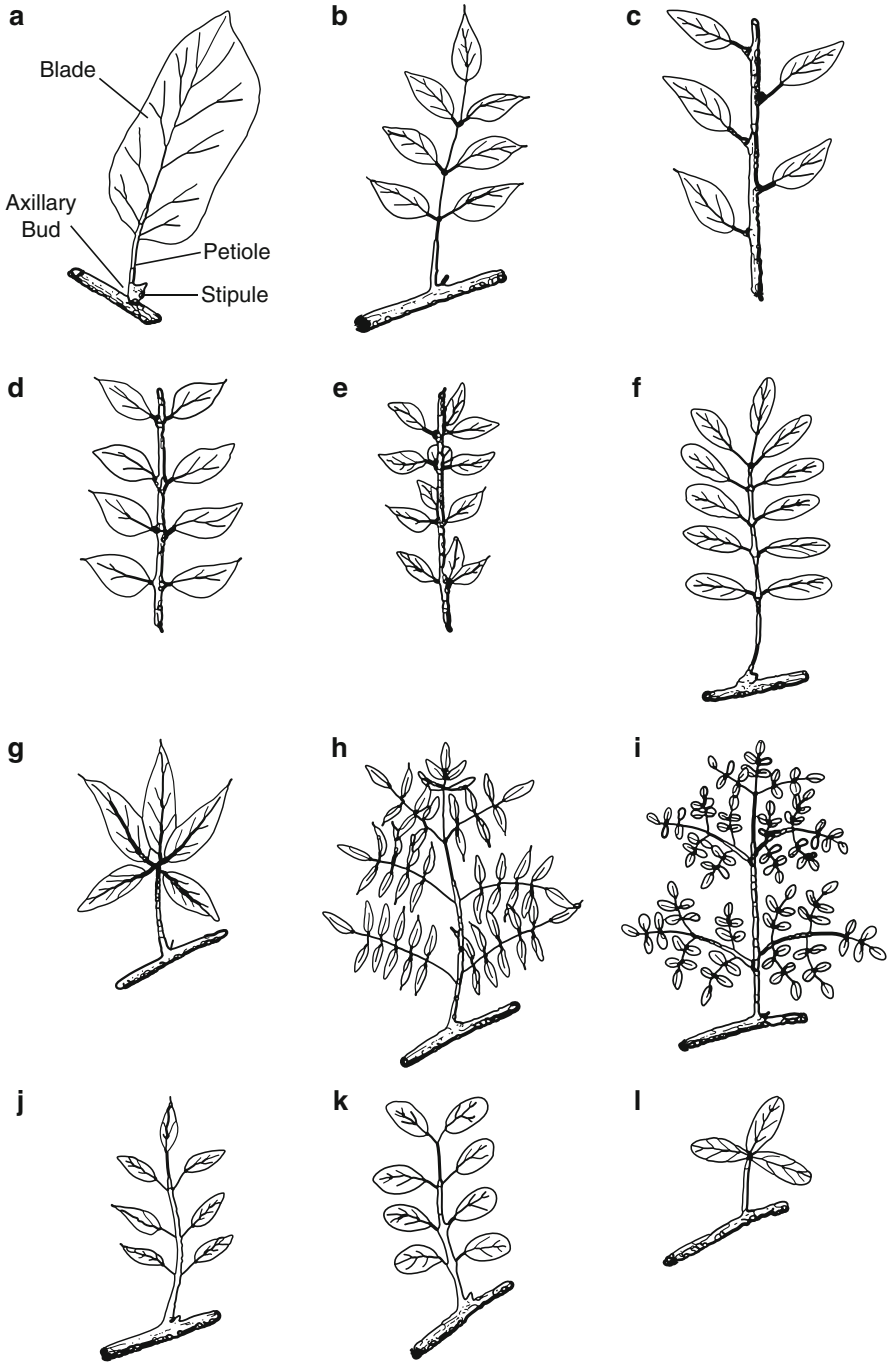

Fig. 8.8 Leaf types and parts: (**a**) simple leaf; (**b**) compound leaf; (**c**) alternate leaf; (**d**) opposite leaf; (**e**) whorled leaf; (**f**) once pinnately compound leaf; (**g**) palmately compound leaf; (**h**) bipinnate leaf; (**i**) tripinnate leaf; (**j**) odd-pinnate leaf; (**k**) even-pinnate leaf; and (**l**) pinnately trifoliate (ternate) leaf. From Jones and Luchsinger (1986:223) and used by courtesy of The McGraw-Hill Companies

Site Formation Processes and Field Considerations for Wood and Wood Charcoal

Although the term "wood" should be restricted to secondary xylem of woody plants, it is used to refer casually to anything from a sizeable chunk of true wood to fragments of twigs and stems. Where decomposition is slowed, uncarbonized plant material of all sorts may be abundant; but plant remains most often survive because they were partly burned. Diagnostic features of wood and other plant tissues are altered in either case (Pearsall 2000:150–153).

Wood

Uncarbonized wood typically is preserved in permanently waterlogged, dry, or frozen contexts (e.g., Jiang et al. 2009; Noshiro et al. 2009; Zheng et al. 2009). The condition of preserved wood varies from near-perfect in acidic peats to perilous friability in contexts with extreme aridity. In some cases, the surviving wood is replaced by minerals and in others it is too spongy, fragile, or decomposed to process for study. Some woods may be unmodified, and others may be substantially altered as tools, architectural elements, ornaments, statuary, and many other objects (e.g., Noshiro et al. 2009).

Wood should be handled with care. Decisions about how to collect uncarbonized wood is best made by a wood specialist who knows what will be useful for further study. If a researcher skilled in wood identification cannot be present, field staff should consult a wood specialist about the size and quantity of wood to collect and how to collect it. If an informed choice cannot be made in the field, the decision as to what to study should be made later, in the laboratory. No attempt should be made to separate wood that is attached to some other substance (e.g., a collapsed wall, a metal object). Removing the wood may cause composite materials to crumble into unidentifiable fragments. Nor should wood or composite materials be washed or handled roughly. As a general rule, dry wood should be kept dry and wet wood should be kept wet until conservation measures are undertaken. A dark, refrigerated environment is preferred for interim curation. If the curatorial facility recommends use of a fungicide or preservative, a permanent label identifying the chemical(s) and the dilution should be kept with the specimen at all times. Materials required for dating by radiocarbon assay should not be treated with chemicals, however.

Drawings of the materials in situ, accompanied by photographs and maps with the positions of the wood samples clearly marked, and unambiguously labeled with the sample number, ensure that subsequent researchers will know which samples were found together and which were not. Pieces of wood may be from the same or different timbers or from different parts of a wattle and daub structure (a lattice work of branches and sticks [**wattle**] embedded in daub). Great confusion arises if many samples are taken from the same construction feature, such as a well casing or a causeway, without adequate notations. It rarely is clear in the laboratory which

samples contain different parts of the same piece of wood, wood from the same feature, or wood from several different features.

It is likely that the conservator and the wood specialist will not be in the same laboratory; thus, if an accelerated identification is required, the project director will need to ensure coordination among field staff, wood analyst, conservator, and curatorial facility. In some cases, a choice must be made between stabilizing wood immediately and having wood available for studies that require untreated materials, such as radiometric dating. Most conservators will want to know the wood type before initiating conservation because different processes may be required for angiosperms, gymnosperms, and specimens with fungal hyphae. Conservators may want to know the condition of the cell walls and other aspects of the specimen. Thus, a preliminary identification may be required before treatment options can be considered. Refined study techniques make it possible to examine very small fragments that can be removed from an object without causing undue harm. This level of coordination is more likely to be successful when arrangements are made in advance.

Wood Charcoal

Wood charcoal becomes part of the archaeological record through a variety of site formation processes (Smart and Hoffman 1988). The most obvious source of wood charcoal is when wood is burned as fuel. In other cases, the charcoal may indicate some other process. The site itself may have burned, intentionally or unintentionally, or wood may have burned as garbage, while clearing land, or for many other reasons.

Studies associating woods with their uses show clear choices between wood properties and specific applications (e.g., Lentz and Hockaday 2009; Noshiro et al. 2009). The properties of woods used as fuels in fast or slow fires, terraces, ship masts, tools, or decorative objects will be very different. Choices will be made about which part of a plant (e.g., twigs, trunks) to use for each purpose. A match between wood properties and function is evident in the wooden trackways at the Somerset Levels (UK) and at other sites where organic construction materials are preserved (Coles 1984; Purdy 1988). Sometimes people use woods that are close to hand (e.g., Newton 2005). At other times, they acquire special woods from much further away. Although exotic woods cannot provide evidence of plant communities previously growing near the site; they provide insights into choices involved and suggest trade networks (Smart and Hoffman 1988).

Burning does not, of course, ensure that wood will survive, and the quantity of charred wood in the ground may be only a fraction of all that was burnt, the rest having become invisible to us as ash dispersed through the deposit. In this way, wood charcoal is subject to the same taphonomic agents as other archaeological materials, beyond the enhanced durability conferred by it being charred (Smart and Hoffman 1988). Characteristics of the wood itself as well as the heating rate

(e.g., fast, slow), duration of heating, and temperature range affect the amount of shrinkage and fragmentation that occurs (Smart and Hoffman 1988). The preservation of wood charcoal is highly variable; it may be solid but so friable that it disintegrates when touched or wood may be reduced to an unidentifiable ash. Charcoal in alkaline conditions (e.g., those with pH levels between 8.5 and 12) may fragment into unrecognizable pieces (Braadbaart et al. 2009). Wood charcoal is particularly susceptible to mechanical damage, such as that caused by trampling, fluctuations in temperature and moisture, and handling during excavation.

Wood charcoal is generally collected from soil and flotation samples as these are processed for seeds and fruits, but it is recovered from in situ sampling of special contexts and from screened materials, as well (Newton 2005). Unbiased recovery of wood charcoal is a primary concern. Careful thought should be given to the amount of charcoal to collect and the context. Just as with wood, wood charcoal should be carefully packed and labeled in such a way that it is obvious in the laboratory whether samples are from the same specimen, from the same feature, or from different parts of the site. Samples should be taken both on-site and off-site so as to compare the charcoal found at the site, which probably is of anthropogenic origin, with charcoal that may not be anthropogenic or may be from intentionally burned fields, pastures, and woodlands. No attempt should be made to separate charcoal that is attached to some other substance and it is best not to expose charcoal to water if it is dry when recovered. Samples may be wrapped in foil before being placed in a sturdy container if radiometric dating is anticipated.

How many fragments and which fragments to collect in the field are decisions that should be guided by the research design and the advice of a researcher who knows what is identifiable. As with all other biological specimens, the size of a fragment that can be identified depends on the taxon. Very small plants will likely produce charcoal that is small, but that nonetheless may be readily identified. Some charcoal may be usefully studied even if it cannot be attributed to a taxon (e.g., Moskal-del Hoyo et al. 2010).

Laboratory Procedures and Identification

Determining the size and number of wood or wood charcoal fragments to study is inherently difficult, as it is for all materials reviewed in this volume (e.g., Tolonen 1986). Sampling generally follows procedures described in Chaps 5 and 7. Many researchers use a predetermined standard count to make sampling decisions, working toward a targeted sample size of 200 specimens, for example (e.g., Asouti 2003; Rhodes 1998). Different woods produce wood charcoal of different sizes and the full range of size classes should be studied in order to consider the full range of woods used (Smart and Hoffman 1988). The full size range may be sampled by passing the materials through a series of graded geological sieves and selecting fragments from the fraction captured in each screen size, as described for seeds and fruits (Chap. 7).

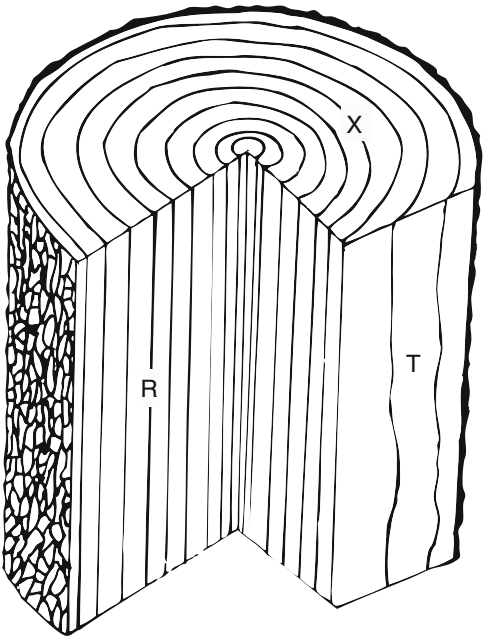

Fig. 8.9 Planes or sections used in wood identification. *X* = transverse or cross section; *R* = radial longitudinal section; *T* = tangential longitudinal section. From Hardy and Garufi (1998:179) and used by courtesy of the authors and Elsevier

Processing

Wood and wood charcoal are prepared by sectioning (waterlogged) or splitting (charred) specimens to expose clear views of three **anatomical planes of reference** defined by their orientation to the main, or longitudinal, axis of the stem (Figs. 6.5, 8.2, and 8.9; Gifford and Foster 1989:512; Hardy and Garufi 1998:179; Jiang et al. 2009). The **cross** or **transverse section** (TS) is cut across the trunk, branch, or stem perpendicular to the main axis, exposing the growth rings ("X" in Fig. 8.9; Hardy and Garufi 1998:179). The other two sections are cut at 90° angles to the transverse section and to each other, oriented down the axis of the branch or trunk. These sections are the **radial longitudinal section** (RLS), which parallels the main axis ("R" in Fig. 8.9), and the **tangential longitudinal section** (TLS), which is cut at a right angle to the RLS ("T" in Fig. 8.9; Hather 2000:4). The radial and tangential sections reveal the growth rings in longitudinal perspectives. These procedures may require treating the materials before sectioning (Hather 1993:16–17).

Identification

As with all environmental archaeology, a good comparative collection and experience, supplemented by illustrated manuals and keys, are needed to identify wood and wood charcoal. The "inevitable variability" noted by Dimbleby (1978:101) does not alter the basic structure, but it does affect more subtle manifestations. Some taxa are readily identified and others are extremely difficult.

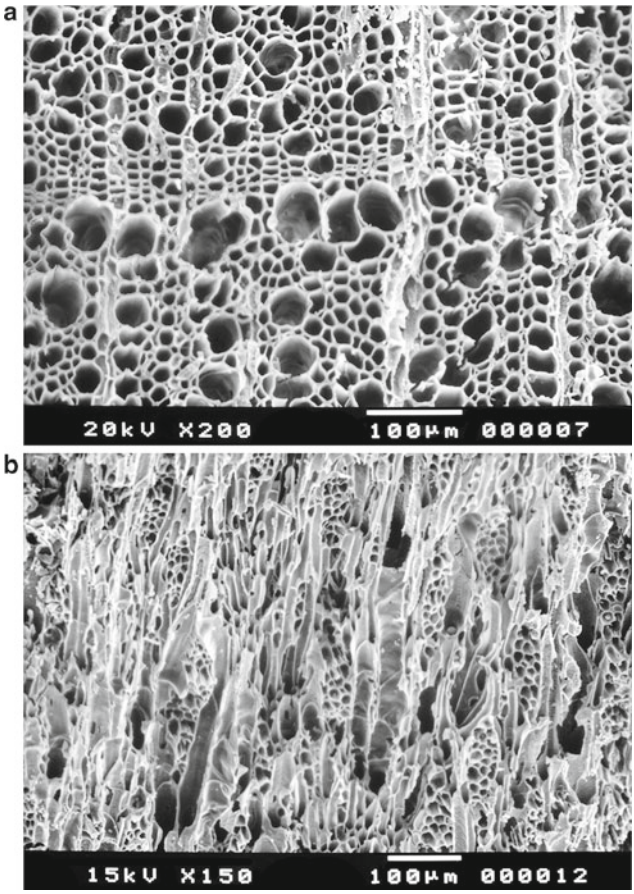

Fig. 8.10 Madrone (Ericaceae: cf. *Arbutus*) wood charcoal from Teotihuacan Valley, Mexico: (**a**) transverse section; and (**b**) tangential longitudinal section. From Adriano-Morán and McClung de Tapia (2008:2932) and used by courtesy of the authors and Elsevier

As with all organic remains, the level to which a piece of wood or charcoal can be attributed is variable, ranging from species to phylum, division, or even kingdom. The reference collection should contain examples of different woody parts of each taxon, some of which are charred, desiccated, waterlogged, or unaltered. Wood samples taken from different parts of the same tree, such as the trunk and a branch, may be markedly different as are healthy, diseased, and reaction wood. Variations within taxa caused by dissimilar growth rates may be especially confusing in conifers, but also cause problems in other groups. Attributions to a species, the most useful level for interpretations, are rare for wood and wood charcoal (Smart and Hoffman 1988), as they are for many biological remains.

Laboratory procedures and identification rely upon characteristics of cell structure and wood anatomy that generally are known to persist in most archaeological materials (Fig. 8.10; Adriano-Morán and McClung de Tapia 2008:2932).

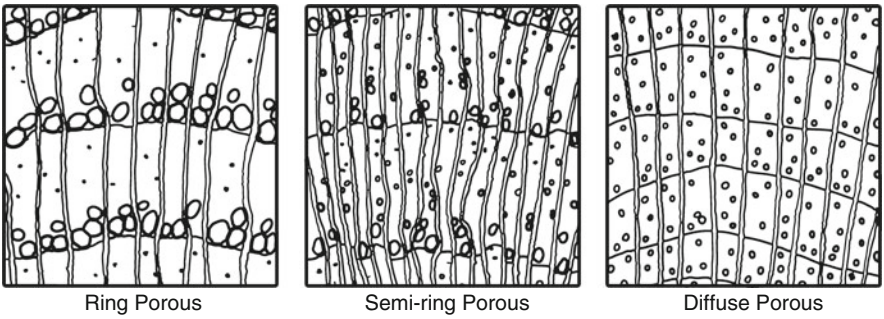

Fig. 8.11 Ring porous, semi-ring porous, and diffuse porous as seen in transverse section of wood. From Pearsall (2000:146) and used by courtesy of the author and Left Coast Press

The identification of wood and wood charcoal is based on the size and arrangement of vessels, pits, pores, and rays; texture; and hardness; as well as on the abundance and nature of parenchyma (Pearsall 2000:145). A preliminary attribute considered is whether vessels are present. If the specimen has vessels it is from an angiosperm; if it does not it is from a gymnosperm. Other characteristics, such as color, luster, taste, and odor, may be absent or distorted in wood charcoal, though present in unburned wood. Familiarity with the appearance of woods in specific archaeological settings is needed to recognize diagnostic characteristics and interpret them correctly. In some cases, for example, radial cracks are encountered in charcoal that may indicate the wood was damp when it burned, or suggest other aspects of wood management (e.g., Marguerie and Hunot 2007; Moskal-del Hoyo et al. 2010).

When present, vessels are variable in size, location, and abundance (Fig. 8.11; Pearsall 2000:146). A common approach to vessels classifies them in terms of their relationships to growth rings, the numbers and size of vessels in a cross-section, and the spacing of vessels (Hather 2000:7; Pearsall 2000:146). In **ring-porous wood**, the vessels formed at the beginning of the growing season are larger in diameter than those formed at the end of the growing season, or they may be proportionately more abundant. In **diffuse-porous wood**, vessels are roughly the same size from the beginning of the growth cycle to the end. In **semi-ring porous wood**, vessel diameters decrease from the early wood to the late wood, a pattern that may be difficult to distinguish from one of the other categories (Hather 2000:7). Vessels may occur singly or be clustered into groups, chains, or other patterns (Pearsall 2000:147).

Rays, which appear in a transverse section as spokes radiating out from the center of the stem, and other parenchyma cells, which may be scattered about the wood fabric, also exhibit diagnostic characteristics (Figs. 8.2 and 8.3; Pearsall 2000:145). Among these are the size, shape, arrangement, and number of rays. They may be narrow bands one cell wide (**uniseriate**), or variable in width containing two or more cells (**multiseriate**). The cells of rays may be characterized as all the same (**homogeneous**) or different (**heterogeneous**), as seen in longitudinal section,

and the regularity of spacing is diagnostic. Parenchyma cells not directly associated with rays may line resin canals or form strands running longitudinally through the wood. Parenchyma cells in each of these locations are distinctive in terms of their abundance and their spacing relative to other features.

The growth rings themselves may be analyzed (e.g., Marguerie and Hunot 2007). The degree of curvature of rings and the angle of the rays relative to that curvature may be examined if the specimen is over 3 mm in size (Marguerie and Hunot 2007). The presence of both pith and bark distinguishes branches from very young stems or roots. Narrow growth increments correspond to slow growth and wider rings indicate faster growth.

Keepax (1975) illustrates an application of SEM to study of woods that have been replaced by iron corrosion products. SEM shows that iron was deposited within the cell spaces of the decomposed wood, leaving internal casts of the original structure. Details such as rays, tracheids, vessels, and fungal hyphae are preserved in these casts. SEM aids the identification of such materials, even when the wood is very brittle or soft. The condition of the wood does not seem to affect the identification, though the use of SEM may be beyond what is available to the specialist undertaking the identification of such material.

Analytical Procedures

Many of the analytical procedures used for seeds and fruits (Chap. 7) are applied to wood and wood charcoal to study ecological and functional wood anatomy, among other attributes (Rhodes 1998; Tolonen 1986). Typically, studies begin with unquantified lists of the taxa present in the study assemblage. Taxa in these lists may be grouped by growth habits (e.g., large trees, shrubs, woody vines), taxonomic affiliation (e.g., gymnosperm, angiosperm), or habitat preferences (e.g., **xerophytic** [capable of surviving prolonged drought or living in arid habitat], ruderal). Ubiquity or presence analyses use taxonomic lists.

Specimen counts, weights, and measurements are the primary data most frequently used in quantified analysis. The count may be summed for each taxon, for specific types of wood or wood charcoal (e.g., xerophytic), or for specific contexts. Counts and weights may be converted into percentages. A density ratio (expressed as the total weight of charcoal per liter of sample) may be calculated. A comparison ratio assessing fragmentation and preservation (**F/P index**) is derived by dividing the total number of indeterminate specimens by the total number of identified specimens per sample (Asouti 2003). This index assesses taphonomic characteristics in the assemblage. Measurements of growth ring widths may be plotted or the percentage of woods with weakly, moderately, and strongly curved growth rings may be calculated (Marguerie and Hunot 2007). Individual charcoal particles may be quantified into size classes defined by particle length or surface area (Rhodes 1998). In some cases, identifications are presented in diagrams very similar to those used for pollen and phytoliths (Newton 2005; Chap. 9).

Non-woody Stems, Fibers, Leaves, Other Plant Tissue Fragments

Other types of plant tissues, such as cereal bran, fibers, twigs, cane, and masticated cuds, offer unique glimpses into life in the past (e.g., Kenward and Hall 1997; Kvavadze et al. 2009). When such materials are recovered, they alert us to how much of the archaeological record is lost as well as to how common such materials were in the past (e.g., Purdy 1988; Vanden Berghe et al. 2009). Ethnographic observations likewise remind us of how critical leaves and stems are as sources of vitamins, minerals, dietary fiber, and proteins (e.g., Marshall 2001). Other sources remind us of the important roles plants play in textiles, basketry, architecture, animal husbandry, and manufacturing. Woad (*Isatis tinctoria*), for example, yields a blue dye used in textiles, but also was used in pigments for hand-painted books, as a medicine, and as animal fodder (Zech-Matterne and Leconte 2010). Soils in which woad is grown must be augmented with manure, linking the production of this economically important plant with livestock management. Producing the indigo dye requires reducing the precursor molecules into a more soluble substance using the bacterium *Clostridium isatidis*, followed by oxidation to blue in the air.

Organic objects recovered from sites that were buried rapidly by ash and mud flows may be staggering in their richness and complexity. Non-woody stems, fibers, and leaves may survive in other contexts where bacterial activity and mechanical damage is limited, such as where anoxic, acidic, wet, desiccated, or very cold settings prevail. Materials that were ingested, such as cereal bran, may be recovered from palaeofeces and abdominal cavities, as well as in the fill of cess pits on sites with waterlogged preservation.

"Fiber" in this chapter refers to materials extracted from plants, distinguishing fibers of plant origin from those of animal origin (e.g., Ryder 1984). As noted above, plant fibers are sclerenchyma cells (Catling and Grayson 1998:14, 15, 21; Gifford and Foster 1989:36–38; Pearsall 2000:163). Fiber cells are divided into **bast fibers**, from the outer part of the stem, and **leaf** or **stem fibers**, from within the vascular bundles of leaf bases, stems, or roots (e.g., Catling and Grayson 1998:7). Bast fibers are soft and derived from dicotyledons such as hemp (*Cannabis sativa*), jute (*Corchorus*), and flax (*Linum usitatissimum*, used to make linen). Leaf fibers are stiff and hard. They are obtained from strongly lignified tissues of monocotyledons such as abaca or manila hemp (*Musa textilis*) and sisal hemp (*Agave sisalana*). A third type of material is exemplified by the seed hairs of cotton (*Gossypium*), in which the "fibers" are individual epidermal hairs attached to each seed (Pearsall 2000:163).

Fibers may occur singly, in strands, or in bundles (Fig. 8.12; Bar-Yosef et al. 2011:345; Kvavadze et al. 2009; Thain and Hickman 2004:638). Identification is based on characteristics such as texture, the arrangement of fibers in a **strand** (bundle of fibers), the length and width of fiber cells, the appearance of the fiber in transverse section, characteristics of the cell wall and lumen, the presence of crystals and cells from tissues other than sclerenchyma, and cross-markings.

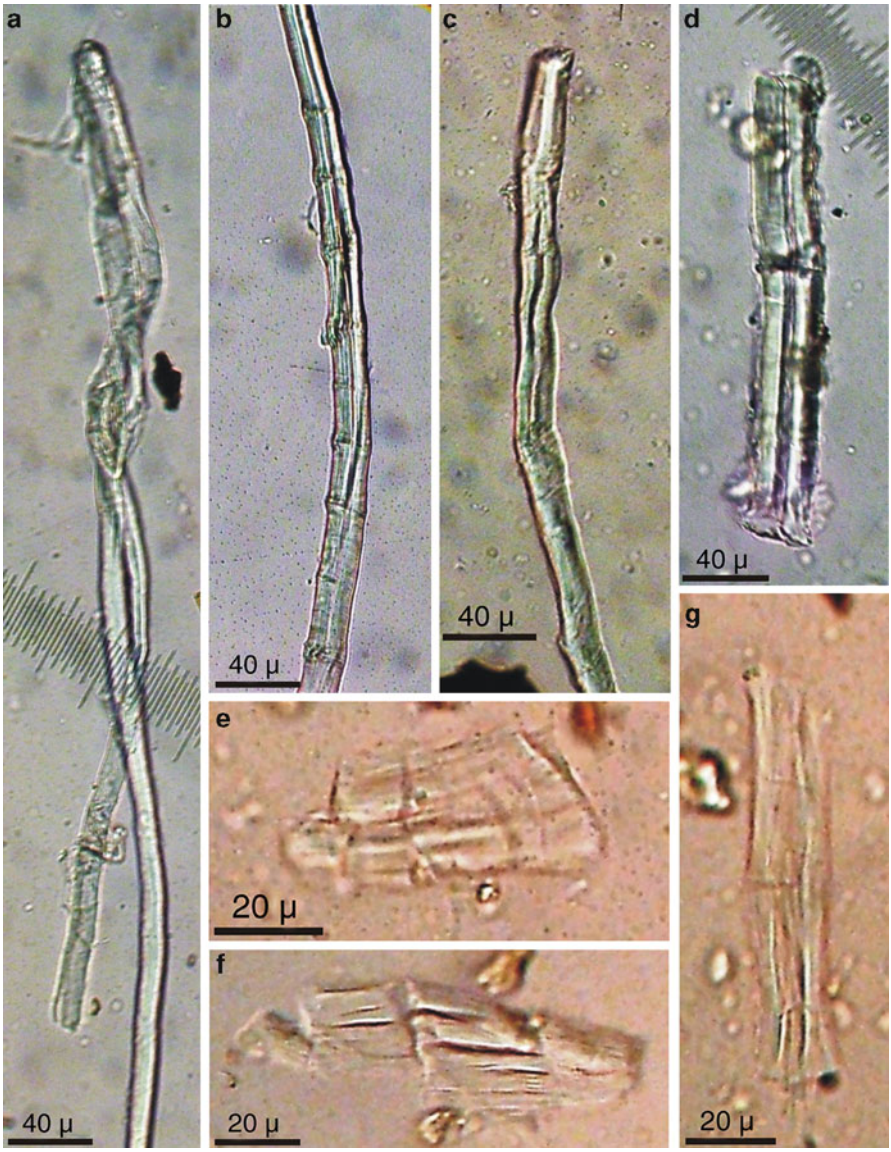

Fig. 8.12 Flax (*Linum*) fibers from Dzudzuana, Georgia: (**a**) twisted flax fibers; (**b**–**c**) complete flax fibers; (**d**) damaged flax fiber; (**e**–**g**) loose flax fibers. Photograph and analysis by Eliso Kvavadze. From Bar-Yosef et al. (2011:345) and Kvavadze et al. (2009) and used by courtesy of the authors, The American Association for the Advancement of Science, and *Antiquity*

Cross-markings are the impressions made by adjacent cells on the cell wall of the fiber (Catling and Grayson 1998:4). Fiber ends have characteristic shapes (Fig. 8.7; e.g., Catling and Grayson 1998:2). Fiber diameter may distinguish between domestic and wild plant sources; the mean fiber diameter of wild cotton is narrower than

that of domestic cotton, for example (Pearsall 2000:165). Fibers sometimes are identified indirectly from seeds or phytoliths embedded in them. When preservation is outstanding, such as in deserts, dry caves, and waterlogged contexts, cords and textiles used in hafting, basketry, and garments may be in good condition and, in arid conditions, may even retain vivid colors.

Other plant tissue fragments include rootlets, epidermal tissues, tracheids, stomata, guard cells, **trichomes** (epidermal appendages, e.g., hairs or hair-like outgrowths), glands, scales, and cells with inclusions such as tannins, oils, and crystals (Gifford and Foster 1989:35, 497–505; Harris and Harris 2001:148–172; Pearsall 2000:165–168). Several different arrangements are characteristic of angiosperms (Gifford and Foster 1989:502). Venation, the shape of the leaf, characteristics of the leaf margin, surface features, and other aspects of leaf anatomy all may have taxonomic significance (Gifford and Foster 1989:496–502). Plant tissue fragments may provide evidence for leaf fodder and for plants not represented by fruits, seeds, pollen, or phytoliths. Most of these are small finds encountered during microbotanical studies (Faegri et al. 1989:203).

Papyrus is a special case. The giant sedge or papyrus plant (*Cyperus papyrus*) is an aquatic sedge used to make paper, as well as bread (Reed 1972:7–8; Trager 1970:16). The paper was made by cutting the pithy centers of the stalks lengthwise into thin strips. The strips were formed into sheets that were pressed and beaten together while still moist. Egypt is one of the few places papyrus reed grows, and it was the center of papyrus paper manufacture and trade.

True Roots and Stem Roots

True roots and stem roots are vegetative storage organs consisting largely of parenchyma cells (in non-woody plants, at least) and whose primary functions are to anchor the plant, absorb water, and store organic products (Gifford and Foster 1989:23; Hather 1993:vii; Holden et al. 1995). The concentration of starch in these tissues makes them important sources of food for many organisms. Roots are used by people as sources of food and beverages, as well as fodder for livestock and as fuel. Inedible roots, of course, are ubiquitous in all landscapes that support plants. Some roots in archaeological samples are modern intrusions; but charred inedible roots may be residual from burned sod or peat, from fires used to clear land, or from accidental (e.g., a burning house) or intentional (e.g., warfare) conflagrations. Edible true roots and stem roots are the primary foci of archaeological interest. Some distinctions among roots reflect differences between monocotyledons and dicotyledons (Table 7.2).

True roots are the underground extensions of the main axis of the plant (Fig. 8.13; Jones and Luchsinger 1986:217; Pearsall 2000:153–154). These include **tap roots**, which are vertical roots that may produce many smaller roots (**rootlets**) branching off from the main axis. True roots have no leaves, buds, or **eyes** (nodes), though rootlets leave secondary root scars. The storage tissues may be enlarged (**tuberous**;

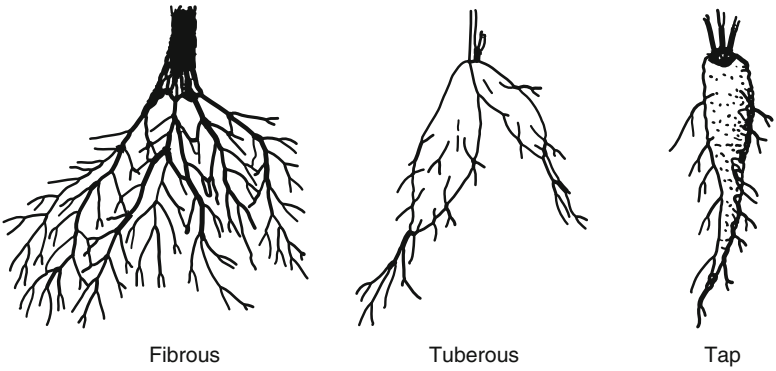

Fig. 8.13 Generalized root forms. From Jones and Luchsinger (1986:217) and used by courtesy of The McGraw-Hill Companies

e.g., carrots [*Daucus carota*], beets [*Beta vulgaris*], sweet potatoes [*Ipomoea batatas*]). True roots may be perennial or biennial, but are not capable of vegetative propagation (Hather 1994).

Stem roots are specialized underground stems (Fig. 8.14; Jones and Luchsinger 1986:218). Stems have nodes, buds, and leaves; underground stems retain many of these features, though in reduced states. Stem roots are known by a variety of names that designate specific forms, with considerable disagreement about this terminology (e.g., Hather 1994). The terminology used here follows Jones and Luchsinger (1986:218) and Harris and Harris (2001). Thus, **rhizomes** are horizontal underground stems (e.g., ginger [*Zingiber officinale*], taro [*Colocasia*]). **Tubers** are swollen storage organs at the ends of some rhizomes (e.g., white potatoes [*Solanum tuberosum*]). **Corms** are short, upright, solid bulb-like underground stems covered by thin, dry leaves (e.g., gladiolus [*Gladiolus*]). **Bulbs** are short, underground stems with thick, fleshy leaves (e.g., onions [*Allium cepa*]). **Bulbils** are small bulbs that arise from the base of a larger bulb and **bublets** are small bulbs borne above ground (Harris and Harris 2001:19). **Stolons** form runners that grow horizontally and root at the nodes or at the tip (e.g., strawberries [*Fragaria*]). Some edible roots have tough, fibrous skins (e.g., cassava or manioc [*Manihot esculenta*]) but others have thinner skins. Considerable processing may be required to remove fibrous skins and compounds that may be unpalatable or toxic.

Most roots lack hard tissues that would preserve under common archaeological conditions. In addition, they generally are consumed or burned so thoroughly that it is unlikely they survive in archaeological sites in proportions that reflect their true roles in human life. Even when they do survive, they may be overlooked because they appear unidentifiable (Hather 1993:3; 1994). As with other plant remains, waterlogged, desiccated, and very cold contexts may preserve these materials and offer insights into their use (Hather 1994). Roots are most likely to be recovered from permanently dry sites where the entire root was discarded. In some cases, it is the outer layer, or peel, that survives, instead of the entire storage organ.

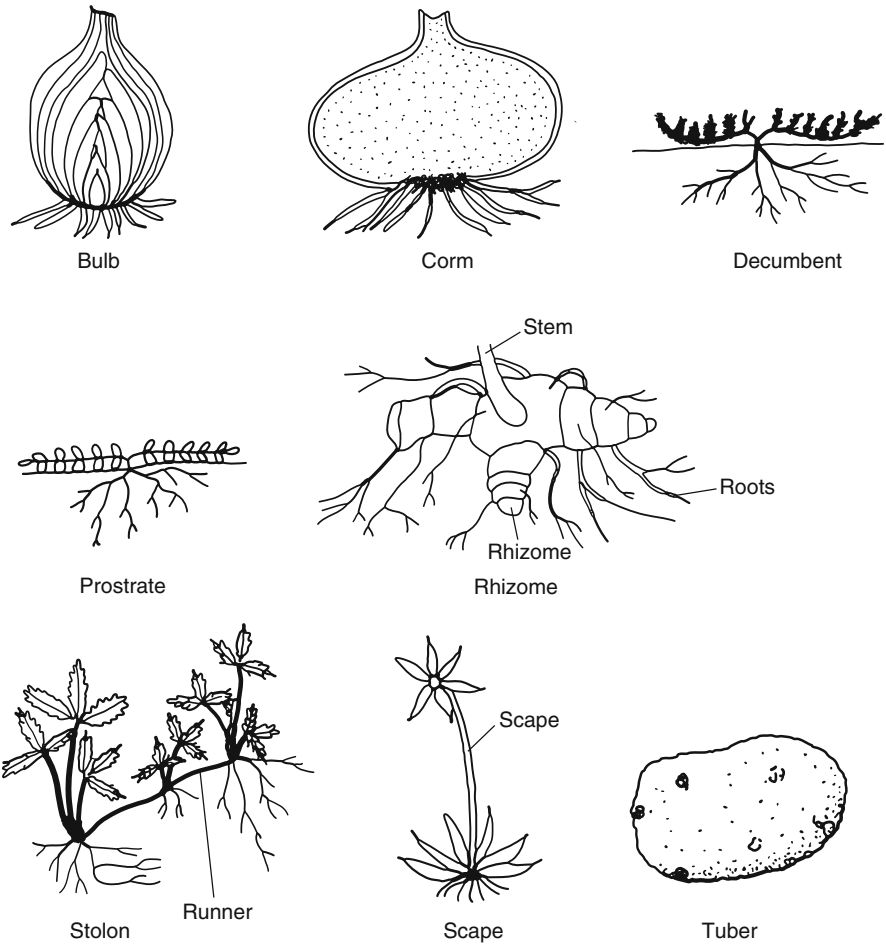

Fig. 8.14 Specialized stems. From Jones and Luchsinger (1986:218) and used by courtesy of The McGraw-Hill Companies

Charred roots may reflect the temperature of the fire, whether the fire was a reducing or oxidizing one, the length of the charring period, the condition of the tissue when it entered the fire (dried or wet), whether the root was at the base of the fire or within the fire, and the size of the tissue fragment originally present.

Characteristics used to identify roots include: the presence, shape, size, patterns, and numbers of nodes; surface characteristics such as striations and folds; stem or leaf base attachment scars; the appearance of cavities within the tissue; and aspects of vascular, parenchyma, and sclerenchyma cells (Hather 1993:3–8; Pearsall 2000:158–161). Color, luster, and hardness may aid in identification when these can be observed. True roots and stem roots are prepared for some of these studies using sectioning procedures similar to those for wood, wood charcoal, and fibers

(Hather 1993:v). Advances in the identification of starch grains have greatly facilitated environmental and cultural analyses of roots (Chap. 9).

In some cases, roots are misidentified as wood charcoal. Because roots and wood originate in different parts of the embryo and develop in different ways, many anatomical features distinguish between them (Pearsall 2000:153–161). Roots have a higher proportion of parenchyma tissue, a smaller proportion of cells with lignified walls, and distinctive patterns of rays and xylem tissues compared with wood. Hather (1993:3) suggests additional characteristics that distinguish between roots and other charred plant materials: fragments of roots often are round; the cells of roots are spherical or rounded instead of elongated as fibers, tracheids, and vessels would be. Portions of roots may be dull in appearance but contain small reflective regions; and the material may contain regular or irregular patterns of cavities. The cells of roots have a clear organization compared with feces, the contents of which are disorganized.

Decorative motifs and tools provide indirect evidence for edible roots. Unequivocal evidence is found when these are depicted in murals, ceramics, and similar formats. The use of edible roots in the Andes, for example, is supported by pots molded in the form of tubers such as potatoes and other root crops. Associated equipment is indicative. Cultivation of manioc has long been inferred from manioc presses and large ceramic griddles used to process and cook manioc in the American tropics.

Dendroarchaeology

Although most closely associated with chronometry, episodic growth rings (bands, layers) in wood have a number of archaeological applications (Fig. 8.4; Haneca et al. 2009). It is important to anticipate the use of growth rings for **dendrochronology** (analysis and dating of growth rings), **dendroclimatology** (analysis of trees and growth rings for climatological data), and other archaeological applications. Many of the characteristics of wood growth that enable researchers to use growth rings to age timbers and date their use are related to growing conditions. Because growth rings reflect the climatic conditions experienced by trees during their lives, they are records of climatic regimes. Growth rings also provide information about forest structures, wood provenances, **silviculture** (forest management), and timber use.

Dendroarchaeology draws upon habits of episodic growth in secondary xylem, which produces distinctive pairs of growth bands in some taxa (Haneca et al. 2009). As a general rule, the thickness of these bands reflects growing conditions, so they will be broader or narrower depending upon whether factors such as temperature, moisture, nutrients, and sunlight encouraged or discouraged growth. Trees experiencing similar growing conditions in a given year produce similar growth bands. Variations in growth patterns are shared among trees on a regional scale over a long period of time. Even within the same species, however, variations in growth occur in response to latitude, altitude, whether the tree is young or old, whether the

wood is from a branch or root, and catastrophic events experienced by individual trees. Conditions from previous years influence growth in subsequent years and bands become narrower as the tree ages. There may be false rings, ones that do not represent regular cyclical growth, and some growth rings may be missing (Haneca et al. 2009). Variability in growth is not unique to trees; it occurs in all organisms.

Such studies rely on the premise that growth rings are annular to establish the age of the tree by counting pairs of fast and slow (or dormant) rings as evidence of a year's growth. For most applications, heartwood needs to be present because it is the heartwood that retains evidence of the sequence of growth over several years. If a cross-section exposes the sequence of growth rings throughout the life of a tree, the age of the individual tree can be measured. If sapwood and bark are present, it is possible to estimate the year in which the tree died. In the case of some ring-porous trees, the season of death can even be estimated (Haneca et al. 2009). If sapwood is missing, it may not be possible to estimate the age of the tree when it was harvested, though a broad estimate of the tree's life span may be possible.

Dendroarchaeology has been used in only a few locations because it requires a long sequence of growth rings in a single, widespread tree species that is common in archaeological sites and dominates plant communities over a broad area (e.g., Büntgen et al. 2011). Dominance is necessary because dominant, upperstory trees are more likely to be influenced by broad climatic phenomena, whereas understory trees may respond more to local forest conditions. Episodic growth must produce clearly defined, distinct pairs of growth rings, a requirement that may exclude trees growing where seasonal variations are less marked than in temperate climate zones. Dendroarchaeology is most useful where growth is cyclical in response to conditions prevailing over a large area and circumstances are favorable to wood preservation (Haneca et al. 2009).

Dating methods fall outside the scope of this volume and the reader is referred to archaeology textbooks for more information. It may be said, though, that this method is considered so reliable that it is used to improve the calibration of the radiocarbon curve and is considered a form of absolute dating (Renfrew and Bahn 2008:138–141). Dendrochronology provides evidence for the age of structures, associating the date of the tree's harvest with the time when it was used in the building. The date the tree died may not be the date when the structure was built or used, however. Where timbers suitable for building materials are scarce, wood may be scavenged from one structure or site for use elsewhere. Likewise, the growth conditions recorded in a timber are those that prevailed when the tree was growing, not those prevailing when the timber was used.

Growth rings provide evidence for environmental histories, as well as dates, by comparison to known series of consecutive rings that may be either master or floating sequences. **Master sequences** extend back in time using archaeological wood and trees from natural deposits and extend into the present using cores from living trees. They establish a temporal succession of tree rings with overlapping growth characteristics. In some cases, dated master sequences for entire regions are available. Master sequences are particularly valuable as dating tools when the bands are dated using radiocarbon dating. Long master sequences have been established

for Douglas fir (*Pseudotsuga menziesii*) and bristlecone pine (*Pinus aristata*) in the southwestern portion of the United States and oak in central and western Europe. **Floating sequences** are shorter; they are local sequences not yet linked to master sequences and may not have absolute dates associated with them. Through master and floating sequences, tree rings offer a climatic and ecological record that may encompass hundreds or even thousands of years.

Growth rings provide insights into cultural uses of trees and shrubs that are related to forest management practices and trade (e.g., Haneca et al. 2009; Lentz and Hockaday 2009; Marguerie and Hunot 2007). The wood anatomy of domestic olive trees (*Olea europaea*) is affected by irrigation, for example (Terral and Durand 2006). **Coppicing** is a management strategy that encourages the production of new shoots. Some broadleaf trees such as oak, hazelnut (*Corylus*), ash (*Fraxinus*), and willow (*Salix*) do not die when the trunk is harvested. Instead, new shoots emerge from the base; these shoots may be used for buildings, fences, basketry, and fuel. Coppiced trees grow faster and have wider growth rings, but smaller diameters and differ in other ways from trees that grow in primary forests or that are not coppiced (Haneca et al. 2009). Coppicing can be natural, such as when trees are pruned by storms or harsh weather. **Pollarding** (cutting branches back to the trunk) and trimming stimulate trees to grow new branches, producing young leaves and shoots as well as changes in wood anatomy and growth rings similar to those associated with coppicing (Haneca et al. 2009). In addition to coppicing, pollarding, and trimming, forests may be thinned, which alters the spacing and growth patterns of trees and shrubs. In some cases, the growth patterns of trees and shrubs that grew in dense stands can be distinguished from those grown in open stands, suggesting periods when forests were partially cleared for field crops, pasturage, fuel, or construction projects. Trees growing in different regions have slightly different patterns of growth that reflect altitude and latitude variations within the plant's range. This enables sources of timbers to be assessed, distinguishing, for example, between woods obtained through trade and those obtained locally.

Applications

Cemeteries usually are studied for insights into ritual, status, health, and demography provided by human and non-human cremations and burials. Newton (2005), however, examines wood charcoal and other charred plant remains from a cemetery and settlement at Adaïma and a cemetery at Elkab (Egypt) for information about vegetational history during the period ca. 3500–2900 BC. Twenty-four taxa from three groups of plants are present in these samples: **riparian** (stream-side) plants associated with the Nile; ruderal plants from the flood plain; and xerophytic plants from sandy plains. Riparian taxa are the most ubiquitous and have the highest specimen count compared with taxa from other habitats. Newton (2005) reports a trend toward increased aridity and a reduction in woody taxa over time that may be evidence of human impact during the period represented by the burials.

People alter their landscapes by removing trees for farming, fuel, building materials, and by expanding settlements. Adriano-Morán and McClung de Tapia (2008) argue that the inhabitants of Teotihuacan (Mexico) practiced a diversified management system or multiple-use strategy that avoided deforestation. Between ca. AD 1 and 650, Teotihuacan covered 20 km^2 and had ca. 100,000 inhabitants. Such large urban centers have the potential to substantially alter local ecosystems. Adriano-Morán and McClung de Tapia (2008) test the hypothesis that the rise and subsequent decline of Teotihuacan was accompanied by environmental degradation, specifically deforestation. The taxa used for firewood are from pine-oak forest, xerophytic scrub, and riparian plant communities. Pine, oak, and juniper/cypress (Cupressaceae) were the preferred fuels throughout the regional occupation sequence between 400 BC and AD 1500. Although the same genera were used throughout the period represented, they were used in different combinations and quantities over time (Fig. 8.15; Adriano-Morán and McClung de Tapia 2008:2933). The authors interpret this as evidence that woods were selected for their specific fuel qualities and other intended uses. The preferred trees were not replaced by shrub species, as would be expected if deforestation had occurred. Woods from both primary and secondary vegetation were used. **Primary vegetation** is the climax community, which included pine and oak. **Secondary vegetation** includes plants found in disturbed and open spaces. They are **heliophilous** (sun demanding) pioneering species, some of which reproduce vegetatively. The use of both primary and secondary vegetation as fuel indicates the landscape was affected by human activities early in the sequence but that both primary and secondary fuels were available throughout the study period. Woods from primary vegetation may be from other parts of the valley and woods from secondary vegetation may be local. Adriano-Morán and McClung de Tapia (2008) conclude that a diversified management system, including silviculture, maximized diversity and subsistence options, controlled erosion, and contributed to landscape stability.

By way of contrast, Lentz and Hockaday (2009) suggest that the Maya at Tikal (Guatemala) initially managed forests to sustain a preferred building material found in old growth forests, but eventually over-harvested this timber. The human population reached its zenith in the Late Classic period (AD 700–830), as did construction projects. A decline in arboreal pollen indicates that forest cover was substantially reduced before and during the Late Classic period as woodlands were converted to farms. Nonetheless, some tree pollen persisted, indicating that deforestation was not complete. The authors test the hypothesis that agroforestry practices changed as wood became scarce and demand peaked. Only two tree species were used for lintels and beams in temples and palaces: the seasonal, wetland logwood (*Haematoxylon campechianum*) and the large-growing, upland forest sapodilla (*Manilkara zapota*). Both habitats are present near Tikal. Logwood probably was more difficult to harvest and use because of its crooked, spiny trunk. Early construction projects used sapodilla exclusively; beam diameters were large and some beams were from trees of considerable age. The decline in arboreal pollen indicates that considerable forest clearance occurred prior to the Late Classic, but the presence of these older sapodilla trees indicates their habitat was protected in the face of

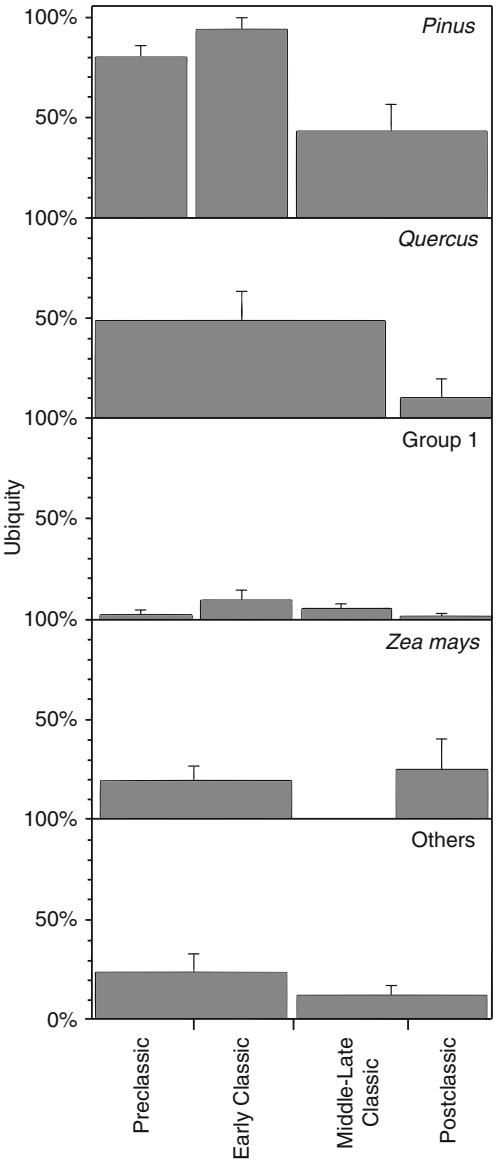

Fig. 8.15 Differences in ubiquity among pine (*Pinus*), oak (*Quercus*), Group 1, maize (*Zea mays*), and other taxa by period in the Teotihuacan Valley (Mexico). Group 1 taxa are present during all periods or during at least four of them. They tend to increase or decrease as a unit. Other taxa are those present in a single sample or that could not be identified to a genus. Periods during which the ubiquity of a taxon showed no significant variation are indicated by the same bar. Intervals correspond to standard errors. Taxa in which ubiquity did not differ in a given period are not shown. From Adriano-Morán and McClung de Tapia (2008:2933) and used by courtesy of the authors and Elsevier

intense population pressure, at least for a while. Eventually, a combination of sapodilla and logwood was used, or logwood exclusively. The final temple project, however, used sapodilla exclusively, but the beam diameters were smaller than those in earlier construction projects. Lentz and Hockaday (2009) suggest that Maya agroforestry practices protected some areas where prime timbers grew, perhaps in sacred groves or in elite, inherited estates. Eventually, however, the preferred

construction material was nearly exhausted and less desirable woods were used. Changes in use of these two construction woods are accompanied by increases in erosion, pollen indicative of disturbance, and nutrient loading in lakes and reservoirs, all standing as evidence for widespread, human-induced ecological strains in the region.

Dendroarchaeology has many applications, some of which extend beyond archaeology. Antonio Stradivari produced many violins that have survived into this century and are highly prized. The "Messiah" violin is thought to be one of these, though some question whether it was made by Stradivari. The label date indicates the violin was made in AD 1716. Stradivari died in 1737 and some argue that the violin was made after his death. Grissino-Mayer et al. (2004) use dendrochronology to address this question. Determining the date of manufacture required dating each tree ring in the violin's wood to a precise year. Tree rings from the "Messiah" and five other instruments were measured, based on the premise that these instruments were made at about the same time using spruce (*Picea*) from forests near Stradivari's workshop in Cremona (northern Italy). The undated, floating chronologies derived from the "Messiah" and other instruments were compared with a dated regional reference sequence that combines 16 alpine chronologies developed from hundreds of trees of three different species from five countries. The tree ring pattern in the "Messiah" does not conform to those in this regional reference chronology, but patterns in two other instruments do and the "Messiah" conforms to those instruments. The researchers argue that the spruce wood used in these other two instruments is from trees that grew in intermediate, mid-elevation alpine forests (perhaps in the same stand) that were more similar to the high-alpine trees used for the reference chronology, whereas the wood used to make the "Messiah" was from a lower-elevation tree in the foothills of the Alps. The authors found that 29 years elapsed between the harvest of the wood used in the "Messiah" (1687) and the construction of the violin in 1716. Although this study does not prove the violin was made by Stradivari, it does indicate it was made during his lifetime.

Summary

The study of wood, wood charcoal, stems, fibers, leaves, and roots enlightens us about earlier environments, construction methods, fuel use, forest management, and other human activities. These diverse archaeological remains broaden our understanding of the ways people use plant products and the impact such decisions have on plants and landscapes. Deforestation may result in erosion, loss of soil fertility, changes in drainage patterns and landforms, and disruptions in ecosystem processes. With the exception of wood charcoal, these materials generally are rare, but provide important insights into life in the past if recovered. Of particular interest is evidence for a wider range of plants used, the variety of ways these might be processed, the particular use of fibers for many purposes, and links between plant and animal husbandry. Ecological and economic interpretations derived from seeds, fruits,

woods, and other plant remains reviewed in Chap. 7 and in this chapter are further enriched by studies of spores, pollen, phytoliths, starch grains, and other microbotanical remains, subjects of the following chapter.

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Chapter 9
Spores, Pollen, Phytoliths, Starch Grains, and Other Microbotanical Remains

Microbotanical remains include spores, pollen, phytoliths, starch grains, and similar materials produced by fungi and plants. Their study provides insights into aspects of environments and cultures otherwise unavailable in the archaeological record and elaborates upon others. They are particularly valuable in multi-proxy studies for these reasons (e.g., Dumayne-Peaty 2001; Nelle et al. 2010).

Spores, pollen, and phytoliths provide records of former vegetation regimes; the influence of climate and human behavior on ecosystems, populations, and communities; and site formation processes. Spores and pollen are produced and dispersed as part of the reproductive cycle of fungi and plants and are among the most common sources of data about environmental and cultural attributes related to temperature and humidity, such as seasonal economic and residential patterns, ritual cycles, and regional climate cycles. This information highlights environmental changes related to vegetation structure and successions, rates of change in plant communities, phytogeography, and forest clearance.

Microbotanical studies provide direct or indirect evidence of resources, such as root crops, typically difficult to identify in archaeological deposits; highlight medicinal and ritual uses of plants; elaborate upon crop cultivation practices and land-use patterns; and provide links between plant and animal husbandry. They suggest habitats where fungi and plants were harvested and locations where animals were pastured. Microbotanical remains adhering to or embedded in harvesting implements, processing tools such as knives and grinding stones, storage wares, and cooking utensils provide insights into the multiple functions of such objects. Some tools usually interpreted in terms of capturing and processing animals (e.g., knives, scrapers) are found instead to be used to process plants (e.g., Mercader 2009). In some cases, microbotanical remains provide evidence for luxury goods, exotic items, and displays that otherwise may be invisible in the archaeological record, such as honey and floral offerings. When incorporated into manufactured objects, microbotanical remains suggest sources for ceramic objects and bricks, in addition to functions of structures. Microbotanical remains in stomach contents and fecal matter are direct

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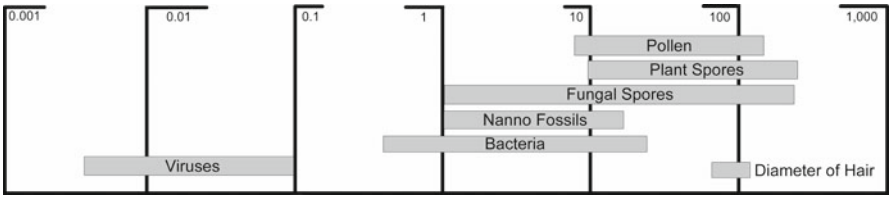

Fig. 9.1 Size range of viruses, bacteria, spores, and pollen compared to the diameter of a human hair. Scale is in micrometers (μm); 1 cm = 10,000 μm. Modified from Traverse (2008:51, Figure 2.4)

evidence of items actually consumed, suggesting seasonality, behavior patterns, foddering strategies, and expanding upon the richness of organisms ingested.

Spores and pollen are reproductive cells of fungi and plants, whereas phytoliths and starch grains are not, though many of the same analytical methods are applied to all of these materials. Due to their small size, it is necessary to use high-powered magnification to study most of them (Fig. 9.1; Traverse 2008:51). Consequently, much of the discussion about identification, counting, and analysis relates to visual traverses of slides under an electron or optical microscope, what is typically visible on a slide within the field of view at a given magnification, and the behavior and appearance of small, irregularly shaped objects suspended in a fluid and topped by a cover slip.

Spores and Pollen: Nomenclature

This summary of spores and pollen provides only a glimpse into their seemingly infinite variety (Fig. 9.2; Pearsall 2000:253–254; Shackley 1981:78). Broadly speaking, spores contain the reproductive cells of algae, fungi, bryophytes (e.g., mosses), and pteridophytes (e.g., ferns). Pollen grains contain male gametes produced by gymnosperms and angiosperms. A spore develops into a new organism without fusing with another cell, whereas a pollen grain contains only sperm (Campbell et al. 2008:602, 620). This means that spores do not need to be transferred to female reproductive cells as pollen grains do, a distinction that influences the quantity of spores and pollen in deposits, their modes of dispersal, and interpretations drawn from them.

Spores are similar but not identical to pollen in many features (Traverse 2008:92, 105, 145–146, 149–150), though they are neither as common nor as readily identified as pollen (Dimbleby 1978:121–122). Fungal spores are strong environmental indicators because of their association with fires, dead wood, and feces (Innes and Blackford 2003). Spores from club mosses (e.g., *Lycopodium*), spike mosses (e.g., *Selaginella*), bracken ferns (*Pteridium*), and polypody ferns (*Polypodium*) are among those found in archaeological materials. These spores are protected by sporopollenin and are more likely to survive site formation processes than are spores with little or no sporopollenin (Traverse 2008:51, 63).

Although both gymnosperms and angiosperms produce pollen to protect the sperm within, gymnosperms produce pollen in sacs (**microsporangia**) and

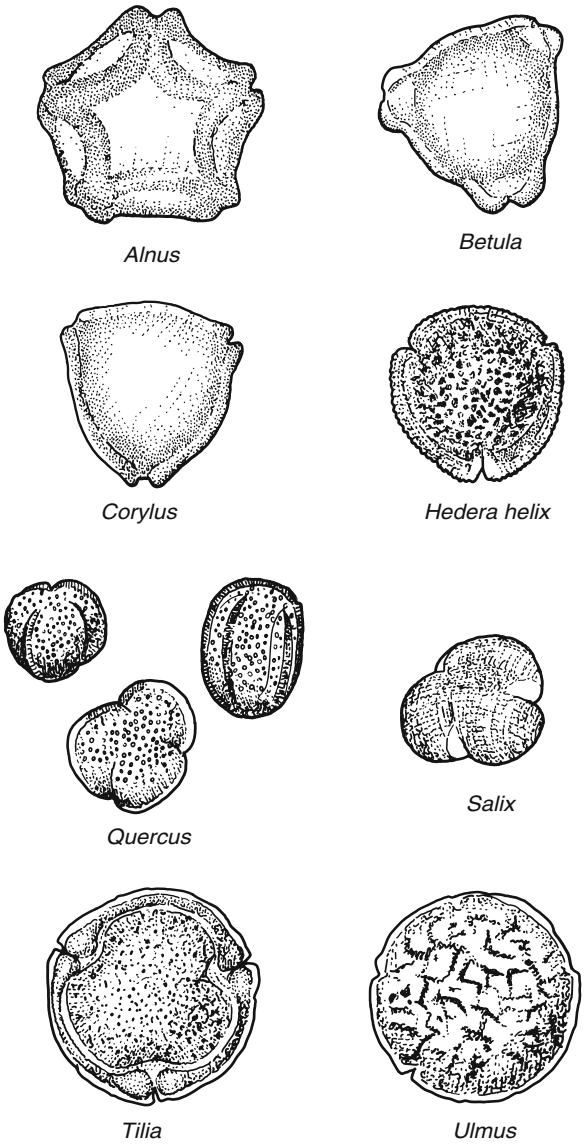

Fig. 9.2 Morphology of some pollen grains. From Shackley (1981:78)

angiosperms produce it in stamens (Campbell et al. 2008:624, 627; Harris and Harris 2001:89). The angiosperm stamen has a stalk (**filament**) that supports a terminal sac (**anther**) containing the pollen (Fig. 7.5). The mass of pollen is surrounded by a wall that breaks open once it is ripe, liberating the pollen for dispersal to female reproductive cells.

Spores and pollen generally are produced in groups of four grains (a **tetrad**). Tetrads break into separate grains (**monads**) upon maturity (Faegri et al. 1989:219; Gifford and Foster 1989:545; Traverse 2008:119, 145, 148; Walker 1974:1114).

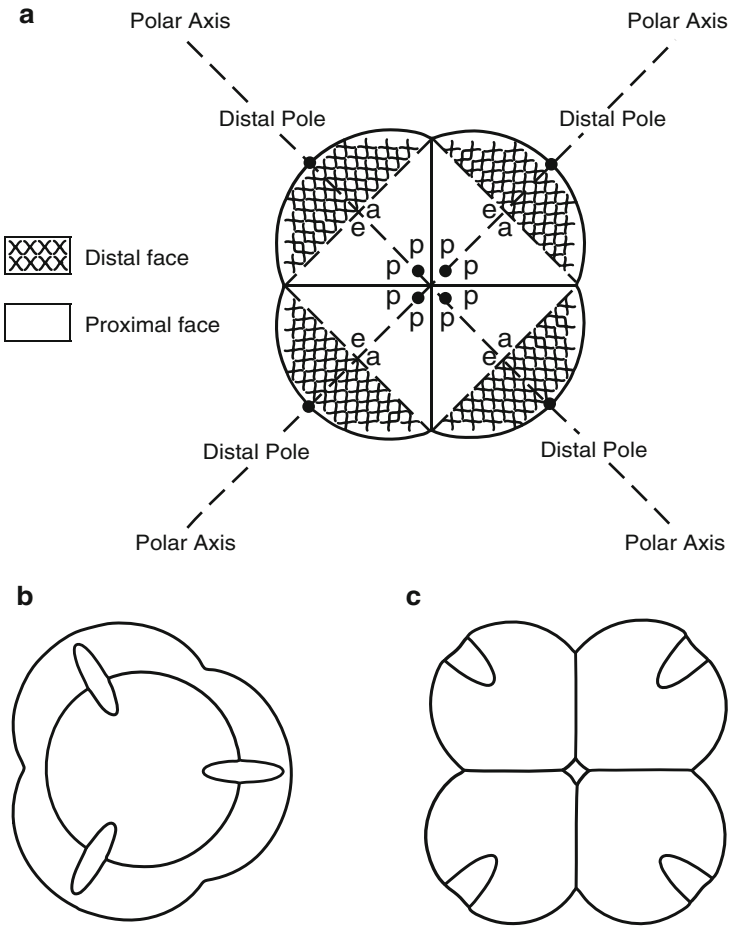

Fig. 9.3 Relationship of pollen tetrads and aperture positions: (**a**) tetragonal pollen tetrad showing polar axes, equatorial axes (ea), distal faces, proximal faces, distal poles, and proximal poles (pp); (**b**) tetrahedral pollen tetrad composed of four tricolpate pollen grains, the top pollen grain shown in distal polar view; and (**c**) tetragonal pollen tetrad composed of four monosulcate pollen grains. From Walker (1974:1114) as modified by Gifford and Foster (1989:545); see also Walker and Doyle (1975). Used by courtesy of the *American Journal of Botany*

The **polar axis** is an imaginary line running from the grain's **proximal pole** near the inner face of the tetrad to its distal pole near the outer face (Fig. 9.3; Walker 1974:1114). This line defines an **axis of symmetry** and side (**lateral**) views. The **equatorial axis** runs perpendicular to the polar axis. The shape of a grain is described by its height, length, width, and other dimensions defined by these axes (Traverse 2008:127).

Pollen grains have three concentric layers, the innermost one being the living cell (Fig. 9.4; Traverse 2008:95). The living cell is protected by a middle layer (**intine**)

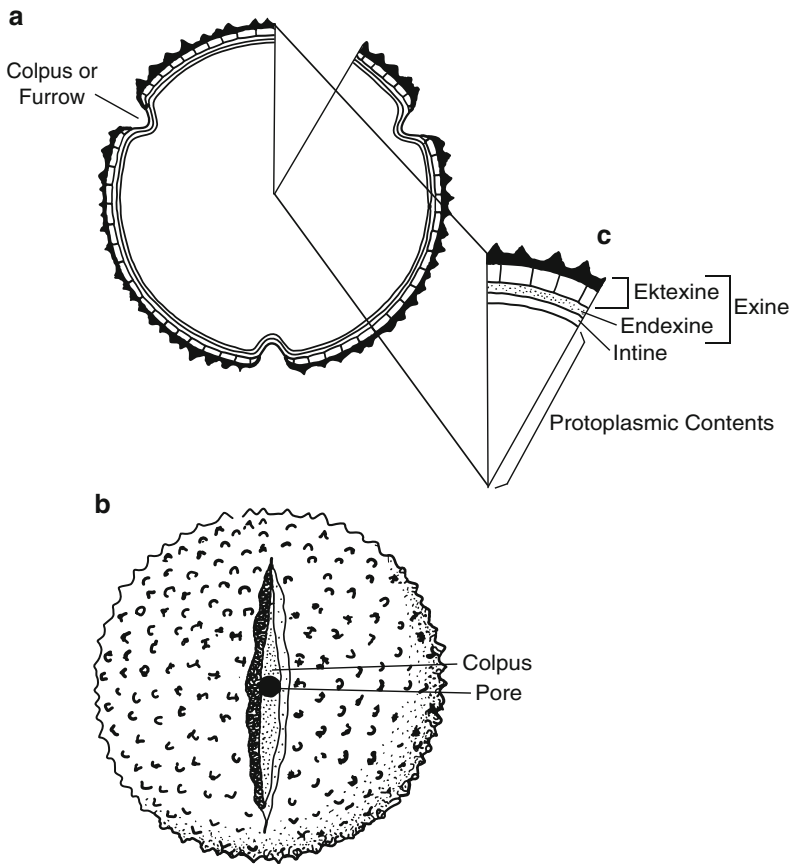

Fig. 9.4 Diagram of a typical tricolporate pollen grain, sectioned: (**a**) polar view in cross-section; (**b**) external, equatorial view; and (**c**) an enlarged section showing the relationship between intine and exine. Following Traverse (2008:95, Figure 5.5) and used by courtesy of Springer Science + Business Media

and an outer one (**exine**). The exine, in turn, consists of inner (**endexine**) and outer (**ektexine**) layers (Walker and Doyle 1975). Neither the living cell nor the intine survives in archaeological contexts (Pearsall 2000:251). The exine, however, contains sporopollenin and may survive temperatures up to 300°C, at least briefly (Faegri et al. 1989:221). It is this property that enables samples to be treated with concentrated chemicals that destroy almost everything except materials protected by sporopollenin. Spores have a slightly different structure, though the external layer of spores, the **exospore**, may be homologous with the exine of pollen (Traverse 2008:144).

The shape, location, spacing, and number of apertures are diagnostic features of spores and pollen (Fig. 9.5; Faegri et al. 1989:229–233, 248–249; Gifford and Foster 1989:546; Pearsall 2000:256; Traverse 2008:93–94). **Apertures** may be present as

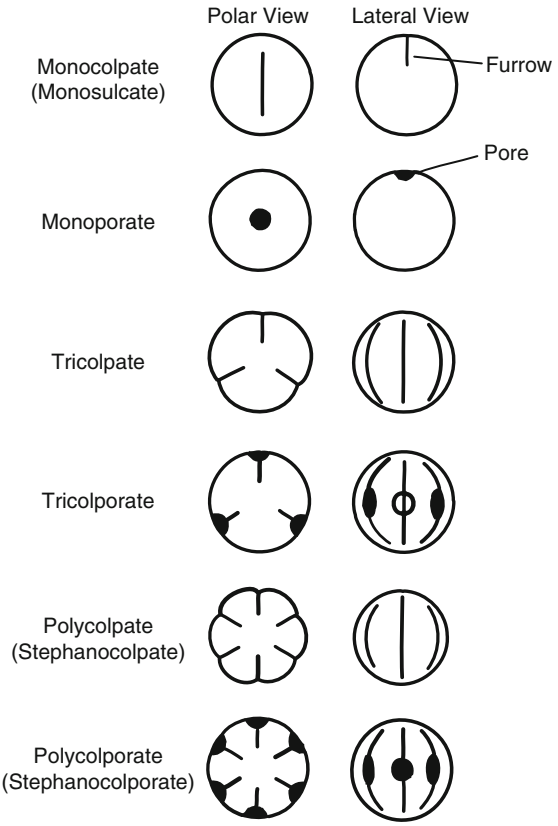

Fig. 9.5 Some aperture types in angiosperm pollen grains. Modified from Faegri et al. (1989:248–249)

pores (the grain is described as **porate**), furrows (**colpate**), or bands (**zonate**). Furrows combined with pores are termed **colporate** and a **sulcus** is a groove or furrow located at the distal pole of the pollen grain. These terms are modified by qualifiers such as "mono-," "di-," and "tri-" to indicate the form and number of apertures. **Monosulcate** grains, for example, have a single long furrow at the distal pole, whereas **tricolpate** grains have three furrows, typically at right angles to the equator (Jones and Luchsinger 1986:244).

In addition to apertures, other features are used to identify pollen (Faegri et al. 1989; Pearsall 2000:252–257; Traverse 2008). Some have highly distinctive shapes (e.g., Fig. 9.2). Size may aid in identification. Some pollen grains are ca. 200 μm in size and others may be no more than 5 μm, though media used to prepare slides may distort sizes (Faegri et al. 1989:83; Traverse 2008:504). Characteristics of the endexine and ektexine may be diagnostic. These include the organization of the **tectum** (the outmost surface of the ektexine) and adjacent layers; the structure or texture of features inside the tectum; sculpturing of the external surface of the tectum; or whether the tectum is present at all (Faegri et al. 1989:226–229; Walker and Doyle 1975).

These characteristics have broad phylogenetic affiliations (Traverse 2008:73–75). Gymnosperm pollen rarely is as sculptured as angiosperm pollen (Traverse 2008:97).

Pollen grains of most dicotyledons have three apertures, but those of many basal angiosperms and monocotyledons have only one aperture (Table 7.2; Pearsall 2000:256). Monosulcate forms are characteristic of ferns, gymnosperms, monocotyledons, and some families of dicotyledons (Gifford and Foster 1989:546; Jones and Luchsinger 1986:92). Tricolpate morphology, or a form derived from tricolpate morphology, is characteristic of most eudicots (Gifford and Foster 1989:547; Jones and Luchsinger 1986:244; Traverse 2008:352).

Spores and Pollen: Modes of Release and Dispersal

Quantity, size, shape, and other attributes of spores and pollen reflect modes of release and dispersal, many of which are similar to those for seeds and fruits (Carlile et al. 2001; Faegri et al. 1989:14). These influence the abundance of spores and pollen in archaeological deposits, their survival potential, whether they are from local or regional ecosystems, and whether they document former ecosystems or modern ones (Faegri et al. 1989; Pearsall 2000:260–263; Traverse 2008:499–502, 632–633). Wind, animals, and water are common dispersal mechanisms, aided by sculpturing, stickiness, size, and other characteristics tailored to specific modes of release and dispersal. As with all environmental phenomena, there are many exceptions to these generalizations (e.g., Traverse 2008:97).

Spores may be less common in archaeological samples than pollen because of their release, dispersal, and growth habits (Carlile et al. 2001:215–216, 221–227; Faegri et al. 1989:201). Spores may be released passively, encased in droplets that attach to passing animals, for example, or launched into the air by rain drops. Active release occurs when structures containing spores burst open and the spores are propelled into the air. Once released, spores disperse via wind, water, animals, or attached to seeds. Many spore-producing taxa are members of the understory vegetation and have limited access to wind currents. Spores that form on the undersides of leaves have even less access to circulating air. On the other hand, some fungal spores are very buoyant and can disperse over hundreds of kilometers when conditions are favorable (Faegri et al. 1989:29). Peat mosses (*Sphagnum*), club mosses, and bracken ferns produce large quantities of spores that are dispersed by wind (Traverse 2008:498).

Unlike spores, pollen must be transferred from an anther to a receptive stigma to complete the reproductive cycle. Although some plants are self-pollinating (**autogamous**), most are cross-pollinating (**allogamous**). The mode of dispersal influences the morphology of pollen grains and influences which plants are most likely to be represented by pollen at archaeological sites.

Wind-pollinated (**anemophilous**) plants produce more pollen than plants using other modes of dispersal (Faegri et al. 1989:14–16), perhaps over 10,000 grains per anther (Pearsall 2000:258). One anther of wind-pollinated hemp (*Cannabis*) may yield 70,000 grains. Faegri et al. (1989:14) conclude that the spruce forests of south and central Sweden produce 75,000 tons of pollen per year. Wind-borne grains are

smooth and dry with minimal tendency for clumping. They may have aerodynamic structures such as wings or air sacs. Small, buoyant grains are transported further than larger, heavier ones. Upper canopy plants have greater access to prevailing winds and contribute a higher percentage of pollen to regional pollen spectra than do understory plants. Fewer understory plants rely upon wind pollination because of this limited access. Isolated trees may distribute more pollen than trees in a dense stand for the same reason (Faegri et al. 1989:14). Pollen grains from higher elevations tend to disperse down-slope following prevailing patterns of wind circulation.

Wind-borne pollen may be distributed far from the plants that produce them, commonly over distances of 10–100 km. Pine (*Pinus*) pollen may be carried 300 km; distances of 3,000 km are reported for pollen of other taxa (Faegri et al. 1989:29–30). When recovered from archaeological contexts, wind-borne pollen often is interpreted as evidence of regional instead of local ecosystems because of the distances over which wind-borne pollen can be transported. It may be difficult to reconstruct spatially precise species occurrences and composition for this reason. Pollen from local and regional sources can sometimes be distinguished, however. If, for example, pine pollen is abundant in a sample and is accompanied by pine stomata from pine needles, likely to be from a local source, then at least some of the pine pollen is likely to be local.

Wind-borne materials contribute to **pollen rain**, a mixture of spores and pollen dispersed into the atmosphere and spread by air currents (Carlile et al. 2001:225; Traverse 2008:502–510). Pollen rain has nothing to do with actual rain. Imagine spores and pollen "raining" down on every available surface. This is only one of several mechanisms by which pollen and spores enter archaeological sites (Fig. 9.6; Faegri et al. 1989:198).

Spores and pollen may be dispersed by animal vectors (**zoophilous**). Animal vectors include insects (**entomophilous**), snails, slugs, birds, bats, rodents, people, and livestock. Spores and pollen may stick to the vector or be ingested and pass out of the gut in the animal's feces. Plants that disperse pollen in this way produce fewer pollen grains compared with wind-pollinated plants, often less than 1,000 grains per anther (Faegri et al. 1989:12–14; Pearsall 2000:258). Animal-borne pollen may be dispersed only 10–100 cm. Spores and pollen may be oily, armored, spiny, or highly sculptured to stick to the vector or survive transit through the vector's digestive tract. In some cases, fungi, plants, and their vectors are highly specialized so that only a specific animal is attracted to the spores or pollen or permitted access to them (Carlile et al. 2001:226–227; Faegri et al. 1989:14). Some flowers produce nectar or excess pollen for their preferred vector. Zoophilous spores and pollen are rare in pollen rain and may be underrepresented in archaeological deposits. Spores and pollen from fungi and plants using animal vectors suggest that the specific fungus or plant once was very close to the sample context, or that a vector died in that context. In the case of flowering plants, it may be evidence of a floral offering.

Aquatic fungi and plants release spores and pollen in wet conditions or underwater (**hydrophilous**) and these accumulate in damp or submerged locations instead of on land. These organisms are even more likely to be underrepresented, leaving the

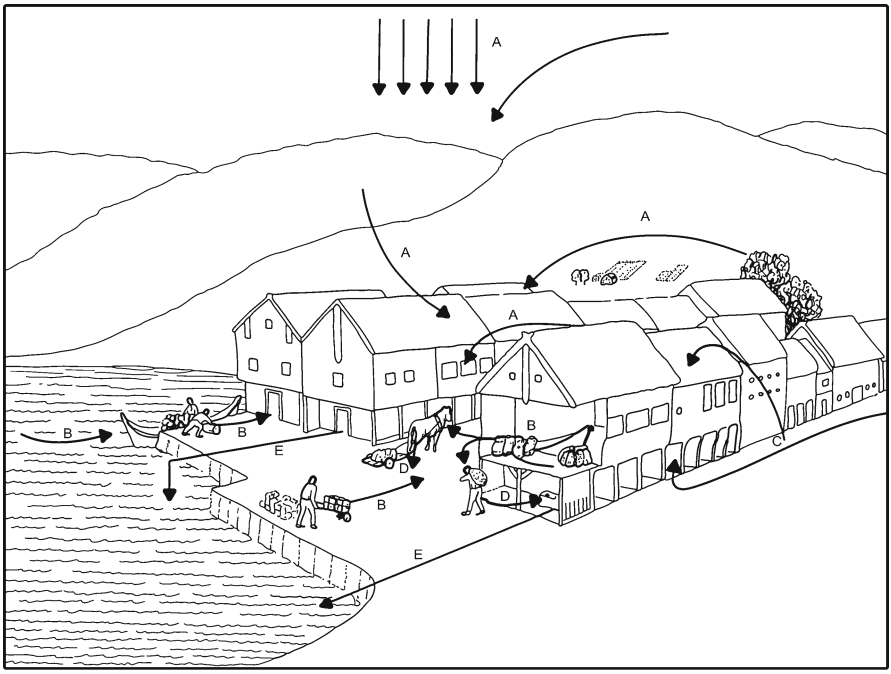

Fig. 9.6 Pollen transport model for an urban shore settlement. Pollen may enter the site: (*A*) transported by air, "pollen rain;" (*B*) with goods brought to the site; (*C*) in soil on floors and turf on roofs; (*D*) as excreta from people and other animals; and (*E*) through redeposition of refuse. From Faegri et al. (1989:198), modified from Krzywinski et al. (1983), and used by courtesy of Wiley-Blackwell

impression that they were not present or used in the past. Some aquatic fungi produce zoospores that can swim, or are dispersed as cysts (Carlile et al. 2001:225). Pollen grains of hydrophilous plants may have thin exines or lack sporopollenin (Faegri et al. 1989:12; Traverse 2008:61). Spores and pollen of hydrophilous fungi and plants may not reach the archaeological site at all and are unlikely to survive if they do.

Self-pollinating angiosperms produce few grains per anther and their flowers may not open until after pollination (e.g., wheat [*Triticum*], some legumes [Leguminosae (Fabaceae)]; Faegri et al. 1989:12). Some of these flowers never open to expose the pollen (**cleistogamous**) and produce as few as 30 grains per anther (Faegri et al. 1989:12). These differences affect interpretations of plant husbandry: domestic grasses such as self-pollinating wheat, for example, may be underrepresented in a pollen assemblage compared with wind-pollinated crops such as rye (*Secale cereale*; Faegri et al. 1989:190–191).

Spores and pollen from animal-dispersed, aquatic, and self-pollinating organisms usually are interpreted as evidence of local ecosystems, whereas wind-borne materials are generally considered regional indicators. These interpretations must be qualified, however. For example, the pollen grains of some zoophilous species

are sticky (e.g., rhododendrons [*Rhododendron*]). Sticky, heavy grains form clumps and may not disperse far from the parent plant. Such pollen may not be recovered unless a sample happens to be taken from exactly where the parent plant once grew. Such underrepresentations may suggest that taxa were less widespread than actually was the case. Twenty-five to forty percent of the pollen from wind-pollinating trees, such as oak (*Quercus*), maple (*Acer*), larch (*Larix*), willow (*Salix*), and pine, form small clumps and may be underrepresented (Faegri et al. 1989:14). On the other hand, wind-dispersed pollen that does not clump, such as that of birch (*Betula*) and hazelnut (*Corylus*), may be overly abundant in the pollen record if one of these trees grew nearby.

In addition to modes of release and dispersal and survival potential, other factors influence the quantity of spores and pollen that might be recovered from archaeological sites. Among these are the abundance of each species near the sample location, the quantity of spores or pollen these species produce, the frequency of reproduction, the sedimentation rate of the deposit, humidity, and nightly temperatures (Faegri et al. 1989:26–30). Production and dispersal may be precluded if pruning or harvesting occurs before pollen grains are produced (e.g., pruning in early spring). Pollen from these plants simply may not be present in the archaeological record. On the other hand, plants harvested before seeds are produced (before "going to seed") or whose use focuses on vegetative parts that are not be preserved at many archaeological sites, may only be represented by pollen.

Spores and Pollen: Site Formation Processes

Sporopollenin is very durable and those spores and pollen protected by it can survive in very large quantities (Pearsall 2000:260–263; Traverse 2008:499–502). Dimbleby (1985:36) reports finding ca. 1.5 million grains/g in an African swamp deposit. This does not mean that sporopollenin is immune to site formation processes. It is vulnerable to microorganisms, physical processes, and oxidation; spores and pollen of some taxa decompose more quickly than do those of others (Traverse 2008:17, 66). A palaeosol may be detected by higher frequencies of pollen than adjacent strata, evidence of the soil's former proximity to the surface (Faegri et al. 1989:148).

Bacteria, fungi, roots, earthworms, millipedes, insects, people, and livestock are among the significant agents of bioturbation. Bioturbation associated with earthworms and other organisms alter the vertical and horizontal context of spores and pollen by transporting them into other parts of the deposit (Faegri et al. 1989:148). Many of these organisms eat the living cell but excrete the exine more or less intact (Traverse 2008:17, 66). Bees transport pollen from one flower to another, but their intention is to eat the pollen; transporting it is an unintended consequence. Earthworms ingest pollen, but appear to excrete it unharmed. Although aerobic bacteria and fungi eventually may destroy spores and pollen, they can survive for long periods in large quantities where bacteria and fungi are restricted by cold temperatures and low moisture (Traverse 2008:67–68).

Physical processes affect spores and pollen. Percolation and gravity move them through soil strata (Faegri et al. 1989:148). Mechanical degradation and abrasion damage the surface of the grain, leaving it vulnerable to bacteria and fungi. Trampling, digging (e.g., cultivation), water transport (e.g., sheet erosion), and alternating cycles of moisture and temperature move spores and pollen through the stratigraphy and damage sporopollenin.

The chemical environment can accelerate or retard decomposition. As a general rule, oxidizing and calcareous contexts (e.g., limestone substrate, dense mollusc shell deposits) have a destructive effect. A low Eh potential (anoxic) enhances preservation because decomposition is slowed. Dimbleby (1957:19) notes that alkaline (pH > 7) contexts contain little pollen and pollen is rare in deposits with pH between 5 and 6. Very high frequencies of pollen, however, may be found in acidic contexts (pH < 5) because high acidity restricts bacteria, fungi, worms, and insects. Eh and pH complement one another; contexts with both low Eh and low pH are better for preservation than when one condition prevails but not the other. Oxidation under mild pH is particularly destructive to spores and pollen (Faegri et al. 1989:148). Dimbleby and Evans (1974:119) note that some materials are almost entirely destroyed after 8 months in alkaline contexts and that all but the most resistant grains (e.g., fern spores) may survive for no more than a few years. In such depositional environments, any spores and pollen recovered generally are likely to be unstratified and essentially modern.

Optimum spore and pollen stratification and preservation are achieved in low-energy, acidic, reducing environments where biological activity and physical disturbances are limited. Minimal preservation is found in well-drained, alkaline deposits, which is why many researchers associate spores and pollen with lakes and peat bogs. Good preservation is possible, however, in terrestrial soils and in very dry or cold locations if biological and physical processes are limited.

Spores and Pollen: Field Considerations

Although spores and pollen are found in other contexts, most studies rely on soil samples and many of the field procedures reviewed in Chap. 5 also apply to samples collected for studies of spores and pollen. The contents of these soil samples may be used in a number of different studies; thus it is prudent to collect more samples, and larger ones, than might be thought necessary for soil or pollen analysis to ensure that enough material is available for other studies if new questions emerge as more is known about the site after field work is over. It is particularly important to control sources of contamination when collecting spore and pollen samples. As with soil samples, pollen samples should be taken from the base of the profile first, working vertically up the profile to avoid contamination by dislodged bits of matrix. It is best to avoid collecting when pollination is intense. Pollen samples should be well sealed and curated to control mold and other damage; refrigeration often is recommended (Faegri et al. 1989:70–72).

Environmental archaeologists prefer to collect their own samples to ensure control over the context and sampling procedures and to become familiar with the stratigraphy of the site. Palynologists may recognize contexts that warrant study and exclude those that are unlikely to be productive. This may place them in a position to coordinate sampling with other researchers who will use these, or related, samples (Dimbleby and Evans 1974; Faegri et al. 1989:39, 192; Traverse 2008:649–652). If the environmental archaeologist cannot be present during excavation, a sampling approach should follow guidelines acceptable to disciplines that will rely on these samples for multi-proxy studies. Implementation of their coordinated recommendations should be assigned to a single staff member to minimize errors (e.g., Faegri et al. 1989; Goldberg and Macphail 2006; Pearsall 2000; Traverse 2008).

Specific contexts to sample should be guided by the research design. In addition to general soil samples, typically taken from excavation unit profiles, samples may be taken from specific functional contexts (e.g., latrines, stables, wells, dung heaps, floors, fields, ditches, abdominal cavities, burial chambers, bricks, tool surfaces, storage pits). In addition to such behavioral contexts, other locations should be sampled, with emphasis on those where preservation is likely to be good (Faegri et al. 1989:53–68, 190–193). Each of these contexts represents different environmental and cultural relationships and is likely to contain different assemblages of spores and pollen.

Deposits beyond the site (e.g., lakes, bogs) and modern surfaces should be sampled to distinguish between anthropogenic and non-anthropogenic spore and pollen spectra as well as between modern and archaeological ones. Sampling both on-site and off-site may establish an environmental history extending beyond the human presence in the landscape. This may not matter when the objective is to know which plants grew at this site when it was occupied; but it does matter if the objectives include regional and historical studies. It may be possible to distinguish between local spores and pollen and those from more distant locations by identifying materials from lakes and bogs, though there may be problems if a stratigraphic hiatus or an area of redeposition is found. The smaller the lake or bog, the greater the likelihood that it will reflect primarily local vegetation histories.

Spores and Pollen: Laboratory Procedures

These materials vary in size from ca. 5 to 200 μm, though most are between 5 and 50 μm in size. Their small size and the need to use microscopes at different levels of magnification and depth of field have led to procedures that restrict what will be identified to a specific, predetermined specimen count. Analysis is largely a statistical procedure that relies upon such sampling, with the confidence limits dependent on the number of specimens counted (Faegri et al. 1989:83–84; Moore et al. 1991).

Preparation

Spores and pollen are prepared for study using procedures that concentrate them, remove all other materials, and control contamination (Faegri et al. 1989:69–83; Pearsall 2000:290–302; Traverse 2008:616–649). The steps are not difficult but they are finicky, time-consuming, and involve hazardous chemicals that should be used with care. Legal requirements for storing, handling, and disposing of these chemicals must be followed. Ideally, samples are prepared in a sterile laboratory with an air-filtering system. A large, powerful fume hood or fume cupboard is essential. It is important to keep good records of the treatments used and to label both the samples and the equipment that come into contact with these chemicals.

Preparation methods vary slightly to cope with different kinds of sediments, but the general steps are similar. After pebbles, macrobotanical remains, and other "large" objects are removed by sieving, the sample is subjected to repeated cycles of chemical treatments, centrifuging, and rinsing to remove silica, cellulose, carbonates, and humic compounds. Other techniques concentrate the grains by flotation using a dense liquid. Some substances with chemical properties similar to those of spores and pollen cannot be removed (e.g., chitin) and other materials (e.g., carbon, pyrite) may persist. After as much debris as possible is removed, the cleaned extract is mounted on one or more slides. In some cases, the mount is temporary and the extract is mixed with a medium such as glycerol and a cover slip is sealed lightly in place. If the mount is a permanent voucher, the extract is dehydrated and sealed sufficiently to keep the cover slip in place. Researchers frequently distinguish between permanent mounts and temporary ones made for a specific study (e.g., Traverse 2008:666).

Identification and Counting

Identifying spores and pollen requires good reference collections, keys, and illustrations, all of which rely on detailed technical knowledge, practice, and intuition to use accurately. The reference collection consists of slides of modern spores and pollen. Archaeological materials are identified under a microscope during a standardized traverse of each slide. SEM images are very clear, though generally they are used to view or record only a few specimens rather than as routine identification aids. Spores and pollen are identified by size, shape, sculpturing, structure, and the number, position, and arrangement of air sacs and apertures with reference to the axes (Faegri et al. 1989:238–239; Gifford and Foster 1989:545–546; Traverse 2008:93–96, 102–104).

Generally, spores and pollen are identified and counted until a predetermined specimen count is reached (Pearsall 2000:302–304). This count may be the sum of all pollen (**total pollen, TP**), **total arboreal pollen** (**TAP** or **total tree pollen** [**TTP**]), or **total land pollen (TLP)**. Spores, and pollen from aquatic and waterside

plants, usually are not included in these totals. **Arboreal pollen (AP)** is traditionally used as the background standard because much of the early research focused on reconstructing forest vegetation in northern Europe, which relied on arboreal pollen (Dimbleby 1985:27; Pearsall 2000:303).

The standard count is highly variable, ranging from 150 grains to over 1,000. At a general level, the count should be high enough to permit statistically valid comparisons among assemblages, but not so high that it requires an unreasonable amount of work. The higher the count, the more likely it is that the sample population will include rare taxa, thereby increasing the probability that the study assemblage more closely approximates the original life assemblage. Although most agree that few new taxa are identified beyond 1,000 grains, typically the sample size is 200 specimens per slide, meaning that some rare taxa will not be represented in the final taxonomic list (Faegri et al. 1989:150–153; Traverse 2008:666–667).

As discussed in Chap. 5, the method of counting must ensure that no specimen is counted twice, one of the reasons for examining slides along evenly spaced traverses on a mechanical stage. If insufficient grains are found on the first slide (based on the predetermined count), more slides can be made from the prepared sample and the traverses continued on these additional slides.

Spores and Pollen: Analytical Procedures

Most analytical procedures use either quantified relative or percentage occurrences or absolute pollen frequencies (Faegri et al. 1989:83; Pearsall 2000:303–308; Traverse 2008:518). To calculate relative or percentage occurrence, the number of grains for each taxon is expressed as a percentage of a denominator, which is typically a count of arboreal pollen or all pollen identified up to a predetermined sum (e.g., 200). Absolute frequencies are based on the density of individual taxa in the deposit; that is, the number of grains deposited per unit volume or unit weight of sediment (**pollen concentration**; Faegri et al. 1989:83; Pearsall 2000:306). **Pollen accumulation rates** (pollen deposition rate, pollen influx) are the number of grains deposited per unit area of sediment per unit of time and are derived from pollen concentration rates (Pearsall 2000:307–308). Absolute frequencies have the advantage that the number of grains of each pollen type is calculated independent of the other types.

Pollen concentration indices are obtained by counting all of the grains in a standardized volume or weight of sediment or by using an exotic marker. Assessing absolute pollen frequency by introducing a known quantity of an exotic marker to a known quantity of sediment before or after processing is the more common technique (Piperno 1988:138–139). Using a subsample (**aliquot**) of known volume or weight, the concentration (grains/g) for each taxon is calculated as the ratio of archaeological grains to the exotic markers, which are counted along with archaeological materials (Faegri et al. 1989:83–84). Adding exotic markers enables analysis to establish a ratio of archaeological materials to the markers, which can be converted into an approximation of the absolute frequency by means of a formula (e.g.,

Traverse 2008:518–519). The markers may be exotic pollen, spores, or pollen-sized glass or polystyrene spheres. Adding a known quantity of exotic pollen or spores as markers before the sample is processed enables the efficacy of processing methods for recovering archaeological materials to be assessed. Another approach is to count up to 150–200 markers and 300–400 archaeological specimens.

The concentration index is converted into pollen accumulation rates by estimating the rate of sediment accumulation using dated materials (grains/g/year; Branch et al. 2005:70; Faegri et al. 83–84). Interpreting accumulation rates requires good chronological control, which often is lacking for specific archaeological deposits. Radiometric and other dating techniques are rarely applied to all strata within a stratigraphic column, and it is even less likely that all of the stratigraphic columns from which samples are taken will be dated thoroughly.

Sample volume as well as sample count are critical to this analysis. Pearsall (2000:305) argues that the "right" sample size depends on the research question, how critical rare taxa may be to that question, and requirements of subsequent quantification. In the case of relative or percentage occurrence, it may not be necessary to obtain a complete taxonomic inventory because rare taxa will probably not influence relationships among the dominant taxa. In those instances where absolute frequencies are required, however, capturing rare taxa may be important. Small samples with total counts that exclude rare taxa may be inappropriate for studies that rely on measures sensitive to sample size, such as richness, diversity, and equitability (Chap. 11).

Stratigraphic spore and pollen spectra are presented graphically in pollen diagrams (Fig. 9.7; Fearn and Liu 1995:112; Pearsall 2000:313). It is ironic that the purpose of these diagrams is to simplify the presentation of complex data, when most diagrams are difficult to read because they violate the principle that "One should therefore be careful not to put too much information into one diagram, losing the salient points in a maze of less relevant data—relevance to be understood in relation to the objective of the investigation" (Faegri et al. 1989:91). Nonetheless, such diagrams are widely used to communicate results and generally can be understood (Traverse 2008:470–472). The conventions used in these diagrams are applied to many other analyses, including phytoliths, insects, and molluscs; thus students should become familiar with their basic style.

Pollen diagrams have at least one horizontal (**x** or **abscissa**) axis, representing the quantity of each spore or pollen type, or groups of taxa, and one vertical **(y** or **ordinate**) axis, showing the vertical stratigraphy (Fig. 9.7). The body of the diagram may include grid lines to enhance clarity. The values of each pollen type in samples from each stratigraphic level are presented as points, bars, continuous curves or lines, or "sawblades" (Faegri et al. 1989:101; Pearsall 2000:312–319). Sometimes these different styles are combined (Fig. 9.8; Greig and Turner 1974:184; Traverse 2008:488). Continuous lines identified by conventional symbols are found in some older diagrams (Faegri et al. 1989:95).

The vertical axis (or axes) conveys stratigraphic and temporal data, such as a time scale (using relative dates, absolute dates, or both), a stratigraphic scale (sediment profile, **lithostratigraphy**), and depth below surface (bs) or below datum

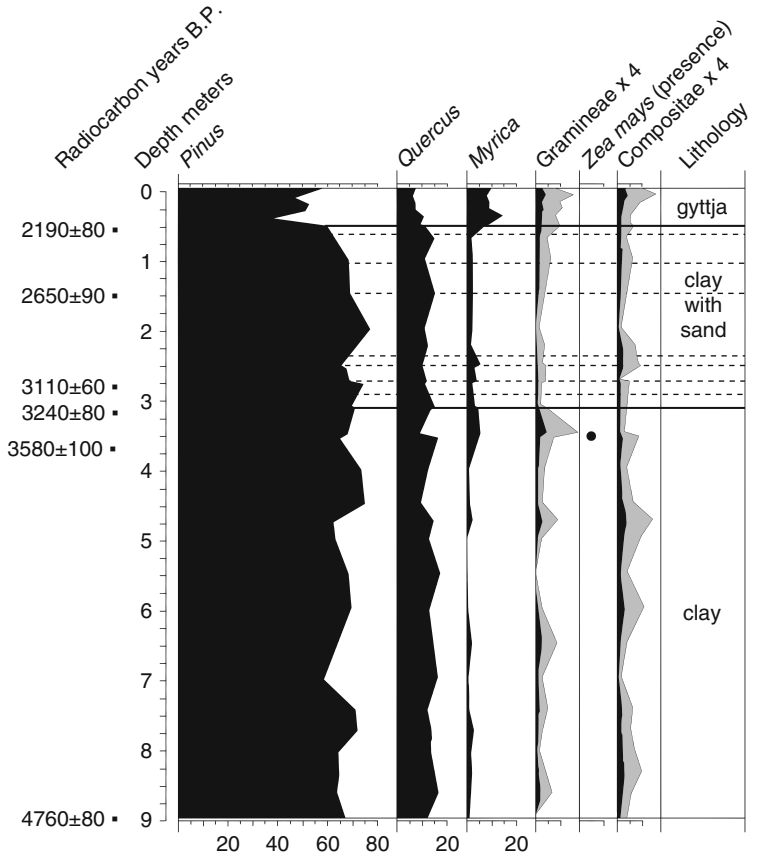

Fig. 9.7 Simplified pollen percentage diagram from core S3E2 taken from Lake Shelby, located on the northern coast of the Gulf of Mexico (Alabama, USA), showing radiocarbon dates and lithology. Sediments above the *upper solid line* are **gyttja**, a rapidly accumulating, organic, muddy deposit that indicates a shift from estuarine to lake sediments. *Dotted lines* indicate sand layers that may be evidence of multiple hurricanes. Clay below the *lower solid line* is characteristic of a quiet back bay estuarine environment. Portions of the Gramineae [Poaceae] and Compositae [Asteraceae] curves are exaggerated by 4; the exaggeration is indicated by the *light gray* portion of these two curves. Note the *single dot* for maize (*Zea mays*), indicating a single pollen grain. From Fearn and Liu (1995:112) and used by courtesy of the authors and the Society for American Archaeology

(bd). Sometimes, the diagram does not indicate if the depth is below the surface or the datum plane, or whether the scale is in feet, meters, or centimeters despite the fact that misinterpretations of several meters can result when the reader is left to guess. Each stratigraphic layer may be distinguished by sediment symbols on the vertical axis (e.g., Faegri et al. 1989:50; Shackley 1981:73). These symbols may or may not conform to standards or be explained in the notes accompanying the diagram. The vertical axis may include additional descriptions for samples from each level, such as the pollen count per slide, total pollen count for that level, and pollen

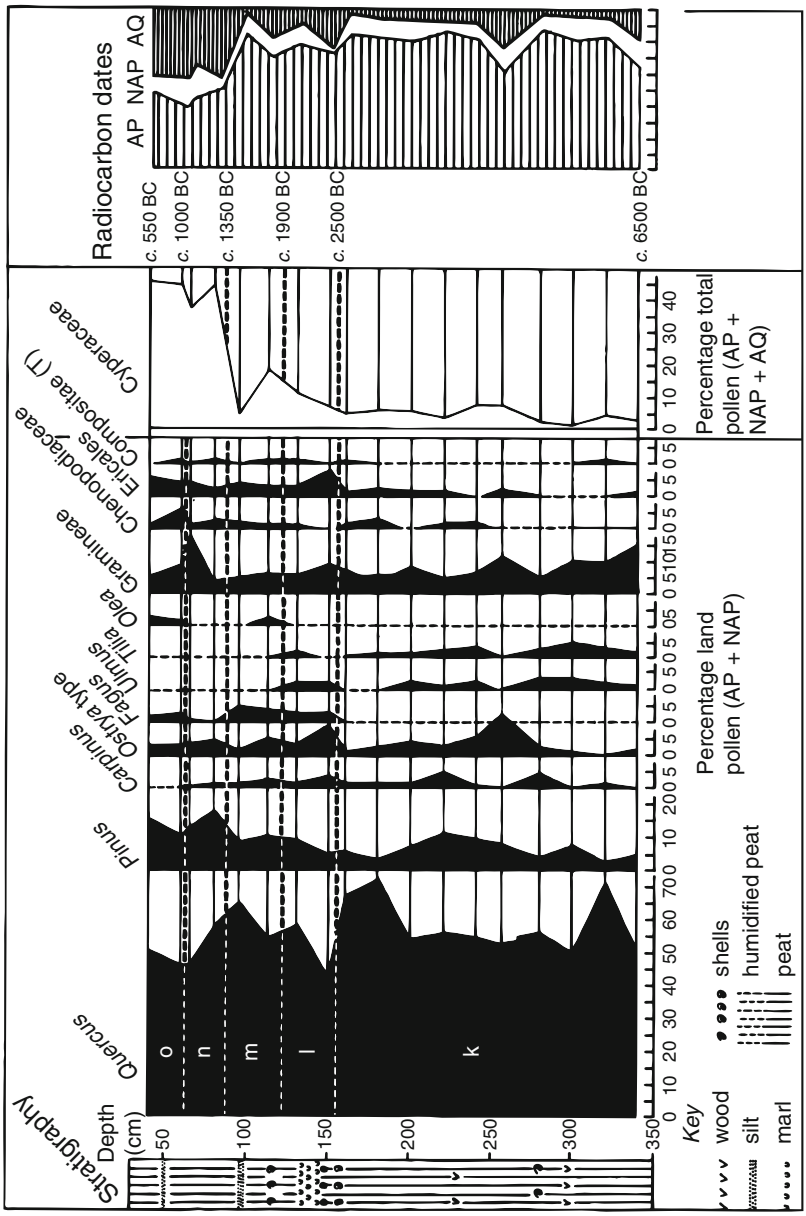

Fig. 9.8 Pollen diagrams from Core 3 at Phillipi, near Sitagroi (Greece). Letters refer to pollen biozones k–o, delineated by the *horizontal dashed lines*. From Greig and Turner (1974:185) and used by courtesy of Elsevier

or wood charcoal concentration or accumulation rates. This information may be divided between the left and right axes.

In most cases, the upper horizontal axis lists the individual taxa, ecological groupings, indicator groups, or cultural categories, and the lower horizontal axis provides a scale for the data presented. Taxa often are not attributed to a specific epithet but to some higher category in the taxonomic hierarchy, such as genus or family, because of inherent limits to identification. Ecological groupings may include categories such as AP (arboreal pollen), **NAP** (non-arboreal pollen), **AQ** (or **AqP**, aquatic pollen), TP (total pollen), or groupings specific to the research region (e.g., puna, Andean forest). It is not uncommon to find unidentifiable types listed, such as Type IV, Unidentified, or Varia. An arithmetic scale is commonly used on the lower axis, though occasionally a logarithmic scale is used. This baseline scale should specify whether the data are reported as percentages (e.g., of TP or AP) or absolute values, such as grains per gram.

The presentation of data in the body of these diagrams fits broadly into two styles: resolved and composite, both of which are used in Fig. 9.8 (Faegri et al. 1989:93; Greig and Turner 1974). A **resolved diagram** presents data for each taxon using a separate baseline scale for each taxon, usually at intervals of 10% or less. The scale is often truncated at the last significant percentage for each taxon (e.g., at 70% for taxa that comprise less than 70% of the total pollen count and at 5% for taxa that less than 5% of the total pollen count). In a **summary** or **composite diagram**, subunits of data (e.g., sedge [Cyperaceae]) are shown as components of the **pollen sum** (the total number of pollen grains identified: e.g., AP + NAP + AQ), adding up to 100%. Alternatively, all arboreal pollen counts are summed and compared with the sum of NAP and aquatic pollen. Other combinations might summarize the data by broad habitat preferences (e.g., alpine, shrubland, grassland), growth habits (e.g., herb, shrub), or categories reflecting cultural phenomenon (e.g., domestic vs. wild grasses). These summaries show relationships between trees and other vegetation over time that might indicate deforestation or other environmental changes.

Other conventions are followed in these diagrams. The scale for rare taxa may be presented in logarithms or exaggerated by multiplying by some factor, which will be indicated next to the taxon's designation (e.g., "Gramineae x 4" in Fig. 9.7). The presence of very rare, but significant, taxa may be indicated by an "x" or a dot within the body of the diagram; as is maize (*Zea mays*) in Fig. 9.7. One method of presentation combines absolute frequencies (grains/g) and percentages on the same figure (Fig. 9.9; Dimbleby 1985:82–83; Pearsall 2000:316). The count or percentage of other materials relevant to the topic, such as diatoms or wood charcoal, may be included. In an effort to emphasize critical information, data for some taxa may be presented in tables instead of diagrams.

Although this describes aspects of most pollen diagrams, many other formats are common. Pie diagrams may be used for regional comparisons of a few taxa or ecological associations (Traverse 2008:470). One type of pollen map uses **isopollen lines** (isobars) to show the distribution of pollen geographically. Isopollen lines connect locations with samples having the same amount of pollen of a given kind. If a series of maps is prepared, it may be possible to see phytogeographic range

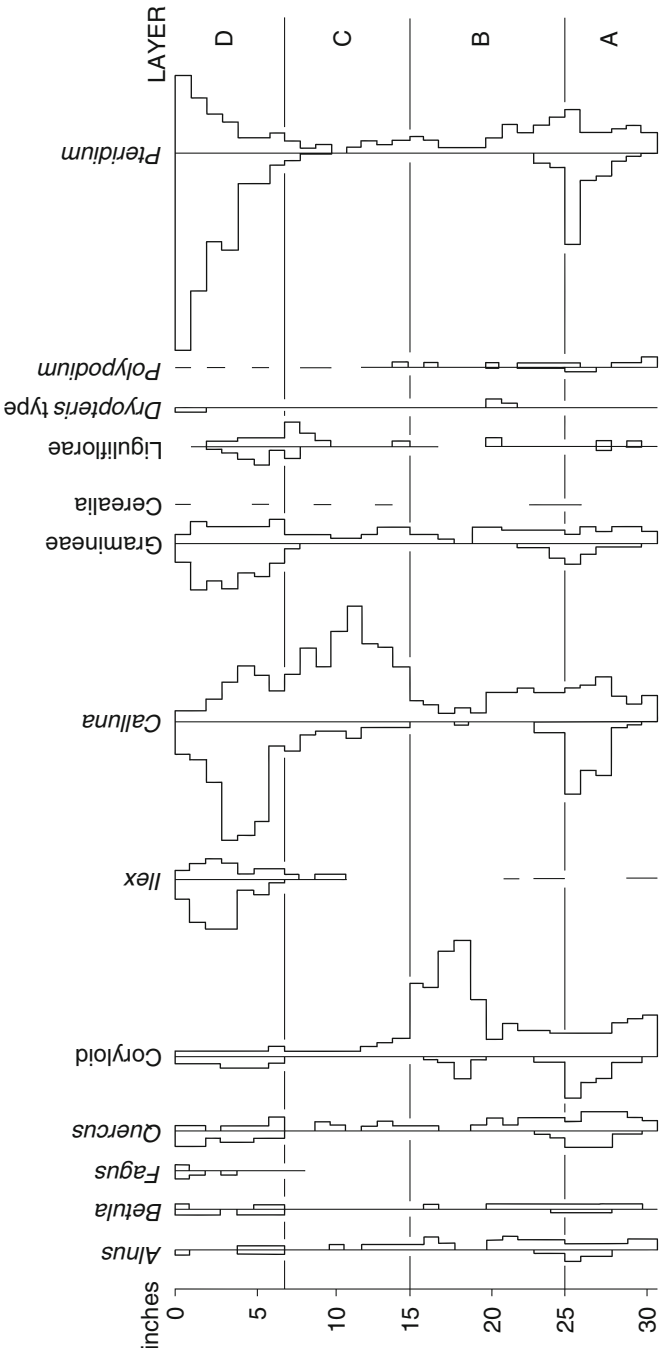

Fig. 9.9 Pollen diagram showing both absolute frequencies and percentages in a double histogram. Absolute frequencies are given as pollen concentration (grains/g) rather than pollen accumulation (grains/area/unit of time). Data from Burley, Hampshire, UK. Modified from Dimbleby (1985:82–83) and used by courtesy of Elsevier

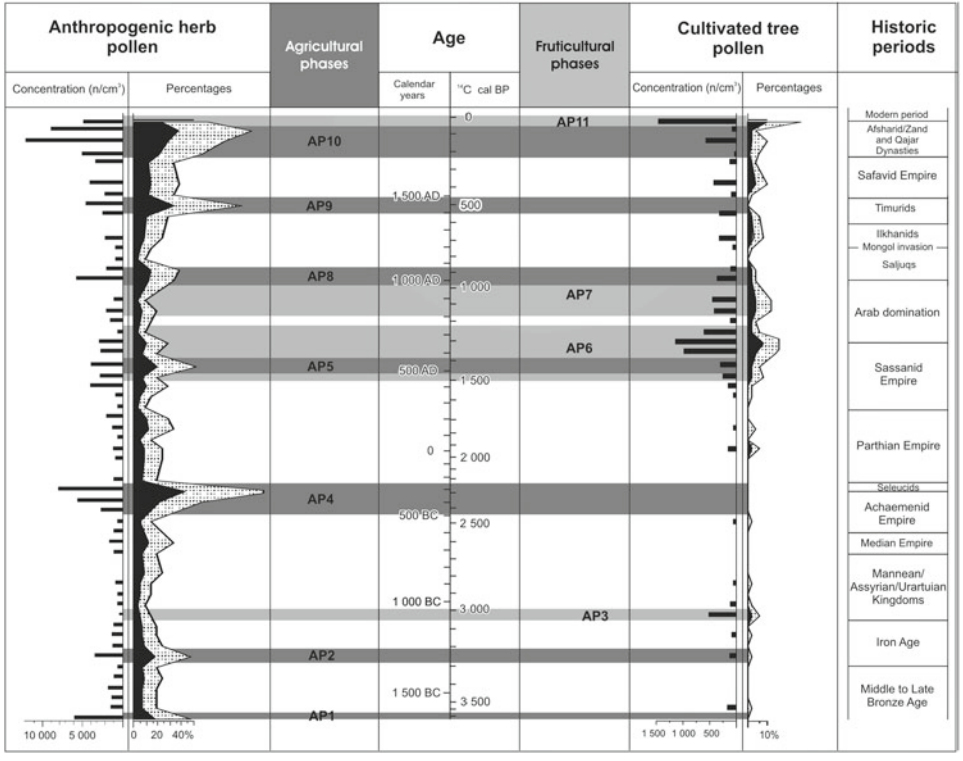

Fig. 9.10 Variations in anthropogenic herb and cultivated tree pollen percentages and concentrations compared with historic events and periods from Lake Almalou (Iran). Cultivated trees are those planted by people, including walnut (*Juglans*), olive (*Olea*), grape (*Vitis*), sycamore (*Platanus*), and aspen (*Populus*). "AP" indicates anthropogenic phases during which human activity was intensified. From Djamali et al. (2009:1370) and used by courtesy of the authors and Elsevier

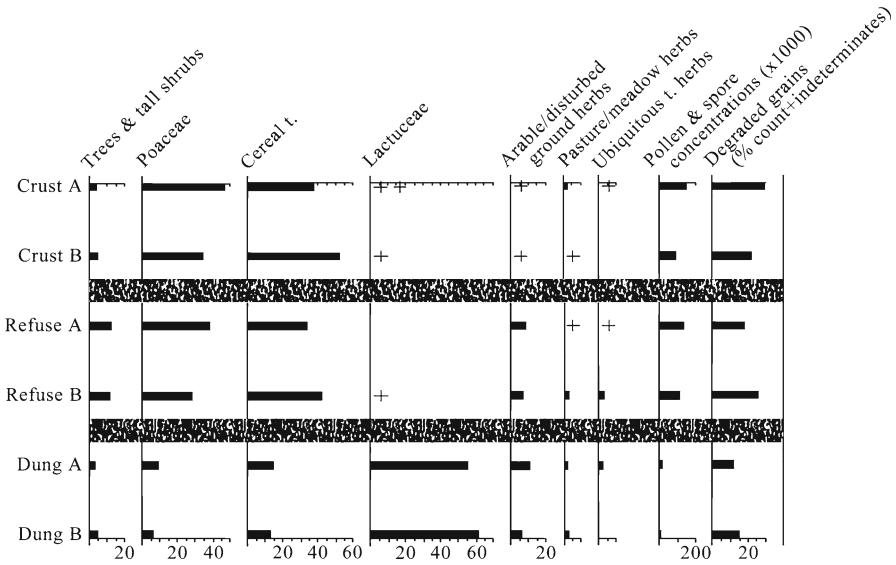

Fig. 9.11 Pollen concentrations in samples collected from the floor of a modern horse stable in Montainville (Yvelines, France) and used as reference materials: crust, floor of the stable; refuse, stable manure heap; and dung, fresh dung. Scales represent percentages, except for the pollen and spore concentration column. *Plus* indicates groups that are present, but rare. Pollen data from G. M. Cruise. From Macphail et al. (2004:182c) and used by courtesy of the authors and Elsevier

expansions or contractions over time, such as the retreat of boreal forests and the advance of deciduous ones in some regions at the beginning of the Holocene (Traverse 2008:514, 683).

Pollen diagrams may include an interpretation of pollen **biozones** or **Local Pollen Assemblage Zones** (Fig. 9.8; Greig and Turner 1974:185, 189; Pearsall 2000:322–324). Each biozone is defined by the habitat preferences and frequencies of the identified pollen independent of stratigraphy, cultural levels, or radiocarbon dates. The sediments in a biozone contain a consistent and homogeneous pollen spectrum that is distinct from spectra in adjacent zones. The boundaries of each biozone are derived using either subjective or objective criteria. Subjective criteria use non-numerical characteristics to delimit zones, in contrast to objective criteria derived statistically (Birks and Gordon 1985). Biozones offer insights into major vegetation changes over time and may highlight phenomena whose importance is initially unrecognized or dismissed. A variation on this theme may associate historic periods with pollen concentrations and percentages (Fig. 9.10; Djamali et al. 2009:1370) or compare pollen in three different types of deposits within the same structure (Fig. 9.11; Macphail et al. 2004:182).

Phytoliths

Silicified plant materials are called opal phytoliths, opal silica bodies, silica phytoliths, and plant opals (Piperno 2006:1). Phytoliths are not reproductive cells, though they may occur within the seeds and inflorescence bracts of many plants, nor are they produced by all plants. They form when hydrated silica from ground water precipitates in and around epidermal and other cells of some ferns, gymnosperms, and angiosperms, creating mineralized casts (Fig. 9.12; Hart 2011:3248; Pearsall 2000:356; Piperno 2006:5–7, 19–20). Some, such as the short-cell phytoliths of grasses (Gramineae [Poaceae]) and the spherical phytoliths of canna lilies (*Canna*), develop in specialized silica-accumulating cells. Others form in some vascular tissues, stems, roots, and parenchyma cells (Chandler-Ezell et al. 2006; Pearsall 2000:360; Piperno 2006:7, 39–42). They can be especially common in the epidermis of seeds and fruits of some trees and herbs, the leaves of some basal angiosperms and many eudicots and monocotyledons, and the inflorescence bracts of grasses and other monocotyledons (Piperno 2006:6–8). In addition to providing taxonomic attributions, they may distinguish between monocotyledons and dicotyledons; between grass leaves/stems and inflorescences; and between wild and domestic grasses. Phytoliths may distinguish between plants that use different photosynthetic pathways (Chap. 13).

Although many exceptions exist, phytoliths may assume the shape of the cells within or around which they form (Pearsall 2000:359; Piperno 2006). They confer support to plants and a degree of protection from diseases and predation by fungi and animals, sometimes in combination with cellulose and lignin (Piperno 2006:12–14). For these reasons, phytoliths can be used to identify timbers and vegetable fibers (Catling and Grayson 1998:3). If phytoliths are burned, it may be possible to evaluate fire regimes and distinguish between anthropogenic and non-anthropogenic fires (Piperno 2006:135–138). Changes in shapes and sizes of some phytolith genera may be associated with domestication (Fig. 9.13; Piperno 2006:45–47; Piperno et al. 2000:202; Piperno and Pearsall 1998:194).

Parts of diatoms, bryophytes, sponges, and some plant spines, prickles, hairs, and fibers are silicified. Phytoliths and other siliceous materials associated with organisms are termed **bioliths** or **biogenic silica**. This terminology distinguishes them from calcareous and siliceous materials that are not biological in origin, though this distinction is blurred in the literature (e.g., Piperno 2006:5; Reinhard and Danielson 2005; Traverse 2008:2).

Phytoliths: Site Formation Processes and Field Considerations

Phytoliths may be present in contexts that lack other plant materials because they are inorganic and less subject to decay. This expands the archaeological contexts as well as the variety of plants and plant parts available for study. They are particularly

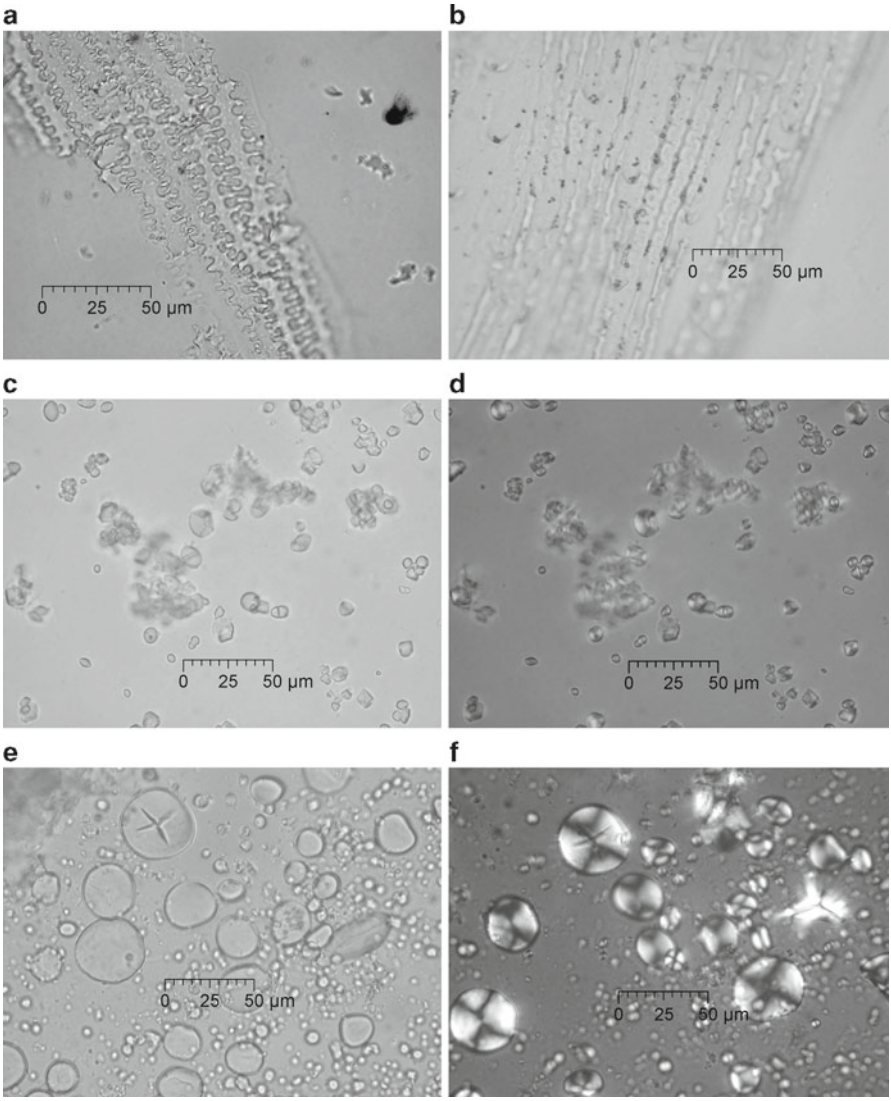

Fig. 9.12 Phytoliths and starch grains: (**a**) common oat (*Avena sativa*) phytoliths; (**b**) cereal rye (*Secale cereale*) phytoliths; (**c**) oat starch grains in transmitted light; (**d**) oat starch grains in polarized light;(**e**) rye starch grains in transmitted light; and (**f**) rye starch grains in polarized light. Scale is 50 µm. From Hart (2011:3248) and used by courtesy of Thomas C. Hart and Elsevier

important because they may survive in hot, humid, tropical conditions when other plant materials may not survive, and they represent plant materials that have decayed in place (Iriarte et al. 2010). Phytoliths are widespread in soils and sediments; they are likely to survive even when the original plant material burns or decays. If it is

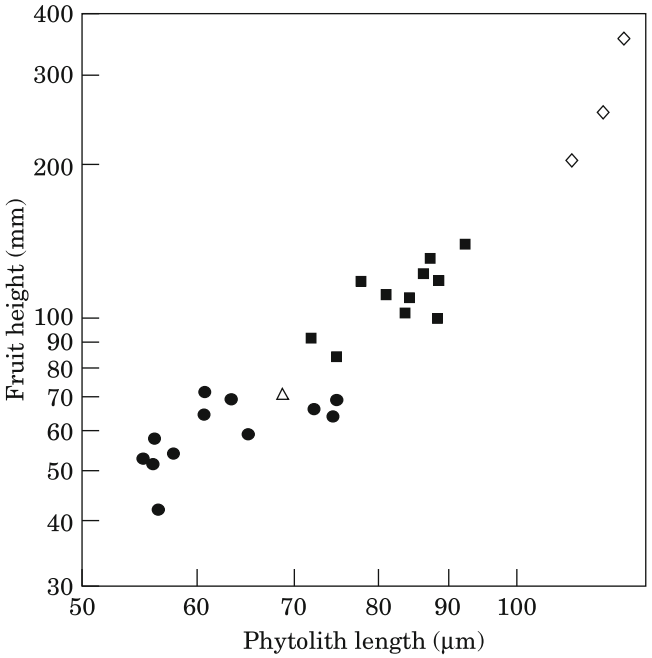

Fig. 9.13 Graph of the relationship between phytolith length and fruit height in modern wild and domestic squash (*Cucurbita*) species, using a log–log scale. (*Filled circle*) *C. argyrosperma* ssp. *sororia* (wild species); (*triangle*) *C. pepo* ssp. *texana* (wild species); (*filled square*) *C. ecuadorensis* (a semi-domesticated species); and (*diamond*) *C. ficifolia* (domesticated species). From Piperno et al. (2000:202) and Piperno and Pearsall (1998:194). Used by courtesy of the authors and Elsevier

possible to associate a phytolith with a specific part of the plant, it may be possible to associate specific plant processing activities with specific locations within the site.

Phytoliths are not impervious to site formation processes, however (e.g., Piperno 2006:114). Shape, surface area, and the amount of silica in each phytolith influence its potential to survive deposition, as do climate, vegetation, sediments, and depositional environments (Piperno 2006:21–22). They are susceptible to chemical and mechanical degradation. Phytoliths tend to be poorly preserved in contexts saturated with carbonates (e.g., shell-bearing deposits) and contexts that are extremely alkaline (pH > 9). They are particularly rare when high levels of carbonates and high alkalinity occur in conjunction with high temperatures and rainfall (Piperno 2006:22). They are likely to survive, however, in oxic settings and those with pH between 3 and 9, contexts in which other plant remains may be less likely to survive. Organisms that digest spores and pollen grains will not be able to digest phytoliths, even if they ingest them.

Phytoliths are unlikely to be included in pollen rain, though they occasionally are transported by wind and water (Piperno 2006:21; Twiss et al. 1969). Most phytoliths enter archaeological settings after being released from decayed or burned plant

materials. Archaeological phytoliths typically originate in plant materials brought to the site by people, in the guts and dung of herbivores, or in plants that grew, intentionally or unintentionally, within the site. Herbivores consume plants in one place and excrete the undigested residue in another, or consume fodder that was harvested elsewhere and fed to them at the site. Phytoliths in fodder and dung may indicate which habitats were used for pasturage or whether domestic animals were foddered. Phytolith layers from Tel Dor (Israel) were originally thought to be lime plaster floors because of their white color and fine texture (Shahack-Gross et al. 2005). The layers were not floors but residue from decomposed dung that had accumulated in what proved to be animal enclosures. They contained concentrations of phytoliths on the order of tens of millions of phytoliths per gram of sediment. Most of these phytoliths were from wild, flowering grasses.

Contexts similar to those sampled for macrobotanical remains and pollen are sampled for phytoliths. This might involve both column samples, samples from specific behavioral contexts, and samples from excavation unit walls, taking precautions to avoid mixing materials (Piperno 2006:82). If phytoliths will be used for radiocarbon dating and stable isotope studies, it is important to use sterile supplies and procedures that limit contamination (Piperno 2006:93–95, 125–129, 131–134). These applications should be anticipated and protective procedures rigorously followed.

In addition to general stratigraphic collections, tightly defined contexts such as hearths, post holes, ash lenses, garbage pits, storage areas, house floors, and livestock areas should be sampled (Piperno 2006:83; Shahack-Gross et al. 2004). Phytoliths adhering to stone tools used to process plants and to ceramic vessels, as well as those in feces, provide direct evidence of plants consumed by people and other animals (Piperno 2006:98–100). They may be present in intestinal areas of burials and adhering to teeth and tools (e.g., Henry et al. 2011). High quantities of phytoliths in areas that were not used by livestock might suggest mats, bedding straw, or dung fertilizer.

Phytoliths: Laboratory Procedures

The laboratory procedures used for phytoliths are similar to those for spores and pollen grains, but different chemicals are involved because some chemicals used to extract pollen destroy silica (Piperno 2006:90–93; Traverse 2008:2). If the same samples are used for both studies, it is necessary to ensure that procedures used to extract phytoliths do not interfere with subsequent spore and pollen extraction (Piperno 2006:95). Phytoliths, or subsamples for phytolith study, should be extracted from soil samples before silica-dissolving chemicals are added. This is just one of the divisions that may be made of soil samples, and a reason why larger samples, or more samples, should be taken than are required for studying sediments, soils, and pollen (Pearsall 2000:399–443). Diatoms are nearly identical to phytoliths in composition and the processes used to extract phytoliths generally recover diatoms, too, if they are present.

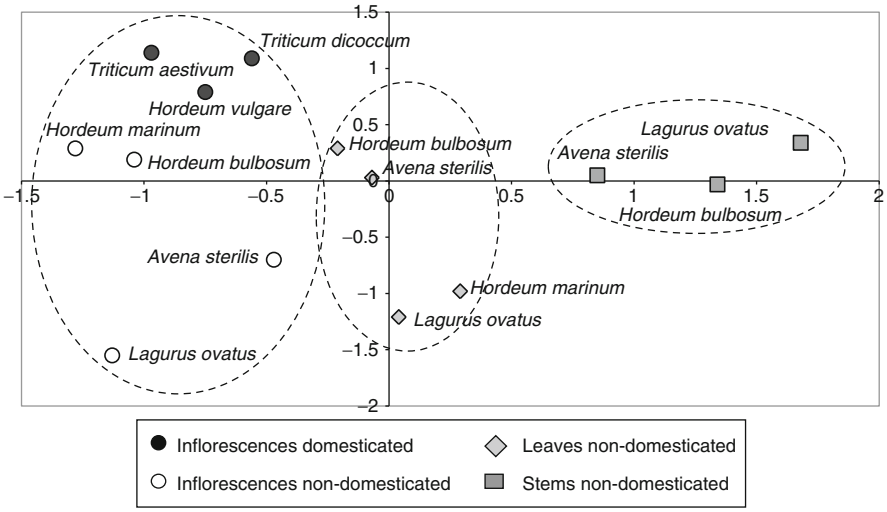

Fig. 9.14 Correspondence analysis of phytolith morphologies for inflorescences, leaves, and stems from oats (*Avena sterilis*), three species of barley (*Hordeum*), harestail grass (*Lagurus ovatus*), and two species of wheat (*Triticum*). Samples are from a modern plant reference collection. Plant parts tend to cluster and the inflorescence phytoliths of domestic species can be distinguished from the inflorescence phytoliths of wild species. From Albert et al. (2008:65) and used by courtesy of the authors and Elsevier

Phytolith identification relies upon reference standards and familiarity with the material. Shape, size, surface features, where the phytolith formed in the plant, measurements, and characteristics of specific plant taxa are used to identify phytoliths. Phytolith-forming plants produce phytoliths whose sizes and shapes reflect environmental conditions under which the plant grew and attributes of the tissue within which each phytolith formed. Thus, shape and size are both distinctive and variable; they even vary within a species and among different parts of the same plant (Fig. 9.14; Albert et al. 2008:65). Most identifications are at the level of family or above, though attributions to genera and even specific epithets are possible for some families. The distinctive attributes of phytoliths in the leaves of ferns, horsetails, and other pteridophytes are important because often their spores are difficult to identify to a level useful for interpretation, but their phytoliths may be identified to family and, occasionally, to genus (Piperno 2006:35–36).

A standardized terminology for classifying phytoliths is emerging as more is learned about relationships among phytoliths, specific plant tissues, and phylogeny. The early literature used terms that described shapes, such as saddle-shaped, cross-shaped, and dumbbell-shaped. Many of these terms now are submerged into classifications reflecting phylogenetic relationships (Piperno 1988:52–60; 2006: 24–27). Phytoliths often are classified using descriptors from the International Code of Phytolith Nomenclature (ICPN Working Group et al. 2005; Mercader et al. 2010; Piperno 2006:24–27, 31, 73). Much of this work has been done with **short-cell phytoliths** (**silica bodies**) of grasses (Piperno 2006:27). Three common short-cell

classifications are **festucoid** (circular, rectangular, elliptical, acicular, crescent, and oblong shapes); **chloridoid** (saddle-shaped bodies); and **panicoid** (cross and dumbbell shapes; Pearsall 2000:363).

Phytolith studies follow protocols similar to those used for spores and pollen grains. An initial scan of a slide may assess dominant phytolith types and relative abundance (e.g., very rare to very abundant). A diagnostic scan follows in which phytoliths are identified until a predetermined standard count is reached (Pearsall 2000:450; Tolonen 1986). Many phytolith studies are based on counts of 200–300 particles, though sometimes larger counts are used (Pearsall 2000:454; Piperno 2006:115). Using a standard count will likely exclude rare taxa and is a compromise between limited time and the desire to sample many different contexts. Phytolith samples may be separated by soil fractions (e.g., fine silt, coarse silt, sand) or by behavioral context before being examined (Piperno 2006:118).

Phytoliths: Analytical Procedures

As with other aspects of environmental archaeology, identification procedures, sample sizes, and counts are important and almost inseparable. Analytical procedures are similar, but not identical, to those for spores and pollen grains (Pearsall 2000:462; Piperno 2006:112–123). Relative or percentage occurrence, absolute frequencies, phytolith concentrations, and accumulation rates are derived following procedures described for pollen (Piperno 2006:118–119). Phytoliths also are measured Fig. 9.13.

As with other botanical data, tables are important; however, graphic presentations are more typical, following conventions used for pollen diagrams (Piperno 2006: 120–125). Piperno (2006:123) recommends presenting percentages, concentrations, and accumulation rates in the same figure to overcome weaknesses inherent in each and to evaluate conflicting trends in data. Graphs may combine taxonomic identifications (e.g., maize), descriptive classifications (e.g., saddle-shaped), ecological types (e.g., disturbed habitat taxa), temperature, precipitation, and other characteristics of the sample, such as woody phytoliths and wood charcoal (Figs. 9.15 and 9.16; Li et al. 2010:129).

An important use of phytoliths is reconstruction of vegetation regimes and, particularly, documenting the conversion of landscapes for agricultural purposes. Iriarte et al. (2010) trace the history of raised field complexes in French Guiana by combining analysis of phytoliths and stable carbon isotopes to study the transition from seasonally flooded savannahs, dominated by a relatively homogeneous vegetation of C_3 and C_4 plants, including C_4 plants such as sedges, arrowroot (Marantaceae), and parakeet flower (*Heliconia*), into agricultural landscapes with raised fields dominated by C_4 plants such as maize (Fig. 9.17; Iriarte et al. 2010:2987). The flooded matrix adjacent to the fields continued to have a high frequency of C_3 plants. Iriarte et al. (2010) document a sequence that begins with marine sediments being replaced by freshwater marshes. Subsequently, raised fields were constructed in these marshes.

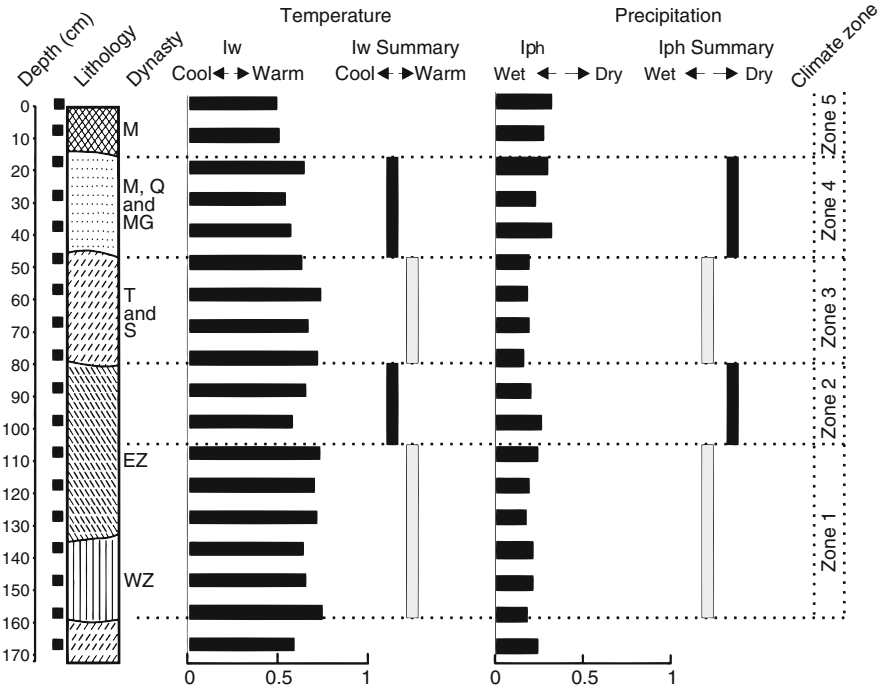

Fig. 9.15 Ratios of warm-type grass phytoliths to the total amount of warm- and cool-type grass phytoliths (*Iw* warmth index) and ratios of phytoliths from a grass subfamily (Chloridoideae) associated with warm/dry conditions to the total amount of Chloridoideae and Panicoideae (a subfamily associated with warm/wet conditions) phytoliths (*Iph* precipitation index). Scales at the bottom of the image indicate the *Iw* and *Iph* index values. These indices show temperature and precipitation changes observed in phytoliths from the Jinluojia archaeological site (China). Vertical bars summarize the direction of temperature and precipitation changes in five major climate zones defined by phytolith assemblages in each. *WZ* West Zhou Dynasty; *EZ* East Zhou Dynasty; *T* and *S* Tang and Song Dynasties; *M*, *Q*, and *MG* Ming and Qing Dynasties, and Ming-Guo Period; *M* Modern Period. From Li et al. (2010:129) and used by courtesy of the authors and Elsevier

Modern experiments show that raised fields can be highly productive, and the channels between each field can be used for fish and turtle farming (Iriarte et al. 2010).

In addition to providing insights into vegetation regimes, crop cultivation, and site formation processes, phytoliths yield data about the origins, manufacture, and use of structures as well as objects such as ceramics, bricks, harvesting implements, and grinding stones (**querns**; Lentfer et al. 1997; Piperno 2006:83–84). It is important to distinguish among phytoliths that were part of the local vegetation when the samples were collected, those that were part of the surrounding matrix, those that were part of the object itself, and those deposited into or on the object through use (Piperno 2006:98–99). Soils near the object should be examined for their phytolith content to determine what might have originated in present-day vegetation or the archaeological

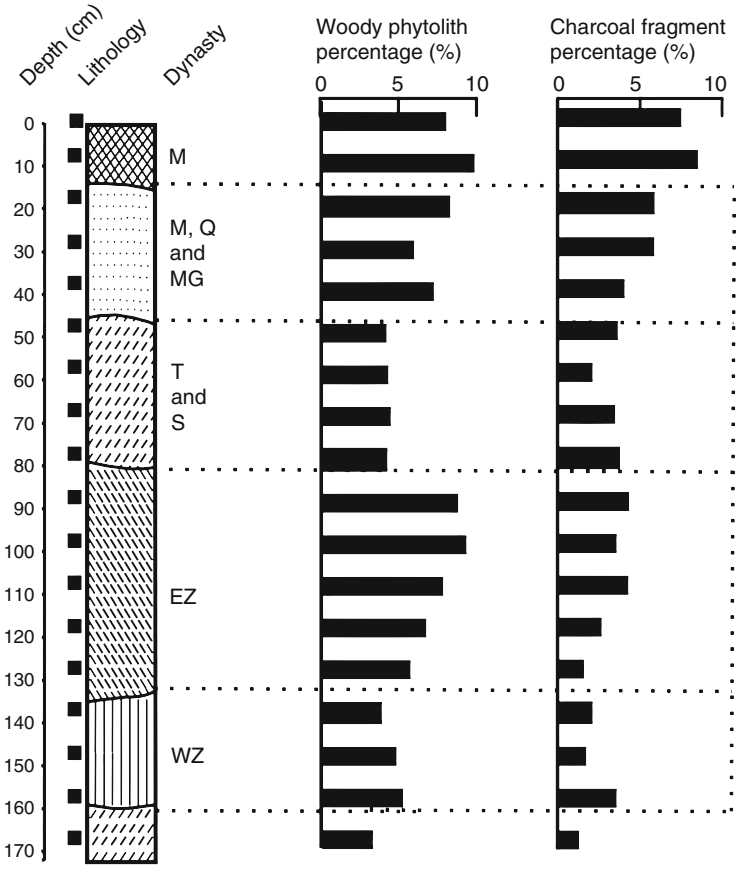

Fig. 9.16 Two increases in microcharcoal and phytolith percentages can be seen in the late East Zhou Dynasty and during the period from the Ming and Qing Dynasties to the present in phytolith and microcharcoal data from the Jinluojia archaeological site (China). Microcharcoal percentages are the ratio of the number of microcharcoal specimens to the sum of sponge spicules, diatoms, microcharcoal particles, and phytoliths in each sample. For dynasty abbreviation see Fig. 9.15. From Li et al. (2010:129) and used by courtesy of the authors and Elsevier

matrix instead of from use of the object. This usually requires showing that the specific phytolith is more abundant on the object than in the surrounding sediments, reinforcing the necessity of taking samples from sediments associated with such objects as well as from the objects themselves. Petrographic study of the object, such as a ceramic pot, may indicate which phytoliths were in the clay or temper used to make the pot, which in turn may indicate where the pot was made. Phytoliths in residue adhering to the interior walls of cooking or serving wares, however, are probably from the foods, dyes, or other materials prepared or stored in such containers (Piperno 2006:135). Analysis of tools for use wear may confirm an association between phytoliths on the

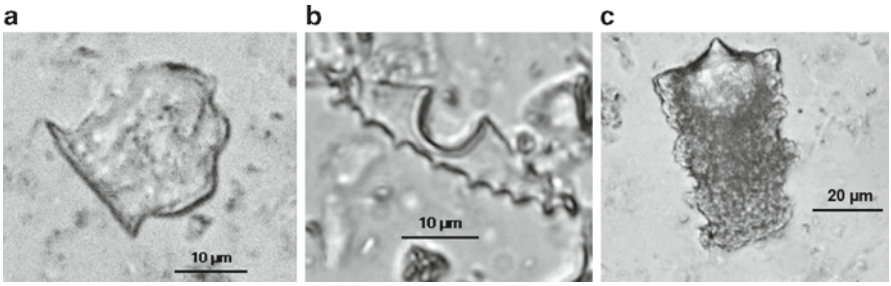

Fig. 9.17 Some phytolith morphotypes identified in the analysis of raised fields in French Guiana: (**a**) half-decorated rondel from a maize cob (*Zea mays*) cob; (**b**) decorated parakeet flower (*Heliconia*) body with troughs; and (**c**) arrowroot (Marantaceae) seed phytolith. From Iriarte et al. (2010:2987) and used by courtesy of the authors and Elsevier

object and the object's function. Strong evidence that a tool was used to harvest grains is provided when phytoliths are present on the cutting edge of a tool, the tool has a silica sheen, and grains are present in the macrobotanical remains from the same or associated deposit. Interpretations that a specific object was associated with a specific plant type are strengthened if phytoliths common on the tool are rare or absent in the matrix from which the object was recovered.

Calcium Oxalate Crystals

Sometimes calcium oxalate crystals are called "phytoliths" or "calcium oxalate phytoliths" (e.g., Reinhard and Danielson 2005). **Calcium oxalate crystals** are calcareous materials that are quite different from silica phytoliths (Piperno 2006:5). Calcium oxalate crystals are produced by cacti (Cactaceae), agaves (*Agave*), yuccas (*Yucca*), grapes (*Vitis*), and olives (*Olea europaea*), among other plants (Pearsall 2000:358), as well as by fungi and some bacteria (Moskal-del Hoyo et al. 2010; Weiner 2010:306). Calcium oxalate crystals are recovered along with starch grains and xylem cells and are particularly associated with ash deposits (e.g., Shahack-Gross et al. 2005; Weiner 2010:169–170). They can assume fine, needle-like shapes (**raphides**), relatively large crystal clusters (**druses**), or small triangles (**crystal sand**; Weiner 2010:170). When heated, calcium oxalate converts into calcite and may further degrade into calcium oxide. Bacteria consume these crystals (Shahack-Gross 2011). The chemicals used to extract pollen from soil samples destroy calcium oxalate crystals (Traverse 2008:2). They can be recovered from palaeofeces, storage vessels, and other contexts if chemicals that dissolve calcareous materials are avoided (Pearsall 2000:359, 434–435; Reinhard and Danielson 2005).

Starch Grains

Plants store energy as a complex carbohydrate (i.e., starch) in true roots and stem roots, other fleshy storage organs, leaves, and seeds (specifically in cotyledons and endosperm). Identifications of starch grains are valuable for many reasons, not the least of which is that they provide evidence for the use of plants and plant tissues that preserve poorly at many sites, such as fibers and root crops (e.g., sweet potatoes [*Ipomoea batatas*], manioc [*Manihot*], white potatoes [*Solanum tuberosum*]). Starch is readily converted to water-soluble **glucose** (a simple sugar) by digestive enzymes, such as those in the mouth (Hardy et al. 2009). As with spores, pollen, and phytoliths, it is necessary to distinguish among starch grains present due to post-depositional transfer from the surrounding matrix onto the object, those intrinsic to the object, and those associated with the object's function (Langejans 2011).

Starch grains are food for many organisms, including bacteria, fungi, and many small animals; thus, consumption is a significant site formation process. Starch grains degrade when heated, soaked, or exposed to strong oxidizing or reducing agents. These are some of the very treatments people use to prepare starchy foods. Heating starch results in gelatinization: the starch grains swell and lose their characteristic **birefringence** (an optical property under cross-polarized light). Food preparation involves diverse combinations of cooking times and temperatures (e.g., Henry et al. 2011). It entails multiple processing stages such as peeling, grinding, baking, parching, fermenting, soaking, popping, and boiling. The nature and sequence of these treatments depends on the desired end product and the specific plant tissue being processed, but they may alter starch grains in characteristic ways (Henry et al. 2009). Mechanical action and high humidity harm starch grains. Starch grains lose their structure as they degrade and the dark, intersecting lines (birefringence, in the form of an **extinction**, **Maltese**, or **interference cross**) used to identify starch grains may disappear, as they do when heated.

Starch grains may be collected from the same contexts sampled for pollen and phytoliths using similar protocols. They adhere to many archaeological objects, under a wide range of pH values, and persist for thousands of years (Barton 2007; Summerhayes et al. 2010). They may be preserved on grinding stones and as food residue on ceramics, within surviving plant cells, and in dental calculus (Hardy et al. 2009; Henry et al. 2011). Preservation in soils, however, may be poor.

The variety of contexts from which starch is recovered highlights the importance of expanding sampling protocols beyond those required for dating or studying soils and sediments. The bags and gloves used to collect and manage starch grains must not contain a starch-based powder (Piperno 2006:82). Materials need to be handled so as to limit contamination with modern starches, balancing conservation against studies that may need untreated samples, and being cautious about both enthusiastic post-excavation cleaning and neglect. Field samples not used immediately should be safeguarded against fungi and other organisms that view these valuable archaeological specimens as free food.

Starch grains are usually recovered from separate fractions and processed using methods adapted to their specific chemical and physical characteristics. Although starch grains, spores, pollen, and phytoliths may be extracted from the same samples, they cannot be removed from precisely the same fractions because the chemicals used to extract spores, pollen, and phytoliths are used specifically to destroy organic residues such as starch (Piperno 2006:1, 95–96). Sacrificing a small amount of starch by exposing some of the sample to an α-amylase enzyme, such as that from *Bacillus licheniformis*, may demonstrate that starch is present in the sample (e.g., Hardy et al. 2009). Starch stains blue to black when exposed to an iodine-potassium iodide solution.

Identification of starch grains is based on size, anatomy, and other characteristics (e.g., Chandler-Ezell et al. 2006; Giovannetti et al. 2008). Starch grains range in size from 1 to 100 μm. Starch develops accretion layers (**lamellae**) around a nucleation point at the hilum (Fig. 7.4). Although the size and shape of starch grains vary within a species, and within an individual plant, in some cases they are diagnostic at the trivial level (e.g., Fig. 9.12; Hart 2011). Figure 9.12 shows clearly the differences between phytoliths and starch grains, as well as between starch grains viewed under transmitted and polarized light. Dark, intersecting lines form the extinction cross where these layers converge at the hilum when the grain is viewed under polarized light (Fig. 9.12). The extinction cross, the density and structure of lamellae, and the shape of the grain (spherical to ellipsoidal) are features that indicate the material is, in fact, starch. Other characteristics used to identify starch grains include dimples, cracks, fissures, angularity, and facets (Henry et al. 2009; Loy 1994; Pearsall 2000:178–182).

Starch grains adhere to objects used to process and cook starchy foods (Chandler-Ezell et al. 2006; Piperno 2006:98–100). In a study of ethnographic artifacts curated at the Australia Museum in Sydney and the Pitt Rivers Museum in Oxford (UK), Barton (2007) found that both unmodified (uncooked) starch grains and modified (cooked) grains persist on wood and stone tools for many years. Although the biases against starch survival seem overwhelming, identifiable starch grains have been extracted from stone tools recovered from deposits dated to 105,000 years ago in a Mozambique cave. Sorghum (*Sorghum bicolor*) comprises 89% of these grains, adding sorghum to the list of plants used by people in the Middle Stone Age (Mercader 2009).

Stomach Contents and Feces

The contents of digestive systems and feces offer unique perspectives on items that were actually consumed, intentionally or unintentionally, willingly or not (Callen 1970; Callen and Cameron 1960; Holden 2001). They provide information about substances for which there is little other evidence, such as bacteria, algae, fungi, leaves, roots, stems, intestinal worms, and arthropods. **Steroids** (a diverse group of lipids, including sterols; Chap. 13) in feces may indicate the sex of the consumer (Sobolik et al. 1996). Sterol biomarkers may also aid in distinguishing between human and non-human fecal materials (Shillito et al. 2011).

The contents of the digestive system (e.g., stomach, intestines) and fecal matter were consumed shortly before death or defecation. Although relatively few very large plant and animal materials are ingested, cysts, diatoms, chitin, seed testa, fibers, epidermis, cereal bran, spores, pollen, phytoliths, calcium oxalate crystals, starch grains, mollusc shell fragments, and small vertebrate remains may be consumed and survive the digestive process (e.g., Holden 2001; Reinhard and Danielson 2005; Shahack-Gross et al. 2005). Some of these materials are the remains of foods, beverages, or medicines; others are from pests and parasites either of the host or of the materials ingested. A few are hallucinogens or poisons. Fecal matter from latrines and stables is more likely to represent accumulations involving several individuals—human or non-human—over a period of time; in contrast to an individual coprolite or the stomach contents of a burial.

Contents of the digestive system and fecal matter are collected from burials and from contexts such as cesspits or stables. Usually they are recovered from arid or anoxic contexts, though occasionally they survive if carbonized, frozen, or mineralized. They are preserved in waterlogged deposits (e.g., bog bodies) and with mummies, though both are rare finds. Substances and organisms with distinctive indigestible elements are more likely to be identified than are those with few indigestible parts, of course (Callen and Cameron 1960; Fry 1985; Holden 2001:408). Palaeofeces are recognized on the basis of anatomy, color, and contents; they typically contain a rich array of materials and they color fluids dark brown or black when rehydrated (Fry 1985). Sterols may distinguish between humans and other animals as well.

Applications

Djamali et al. (2009) address one of the most difficult topics in archaeology: determining how climatic, socioeconomic, and historical events correlate with vegetation changes. The authors reconstruct the local and regional vegetation of the Lake Almalou region (Azerbaijan, Iran) over the past 3,700 years with the goal of studying regional environmental and cultural changes. They base their study on a pollen core from Lake Almalou, a high-altitude (2,500 m a.s.l.) wetland bog that today lies above the tree line. Although the study focuses on pollen, a preliminary assessment of chironomid (Insecta: Diptera) remains from the earliest part of the depositional sequence provides knowledge about initial hydrological changes when peat formation began. Irrigation, cultivation of grasses, pulses, and fruits, and regional cycles of farming, herding, sedentism, and nomadism were present in northwestern Iran by the second half of the second millennium BC, accompanied by dense human occupations, urbanization, and complex socioeconomic and political systems. Pollen from cultivated plants such as walnuts (*Juglans*), olives, grapes, and castorbeans (*Ricinus communis*) is evidence of fruiticulture, either within the basin or at lower elevations. Castorbeans were domesticated in tropical Africa, transported to India about 4,000 years ago, and introduced to the Lake Almalou area ca. AD 1550, providing a date

for the addition of this crop to the region. The pollen record contains evidence for 11 phases of intensified anthropogenic activities, with two particularly strong agricultural phases at 2450–2220 cal BP and 230–30 cal BP (Fig. 9.10). Djamali et al. (2009) interpret the cycles of fruiticultural and agricultural (and/or pastoral) activities apparent in the pollen core as primarily responses to historical events in the Near East, with the exception of the Little Ice Age in the sixteenth to mid-nineteenth centuries AD. The authors conclude that a more detailed ecological record is needed to resolve the role of climate in these land-use changes.

Honey leaves little direct evidence, but its use can be demonstrated through pollen analysis. Deforce (2010) reports on the identification of pollen recovered from two fifteenth-century AD cesspits at one of the main residences of the Dukes of Burgundy in Bruges (Belgium). The cesspits contained pollen from four insect-pollinated plants for which no macrobotanical remains were identified. Nor are macrobotanical remains for these four taxa present in cesspits or other Medieval archaeological contexts elsewhere in the Low Countries. The taxa are not native to the Bruges area today, but they are found in modern honey from the southwestern Iberian peninsula. The author proposes that this pollen represents local use of honey imported from the western Mediterranean region. Before widespread use of sugar, honey was popular in Medieval food products and medicines. The presence of imported honey may be evidence of the high status, wealth, and international connections enjoyed by the household (Deforce 2010).

In much of the tropical world, plant cultivation focuses on starch-rich root crops and arboreal fruits instead of grains, but evidence for the use of these plants is rare. Fullagar et al. (2006) and Denham et al. (2003) study lithic use-wear patterns, phytoliths, and starch grains for evidence that taro (*Colocasia esculenta*) and yams (*Dioscorea* sp.) were cultivated at Kuk Swamp (Papua New Guinea). Fullagar et al. (2006) report that both of these plants were used by 10,000 cal BP and likely are indigenous to New Guinea. The identification of taro in Kuk Swamp residues is the primary evidence that taro was used in New Guinea. The authors are unable to conclude that these plants were domesticated, but argue that taro, yams, and bananas (*Musa*) were cultivated by 6950–6440 cal BP. The wetland location of the site may have facilitated exploitation and subsequent domestication of taro and yams. Tools show signs of a wide range of functions and many were used for multiple tasks, such as processing wood, reeds, skin, bone, and ochre, in addition to root crops.

Environmental archaeologists rely on anatomical and biometrical properties derived from reference materials for most identifications and analyses. Although landmarks for identification and an understanding of the potential for analysis are available for the most common economic plants, for other plants protocols and reference collections are only now being developed. The sweet, edible mesocarp of algarrobo (Leguminosae [Fabaceae]: *Prosopis*) pods has a long history of use in South America (Giovannetti et al. 2008). The pods of this legume are used in foods, beverages, medicines, fuels, tanning agents, and dyes. Although the pulp of the fresh fruit is edible, algarrobo today is more likely to be ground into a flour for use in other products. Pods, seeds, mastication products, endocarps, and mesocarps are present at sites in Argentina

as early as 10,550 ± 300 BP. Giovannetti et al. (2008) demonstrate that algarrobo starch grains also are present. The authors began their study by developing a reference collection and comparing algarrobo starch to that of maize, a grain well known for its high starch content. The authors did not find starch in algarrobo seeds, but they did find it in the mesocarp. Their experiments show that algarrobo pods contain low amounts of starch compared with maize but that the starch grains present in algarrobo pods do have diagnostic features. Guided by these experimental results, the authors identified algarrobo starch on mortars from El Shincal Inka (Catamarca, Argentina), elaborating on the uses of both grinding stones and algarrobo at this site.

Summary

Although the distinction between macrobotanical and microbotanical remains is a traditional one, a more comprehensive interpretation is possible by combining these lines of evidence with analyses of sediments and soils, tools, structures, and activity areas. From such studies we obtain information about the organisms present at a site and in the region before the site was occupied as well as during that occupation and subsequently. These historical records clarify the trajectory, processes, causes, and consequences of environmental changes as well as the human role in and responses to those changes. Both macrobotanical and microbotanical remains may be used to document the presence and use of a particular taxon, the distribution of taxa during different stages of the Holocene, or the complete botanical record for a cultural phase, a specific region, or for a broader geographical unit. Cycles of plant productivity are important aspects of plant use and many cultural institutions manage seasonal cycles and merge them with other aspects of domestic, social, and ritual life. Plant domestication figures prominently among the significant economic strategies, with far-reaching consequences for Holocene environments and human history.

Whatever the processes and consequences of their use, plants in the human sphere are closely linked to animals. Although plants dominate the visible landscape, and provide many resources important to human life, a more complete record of environmental change and stasis, human–environmental interactions, and cultures is obtained by expanding studies of these complex phenomena to include animals, the focus of the next three chapters.

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Chapter 10
Arthropods and Some Other Invertebrates

Animals provide valuable services to people as sources of food, labor, raw materials, and symbols in belief systems and iconographies. They also offer companionship. Many animals provide significant ecosystem services, such as pollination, aeration of soil, and maintenance of vegetation regimes. Having said this, however, most animals, such as arthropods (e.g., insects), are ignored by people unless they are considered pests.

Due to the fidelity of many animals to specific habitat types, they provide information about former environments and many cultural activities, documenting change, stasis, and interactions in both arenas. Many animals are defining characteristics of soil and some are significant bioturbation agents. Others are sensitive seasonal or ecosystem indicators. As with plants, however, it is necessary to distinguish among animals that lived at or near the archaeological site and those from more distant locations and different habitats. It also is necessary to determine how the animal came to be part of the study assemblage: was it a background organism, an incidental inclusion on materials brought to the site from elsewhere, or an animal with economic or other cultural value, perhaps exotic to the area and obtained through a long-distance trade network? In many cases, animals enable the functions of structures and other activity areas to be resolved.

The darker side of some animals is their role as vectors or causal agents of disease, afflicting domestic plants and animals as well as people. Studies of these larger vectors and pathogens enable us to consider environments, parasite ecology, and disease histories in addition to aspects of human behavior associated with sanitation, water quality, residential patterns, seasonal cycles of resource use, interactions with domestic animals, trade, and nutrition.

Compared with plants, few animals have been domesticated, though one of these animals, the dog (*Canis familiaris*), is the earliest and most ubiquitous domestic organism. Although most domestic animals are mammals and birds, two domestic animals are insects. Animal domestication is associated with extensive changes in environments and cultures; the stimuli, processes, and consequences of domestication

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are important aspects of environmental and human history. Quite a few animals, if not actually domesticated, have been maintained at least briefly, while young, or in menageries.

Nomenclature

Most of the members of the Kingdom Animalia represented in archaeological deposits are from four phyla: Arthropoda, Mollusca, Echinodermata, and Chordata (Table 10.1; Brusca and Brusca 2003; Campbell et al. 2008:696; Krogh 2009:470; Williams et al. 1989). After an overview of the kingdom, this chapter focuses on arthropods and a few other invertebrates. Molluscs and echinoderms are discussed in Chap. 11 and chordates in Chap. 12. Most of the animals reviewed in this chapter are termed "microfauna" to distinguish them from animals that tend to be larger bodied in archaeological sites (molluscs, echinoderms, vertebrates) reviewed in Chaps. 11 and 12. Like other generalizations, this does not do justice to the diversity of animal forms and functions.

Animals are divided into **invertebrates** and **vertebrates** based on whether or not they protect a spinal cord with a flexible, bony column (e.g., vertebral column). Most animals do not have vertebral columns and are invertebrates. Only members of one subphylum are vertebrates (Phylum Chordata, Subphylum Vertebrata); this is the phylum that includes people (*Homo sapiens sapiens*).

Broadly speaking, animals exhibit two forms of normal growth. The most common of these is indeterminate growth, in which animals grow throughout life, though growth may be slow or irregular in older animals. Animals with **determinate growth** grow until they reach a specific adult body size, at which time most growth ceases. Indeterminate growth occurs in both invertebrates and vertebrates; determinate growth is characteristic only of birds and mammals.

A useful distinction among animals is whether they have **endoskeletons** (internal skeletons) or **exoskeletons** (external skeletons, carapaces, shells). The difference between endoskeletons and exoskeletons is whether the skeleton derives from internal (**mesoderm**, endoskeleton) or external (**ectoderm**, exoskeleton) portions of the embryo (Brusca and Brusca 2003:48, 53–54). Skeletons may be very simple or very complex; some animals combine a simple endoskeleton with an elaborate exoskeleton. Skeletons usually are composed of biominerals, commonly carbonates, phosphates, halides, sulfates, and iron oxides (Brusca and Brusca 2003:53–54). The resulting hardened structures provide muscle attachments, support, and protection.

Exoskeletons appear in many configurations. Even organisms that may not appear to have an exoskeleton may have some form of external protection, if only a covering of sand glued together to form a "test." A more elaborate protective covering consists of cuticle, which is an acellular layer or exoskeleton found in many organisms (Chap. 7). The cuticles of animals contain chitin, proteins, calcium, and waxes and may bear spines, scales, rings, or segments. Chitin is produced by many eukaryotic organisms and is both flexible and tough. A portion of the chitinous cuticle of some

Table 10.1 Classification of some invertebrates[a]

Category	Examples
Phylum Porifera	Sponges
Phylum Cnidaria	Sea anemones, jellyfishes, corals
Hydrozoa	Portuguese man-of-wars, hydras, some corals
Anthozoa	Sea anemones, most corals, sea fans
Scyphozoa	Jellyfishes, sea wasp, sea nettle
Phylum Ctenophora	Comb jellies, sea walnuts
Phylum Platyhelminthes	Flatworms, polychaetes
Turbellaria	Flatworms (helminths), planarians
Monogenea	Monogenetic flukes
Trematoda	Flukes, trematodes
Cestoda	Tapeworms
Phylum Nemertea	Ribbon worms
Phylum Rotifera	Rotifers, wheel animalcules
Phylum Nematoda (=Nemata)	Roundworms, threadworms, pinworms, hookworms
Phylum Acanthocephala	Thorny-headed worms
Phylum Annelida	Segmented worms
Polychaeta	Segmented marine worms, tubeworms, sandworms
Clitellata	Earthworms, leeches
Oligochaeta	Segmented worms, earthworms
Hirudinida	Leeches
Phylum Arthropoda	
Cheliceriformes	
Merostomata	Horseshoe crabs
Arachnida	Spiders, ticks, mites, scorpions
Crustacea	Water fleas, ostracods, copepods, barnacles, crabs
Branchiopoda	Water fleas, Cladocera, *Daphnia* spp.
Malacostraca	
Euphausiacea	Krill
Decapoda	Shrimps, crabs, lobsters
Brachyura	"True" crabs, mud crabs, land crabs
Anomura	Hermit crabs, stone crabs, king crabs
Astacidea	Clawed lobsters, crayfishes
Palinura	Spiny lobsters
Isopoda	Pill bugs, wood lice
Maxillopoda	
Cirripedia	Barnacles
Copepoda	Copepods
Ostracoda	Mussel or seed shrimps
Hexapoda	Springtails, insects
Entognatha	Springtails
Insecta	
Blattaria	Cockroaches
Coleoptera	Beetles
Dermaptera	Earwigs
Diptera	Flies, mosquitos, midges

(continued)

Table 10.1 (continued)

Category	Examples
Hemiptera	True bugs
Hymenoptera	Ants, bees, wasps
Isoptera	Termites
Lepidoptera	Butterflies, moths
Mantodea	Mantises
Odonata	Damselflies, dragonflies
Orthoptera	Crickets, grasshoppers
Phthiraptera	Lice
Siphonaptera	Fleas
Trichoptera	Caddisflies
Myriapoda	Centipedes, millipedes
Chilopoda	Centipedes
Diplopoda	Millipedes
Phylum Mollusca	Univalves, bivalves, squids (see Chap. 11)
Phylum Phoronida	Phoronids
Phylum Bryozoa	Moss animals, ectoprocts (Ectoprocta)
Phylum Brachiopoda	Brachiopods, lamp shells
Phylum Echinodermata	Echinoderms
Phylum Chordata	Lancelets, tunicates, vertebrates (see Chap. 12)

[a]Following Brusca and Brusca (2003), Campbell et al. (2008:696), Krogh (2009:470), and Williams et al. (1989)

invertebrates is **mineralized**, a process by which calcium salts are deposited in tissues during life (Brusca and Brusca 2003:53–54, 479; Stevenson 1985). Mineralized exoskeletons are particularly characteristic of crustaceans (e.g., crabs).

An important distinction among animals is whether they have both larval and adult stages. **Larvae** (singular: larva) are pre-adult, sexually immature forms that differ from adults in anatomy, behavior, and habitat (Thain and Hickman 2004:400). Larvae are one way for animals, especially aquatic ones, to disperse progeny over vast areas. Parasitic larvae may occupy intermediate hosts before dispersing to definitive or primary hosts, where, as adults, they reproduce. Capsules (**cysts**) formed during a resting stage in larval development enable larvae to survive unfavorable conditions, and many persist in the archaeological record for long periods of time. Larvae mature into adult forms through **metamorphosis**.

Some form of symmetry is another common characteristic of animals. Sponges (Porifera) generally lack symmetry (**asymmetrical**) but most animals are symmetrical during at least part of their life cycle. Some of these are **radially symmetrical**, with equal parts radiating out from a center to form a roundish barrel, pie, or star shape (Campbell et al. 2008:659). Others are bilaterally symmetrical and have one plane that clearly separates them into halves that are more or less identical (Krogh 2009:444, Thain and Hickman 2004:76). Symmetry gives animals orientations that can be designated with reference to the mid-line (**medial**, dividing the animal into identical halves) that defines dimensions such as top (**dorsal**), bottom (**ventral**), front (**anterior**), back (**posterior**), left, or right (Fig. 10.1; Davis 1987:54).

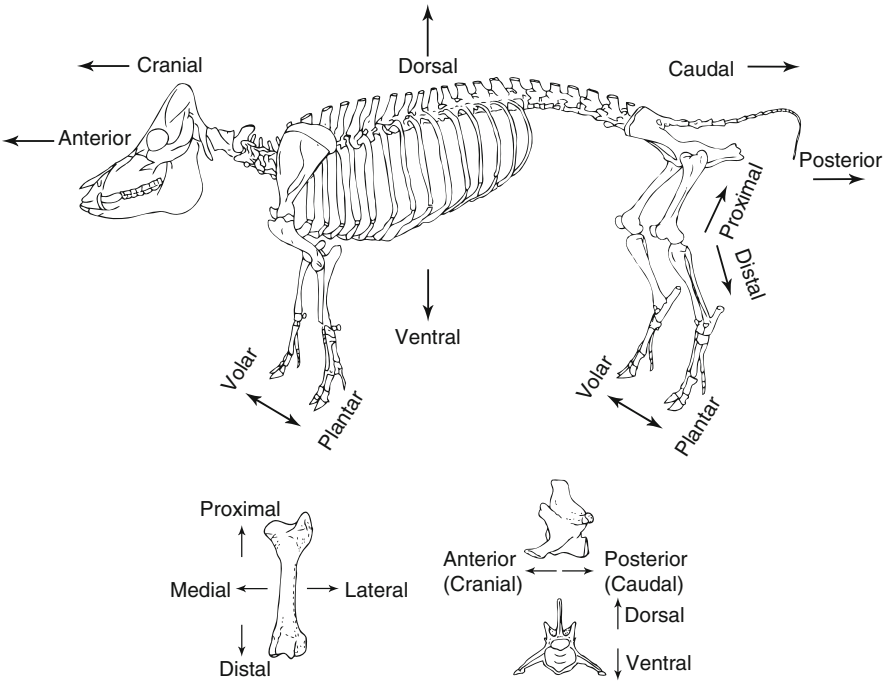

Fig. 10.1 Directional terms for vertebrates shown using a pig (*Sus domesticus*). Modified from Davis (1987:54); © 1987 by Yale University Press and used by courtesy of Simon J. M. Davis, Yale University Press, and Taylor & Francis Books UK. Drawn by Evelyn Davis

Most Porifera, Cnidaria, and Ctenophora are radially symmetrical marine organisms with a larval stage. Sponges are sessile; depending on the species, they may be fixed to a living or non-living substrate. They are distinguished from the other animals because they do not have nerves, muscles, or other true tissues. Some sponges have microscopic calcareous or siliceous needle-like structures (**spicules**) that provide protection or support. These spicules can be very elaborate and distinctive (e.g., Brusca and Brusca 2003:193). Hydras, sea anemones, corals, and jellyfishes (Cnidaria, Ctenophora) have true tissues. Many Cnidaria are colonial and sessile during parts of their life cycles and may have simple or elaborate skeletal systems (Brusca and Brusca 2003:219–222). Some corals (Anthozoa) combine calcium carbonate with other materials to form distinctive skeletal frameworks (Brusca and Brusca 2003:223–224, 236–239; Krogh 2009:449). Others have horny or wood-like **axial** skeletons (centered along the body axis), thick calcareous plates divided by sutures **(sclerites)**, or calcareous skeletons (Brusca and Brusca 2003:236–237).

Animals with bilateral symmetry are classified as either protostomes or deuterostomes based on aspects of their embryonic development (Krogh 2009:444–445). Among the protostomes are Platyhelminthes (flatworms), Nematoda (roundworms, threadworms), Annelida (segmented worms), Arthropoda (spiders, crabs, insects),

and Mollusca (snails, clams). These phyla illustrate the limitations of vernacular names. For example, the vernacular English word "worm" is applied to many of these animals because of their "worm-like" appearance. Members of these phyla are very different in their phylogeny and anatomy despite their vernacular names.

Platyhelminthes are so named because of their flattened anatomy. They have few, if any, hard tissues, though some have small calcareous plates or spicules embedded in their body walls and some are encapsulated in cysts during parts of their life cycles (Brusca and Brusca 2003:294, 309–312). Platyhelminthes come to our attention largely as commensal organisms or parasites (Barnes 2005). Turbellaria are primarily non-parasitic, free-living marine organisms; but many Monogenea, Trematoda, and Cestoda are parasitic and live in or on other animals (Campbell et al. 2008:674–676). Monogenea (flukes) usually are external parasites of fishes. Another group of animals known in the vernacular as flukes (Trematoda) typically have suckers by which they attach themselves to their hosts. Many trematodes have complex life cycles that involve multiple hosts for developing larvae and adults. Generally at least one of these hosts is a mollusc; in some cases, an intermediate host is a mollusc and the final host a vertebrate (Brusca and Brusca 2003:288).

Cestoda (tapeworms) are primarily internal parasites of vertebrates; they have suckers and hooks, but no digestive tracts, relying upon nutrients absorbed from the host. Tapeworms require at least one intermediate host and a primary host (Brusca and Brusca 2003:288–289; Campbell et al. 2008:676). The tapeworm (*Echinococcus granulosus*) associated with echinococcosis (cystic hydatid disease) forms calcified cysts in the organs of intermediate hosts. The cysts are transmitted to primary hosts when the host consumes infected, cyst-containing organs. Primary hosts generally are carnivores, such as dogs. Herbivores, such as cattle (*Bos taurus*) and sheep (*Ovis aries*), serve as intermediate hosts. Humans are accidental hosts, but the slow-growing masses can become very large and the infected person may be chronically ill. Kristjánsdóttir and Collins (2011) report that eight individuals with hydatid cysts were grouped together in the burial ground of a monastic hospital in Iceland. The authors postulate that the disease became endemic in Iceland around AD 1200 when dogs were introduced to the island. The fish tapeworm (*Diphyllobothrium latum*) also has a life cycle that involves several hosts and vectors (Brusca and Brusca 2003:314).

Nemertea, Rotifera, Acanthocephala, Phoronida, Bryozoa, and Brachiopoda seldom have hard tissues, but exceptions are important. Nemertea (ribbon worms) have specialized feeding mechanisms (**stylets**) consisting of an organic matrix surrounded by a calcium and phosphorus cortex (Brusca and Brusca 2003:325). Most ribbon worms parasitize invertebrates. The zygotes of rotifers may be encapsulated in dormant or resting forms if their aquatic habitat dries up (Campbell et al. 2008:676–677). Some rotifers have thick cuticles with sculpturing such as spines and tubercles (Brusca and Brusca 2003:340). Most rotifers live in fresh water, though some are marine and others live in damp soil or even in the water film on mosses. Rotifers remind us that a widespread organism may leave little evidence in archaeological sediments. Acanthocephala (thorny-headed worms, e.g., *Moniliformis clarki*), intestinal parasites of freshwater fishes and other vertebrates, require intermediate arthropod hosts (Brusca and Brusca 2003:368–370). They do not have digestive tracts and

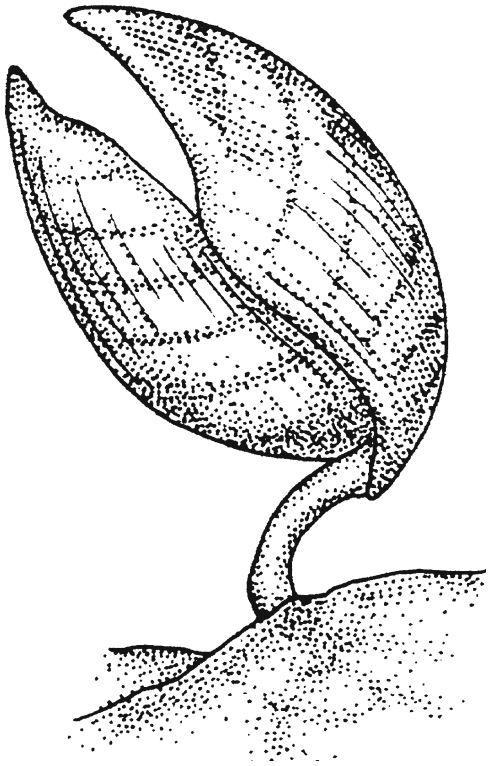

Fig. 10.2 Lamp shell (Brachiopoda: *Hemithiris*). From Brusca and Brusca (2003:792, Figure 21.18d). Used by courtesy of Sinauer Associates, Inc

are obligatory parasites. Phoronids are tube-dwelling worms that lack hard tissues, but construct chitinous tubes in the substrate (Brusca and Brusca 2003:773–774). Sessile, aquatic bryozoans (also known as **ectoprocts**) are encased in exoskeletons. Colonies of bryozoans may form reef-like structures in shallow waters or incrustations on other organisms (Brusca and Brusca 2003:779–780; Campbell et al. 2008:677). Brachiopods (lamp shells) are marine animals that produce paired valves similar to those of molluscs, though the symmetry is distinctive (Fig. 10.2; Brusca and Brusca 2003:792–793). Brachiopod valves form on the dorsal (**brachial valve**) and ventral (**pedicle valve**) surfaces of the animal (jointly termed **dorsoventral valves**), in contrast to mollusc valves, which form on the left and right (**lateral**) surfaces. Brachiopod valves may or may not articulate with each other.

Nematodes (=Nemata; hookworms, pinworms, ascarids, filarial worms, roundworms) include important soil organisms and pathogens. Nematodes are found in aquatic and terrestrial environments. The well-known research organism *Caenorhabditis elegans* (more familiar as *C. elegans*) is a soil nematode. Nematode bodies are unsegmented, unlike those of annelids (Campbell et al. 2008:683). Some nematodes have a well-developed, tough cuticle that they shed and replace with a new, larger one several times until the adult stage is reached (Brusca and Brusca 2003:353). We know of them largely through the plant and animal diseases associated

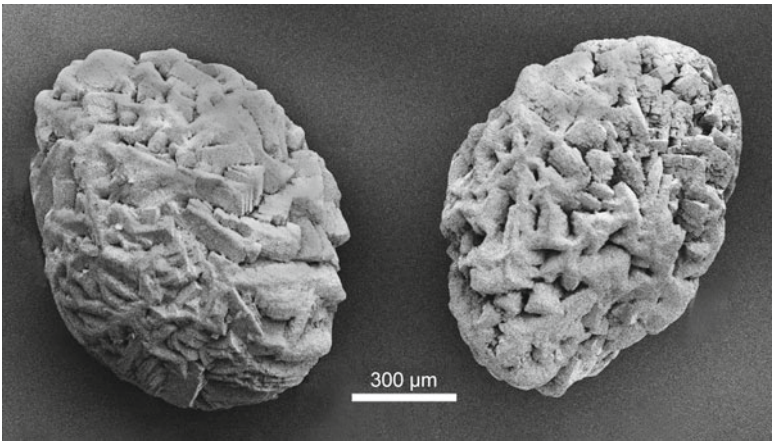

Fig. 10.3 Modern earthworm granules produced by *Lumbricus terrestris* under experimental conditions. From Canti (2003:146) and used by courtesy of the author and Elsevier

with them. Their ova and zygotes may be found in soil samples or in the remains of infected animals (Campbell et al. 2008:683). Some parasitic nematodes (e.g., human whipworms [*Trichuris trichiura*]) have relatively simple life cycles and others (e.g., trichina worms [*Trichinella spiralis*]) have very complex ones (Brusca and Brusca 2003:359–362).

Annelids have segmented bodies, which distinguishes them from other "worms." Although they do not have skeletons, chitin may be present in jaws, stylets, or bristles and strengthen at least some parts of their bodies (Brusca and Brusca 2003:388; Campbell et al. 2008:680–682). Polychaeta include segmented, tube-dwelling, burrowing marine worms. Some polychaetes burrow into coral and mollusc exoskeletons, causing considerable damage. Their chitinous mouthparts (**scolecodonts**) may be recovered in soil samples (Traverse 2008:9). Oligochaeta include aquatic worms, but the most well-known members are earthworms (e.g., Lumbricidae: *Lumbricus terrestris*). Earthworms are important to soil fertility because they aerate the soil and enrich it with their feces. Burrowing by earthworms is a significant source of bioturbation. Their feces and granules of calcite aggregates may survive because they are rich in minerals (Fig. 10.3; Canti 2003:146). Feces, granules, burrows, and egg sacs are more common in archaeological deposits than is realized (Canti 2003). Hirudinida include leeches, freshwater annelids that feed primarily on other invertebrates (Brusca and Brusca 2003:397). Some parasitize vertebrates. Leeches are used for medicinal purposes, though the absence of hard tissues precludes verification of this in archaeological contexts.

Arthropods are segmented animals with well-developed cuticles (Campbell et al. 2008:684–686). They live in nearly every habitat. Most have pairs of jointed, segmented appendages used for feeding and locomotion; the segments are known as **articles** or **podites** (Fig. 10.4; Brusca and Brusca 2003:480). Arthropods include spiders, crustaceans (e.g., lobsters, pill bugs, barnacles), and insects, among other

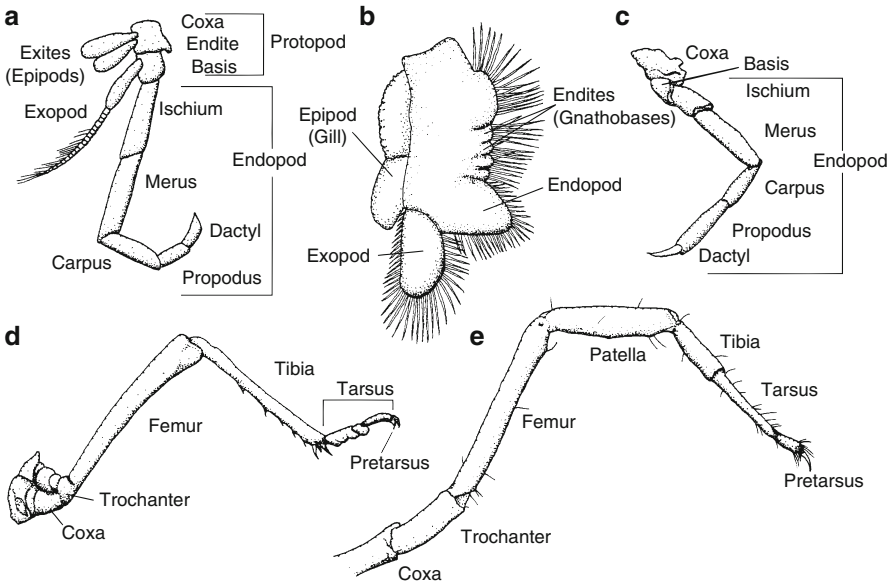

Fig. 10.4 Arthropod appendages: (**a**) generalized crustacean biramous limb; (**b**) generalized crustacean biramous phyllopodial limb; (**c**) crustacean uniramous walking leg (stenopod); (**d**) uniramous leg (stenopod) of a grasshopper (Orthoptera); and (**e**) uniramous walking leg (stenopod) of a scorpion (Scorpiones). **Uniramous** appendages have a single branch, or **ramus**, in contrast to **biramous** appendages, which have two rami. **Stenopodia** are used in walking and **phyllopodia** are used in swimming. Reproduced from Brusca and Brusca (2003:480, Figure 15.17). Used by courtesy of Sinauer Associates, Inc

organisms. Some extant subphyla are Cheliceriformes, Crustacea, Hexapoda, and Myriapoda.

The chitinous exoskeleton or cuticle present during at least part of the arthropod life cycle survives many archaeological processes. The cuticle serves as armor and waterproofing, among other functions (Brusca and Brusca 2003:475; Krogh 2009:456). It may contain individual sclerites and be hardened by a tanning process known as **sclerotization**, which usually produces colored exoskeletons (Brusca and Brusca 2003:479). Portions of the cuticle of crustaceans (e.g., crabs) and of some other arthropods are mineralized with calcium carbonate.

Exoskeletons are shed and replaced during growth: a molting process known as **ecdysis** (Brusca and Brusca 2003:477, 486). **Instars** are incremental stages in the development of arthropod larvae. Each instar is larger than the previous one; the animal sheds its old exoskeleton and replaces it with a new one at each stage. Larvae have a transitional form (pupae; **chrysalis** or cocoon in butterflies and moths; plural: chrysalises) between the final larval instar and the adult state. Puparia are the casings that protect insect pupae.

Hard tissues of arthropods are known by a variety of names, most of which are standardized only within a specific taxonomic group (e.g., Brusca and Brusca

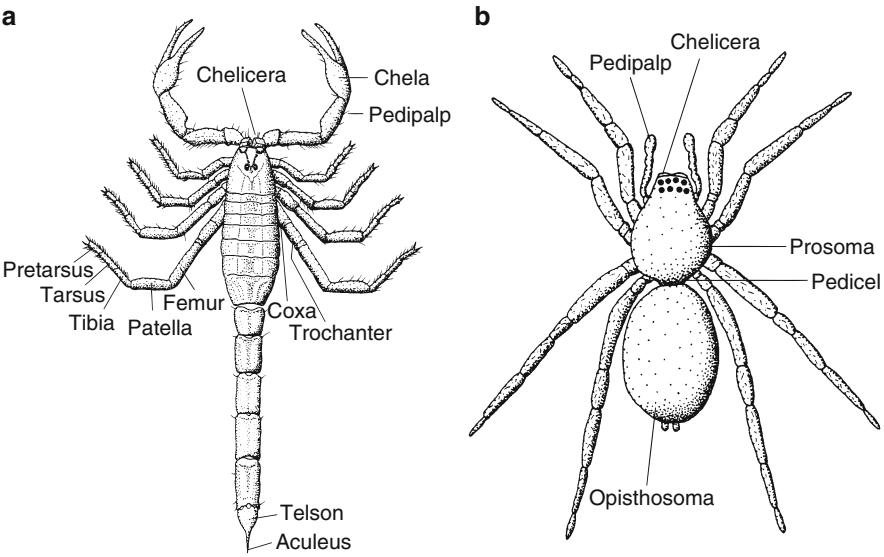

Fig. 10.5 Dorsal view of two arachnids: (**a**) scorpion (Scorpiones); and (**b**) a generalized spider (Araneae). Reproduced from Brusca and Brusca (2003:662, 665, Figures 19.5a and 19.6b). Used by courtesy of Sinauer Associates, Inc

2003:480). The multiple terms used for these structures reflect the diversity of arthropods (Brusca and Brusca 2003:481). Many names duplicate those used for the vertebrate skeleton (Chap. 12), though the origins, structures, and functions of these elements are dissimilar. Readers who wish to know precisely which structures are referenced by these terms in archaeological applications should consult the literature or the author of the specific publication.

Chelicerata include Merostomata (horseshoe crabs), Arachnida, including spiders (Araneae), mites and ticks (Acarina), and scorpions (Scorpiones; Brusca and Brusca 2003:654). Spiders and, particularly, mites, are much more common in archaeological deposits than are horseshoe crabs. Horseshoe crabs live in shallow ocean waters, but occasionally come on shore in very large numbers (Brusca and brusca 2003: 656–657). The defining feature of spiders and mites is the presence of one or two pairs of **chelicerae**, prehensile first appendages used in feeding instead of the lower jaw (**mandible**; Fig. 10.5; Brusca and Brusca 2003:662, 665). They do not have antennae and their bodies are divided into two main regions: a **cephalothorax** (**prosoma**) and an **abdomen** (**opisthosoma**), with no distinct head (Brusca and Brusca 2003:653). The junction between these two regions is known as a **pedicel**. Spiders and mites have six pairs of appendages. These are divided into a pair of anterior appendages (chelicerae), **pedipalps** (a second pair of modified appendages used in feeding), and four pairs of walking legs. A medial flap (**labium**) is used in feeding. In spiders, the proximal segment of each pedipalp is enlarged into a **maxilla** (Brusca and Brusca 2003:661). Many spiders are known for their ability to spin webs of silk, a protein produced from **spinnerets** at the end of the abdomen.

Crustacea (water fleas, ostracods, copepods, barnacles, crabs, pill bugs) include some of the most visible arthropods in archaeological deposits. Crustaceans are found in marine, freshwater, and terrestrial habitats. They have multiple appendages: two pairs of antennae and three or more pairs of feeding appendages (Brusca and Brusca 2003:514; Campbell et al. 2008:686; Krogh 2009:459). The basic crustacean body plan includes a five-segmented **cephalon** (head) and a trunk, which may be divided into an eight-segmented **thorax**, and a six-segmented abdomen (**pleon**; Brusca and Brusca 2003:550–551, 554). All, a portion, or none of the thorax may be covered by a carapace. If the carapace grows beyond the head, it may be termed a **rostrum**; if it fuses with the thoracic segments, it may be termed a **cephalothorax**. Most crustaceans have five pairs of appendages: a pair of **antennules** (first antennae), **antennae** (second antennae), mandibles, **maxillules** (first maxillae), and maxillae (Brusca and Brusca 2003:550–551). In some crustaceans, appendages fuse to form additional mouth parts (**maxillipeds**). Appendages used in locomotion, gas exchange, feeding, and defense may be termed **protopods, pereopods, endopods, exopods**, and **pleopods**, depending on the species and the location of the appendage on the body.

Crustaceans periodically shed their exoskeleton and replace it with a larger one. The term "soft-shelled" refers to the brief interval after the old exoskeleton is shed and before the new one hardens. During molt, calcium is absorbed from the old exoskeleton and may be stored in a pair of sacs, forming **gastroliths**. The stored calcium is reabsorbed and deposited in the new exoskeleton as it hardens. Gastroliths usually are produced only by animals that live in calcium-poor environments, and are present only in the "soft-shelled" stage of those crustaceans that produce them.

Branchiopoda (water fleas, Cladocera: *Bosmina*, *Daphnia*) are primarily freshwater crustaceans, though some of these small animals live in marine waters (Fig. 10.6; Brusca and Brusca 2003:519–521; 522; Frey 1986). Most are attached to a substrate, burrow into it, or live close to it, but some marine forms are common members of the zooplankton. A carapace is present in some branchiopods, but in the cladoceran family Daphnidae, most identifications are based on egg sacs (singular: **ephippium**; plural: ephippia), which are protected by the carapace and shed when the parent molts (Brusca and Brusca 2003:522). Marine water fleas may have a reduced carapace. Changes in temperature, salinity, precipitation, primary productivity, erosion, suspended sediments, and water level are accompanied by changes in the taxonomic composition of cladocerans. Some undergo seasonal changes in body form. Changes in the community structure of diatoms and cladocera are used to assess the effects of climate change and farming on lake productivity (Branch et al. 2005:85–88; Guilizzoni et al. 2002; Szeroczyńska 2002).

Some Malacostraca (krill, crabs, wood lice) are found in archaeological deposits (Brusca and Brusca 2003:522–523). Huge schools of krill (Euphausiacea) are important food sources for much larger organisms, such as baleen whales (Cetacea: Mysticeti). Although most malacostracans are aquatic, land-dwelling members, such as pill bugs and wood lice (Isopoda), live in damp, terrestrial environments. Archaeologically, the most common malacostracans are shrimps, crabs, and lobsters (Decapoda; Figs. 10.7 and 10.8; Brusca and Brusca 2003:515, 522; 527–530).

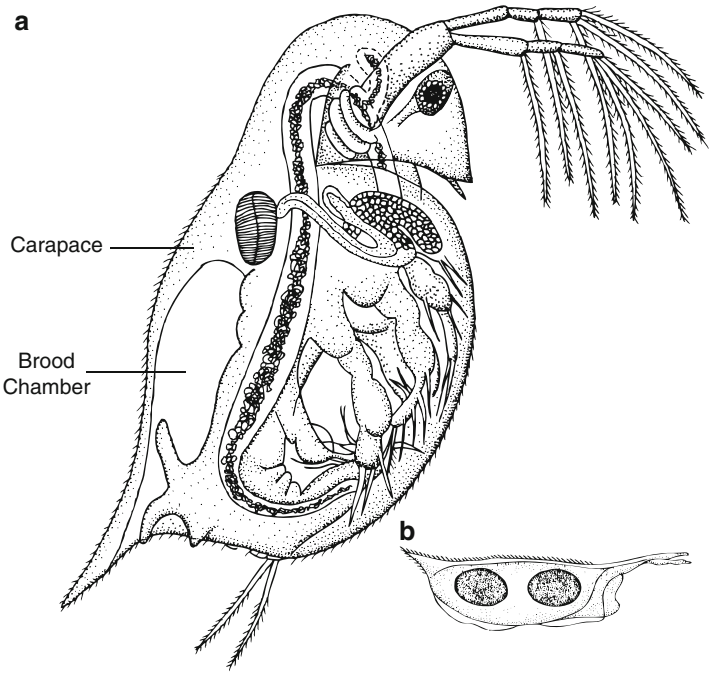

Fig. 10.6 Branchiopoda, Cladocera: (**a**) *Daphnia*; and (**b**) shed carapace, or ephippium, of *Daphnia* with embryos enclosed. Reproduced from Brusca and Brusca (2003:520–521, Figure 16.4f, h). Used by courtesy of Sinauer Associates, Inc

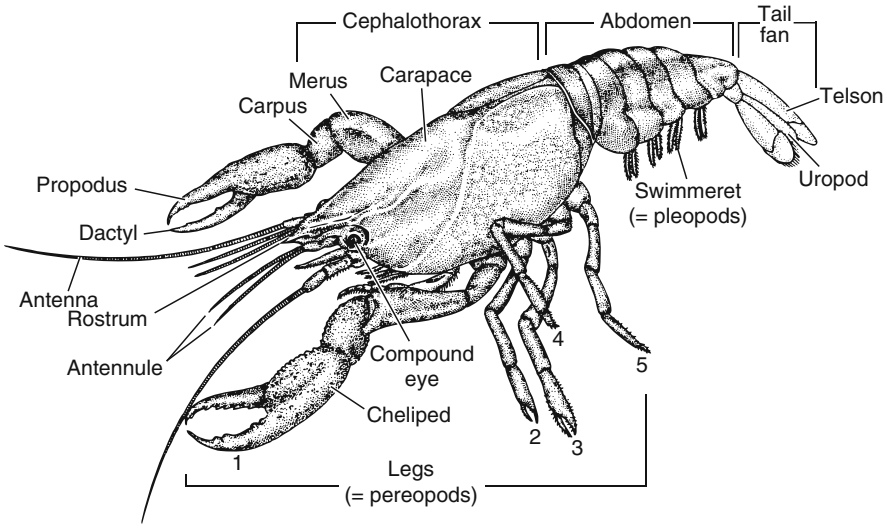

Fig. 10.7 External morphology of a crayfish (Malacostraca: Astacidea). Reproduced from Brusca and Brusca (2003:515, Figure 16.2a). Used by courtesy of Sinauer Associates, Inc

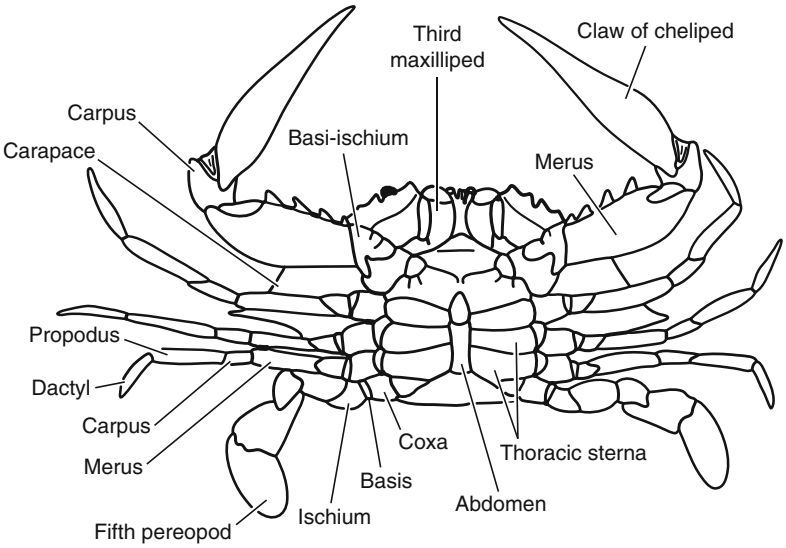

Fig. 10.8 Ventral view of a swimming crab (Malacostraca: Decapoda, Portunidae). Reproduced from Brusca and Brusca (2003:530, Figure 16.10b). Used by courtesy of Sinauer Associates, Inc

Decapod exoskeletons consist of a mineralized cuticle composed of chitin and protein. The thickness of the cuticle and the degree of mineralization vary a great deal throughout the exoskeleton and among species. Although most parts of the exoskeleton are thin and flexible, others, such as claws and pincers (**chelipeds**) and mandibles, are more heavily calcified, often producing thick, rigid structures (Stevenson 1985; Vermeij 1977). Most decapods are recognized by their distinctive paired, prehensile thoracic chelipeds, which are used to capture and manipulate prey. The movable **dactyl** (upper portion; plural: dactylus) and the stationary **propodus** (lower portion; plural: propal) of the cheliped may be very prominent in members of this group, even if the exoskeleton is fragile (Fig. 10.9; Losey et al. 2004:1606). The dactyl and propodus articulate with a structure known as a **palm**, which generally is thin. Chelipeds are lined on their gripping surfaces by projections referred to as teeth. Although they function as teeth do in some vertebrates, they are structurally different from vertebrate teeth. In some malacostracans, the last segment of the abdomen is known as a **telson**. This forms a tail fan in combination with the terminal appendages (**uropods**).

Maxillopoda include barnacles (Cirripedia), copepods (Copepoda), and seed shrimps (Ostracoda). Many maxillopods are either planktonic or ectoparasites of other aquatic organisms. Most barnacles are free living, but a few are parasitic (Brusca and Brusca 2003:540). The free-living larvae of many barnacles transform into sessile adults; the external calcareous plates of adults are sometimes common in archaeological deposits (Fig. 10.10; Brusca and Brusca 2003:541). Some barnacles are encrusting organisms and may be attached to biological substrates such as molluscs, turtles, and whales, entering the archaeological record inadvertently when these other organisms are brought to the site. Other barnacles, such as goose neck

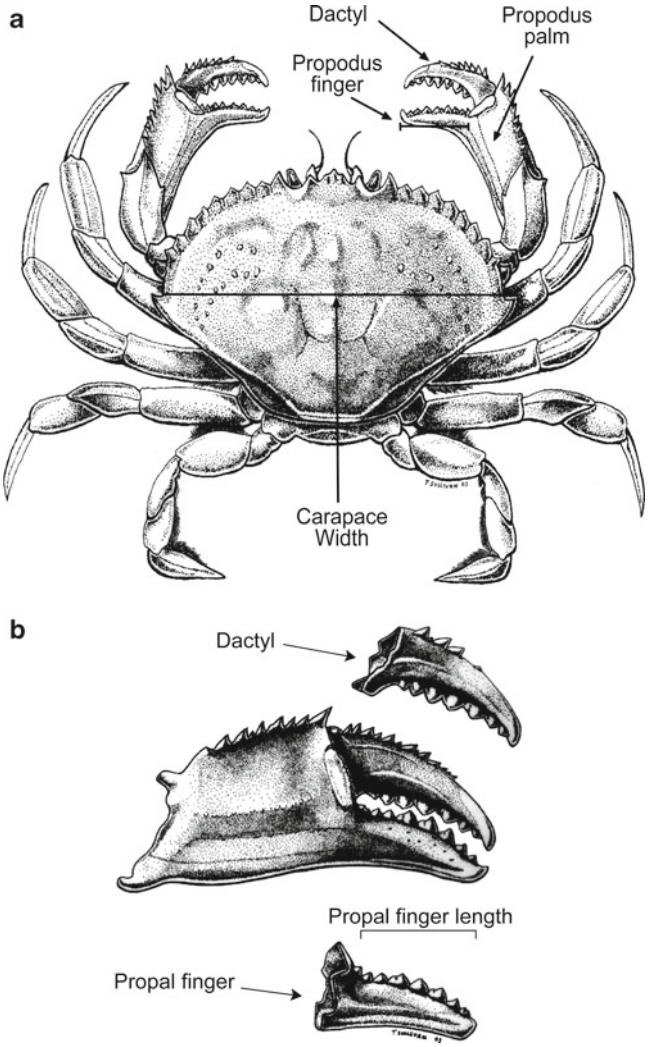

Fig. 10.9 Dungeness crab (*Cancer magister*): (**a**) dorsal view of the carapace with width measurements shown; and (**b**) left cheliped of modern comparative specimen and left dactyl and propodus of archaeological specimens. The length dimension measured on the propodus is indicated. Both archaeological samples are eroded and worn, likely due to post-depositional erosion and damage caused by being harvested long after the most recent molt. Illustrations by Timothy Sullivan. From Losey et al. (2004:1606) and used by courtesy of the authors and Elsevier

barnacles (*Pollicipes pollicipes*) and thatched barnacles (*Semibalanus cariosus*), may be consumed and contribute to the dietary refuse at a site (e.g., Dean 2010; Moss and Erlandson 2010).

Other maxillopods are less visible archaeologically, though no less important in ecological terms. Copepods are small benthic and planktonic crustaceans found in

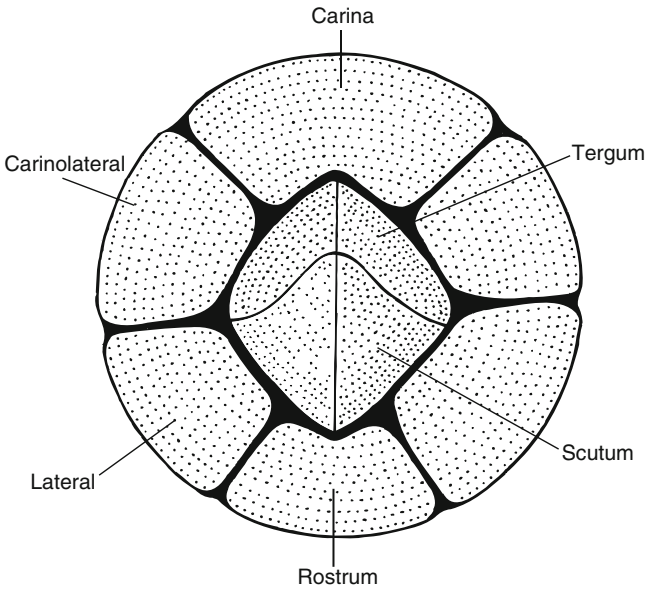

Fig. 10.10 Plate terminology in barnacles (*Balanus*). Reproduced from Brusca and Brusca (2003:541, Figure 16.16b). Used by courtesy of Sinauer Associates, Inc

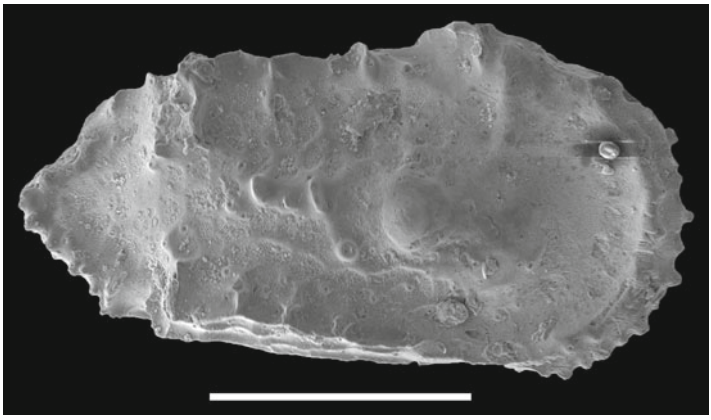

Fig. 10.11 An ostracod (*Cythereis* [*Rehacythereis*] *luermannae luermannae*, right lateral view, MPK 13863) found in building material used in the bastion at Wallingford Castle (Oxfordshire, UK). The scale bar is 300 μm. Identified by Ian P. Wilkinson, original SEM photo by Mark Williams, and plate made by Alison Tasker. From Wilkinson et al. (2010:Plate 1, Figure 17). Used by courtesy of the authors and The Micropalaeontological Society

marine and freshwater habitats. Copepods range in size from 0.1 to 2.0 mm, though some reach 32 mm in size (Brusca and Brusca 2003:547). Copepod carapaces probably are made of chitin (Traverse 2008:57). Ostracods are small crustaceans enclosed within a bivalved carapace of calcite and chitin (Fig. 10.11; Branch et al. 2005:84;

Leng 2006:299; Wilkinson et al. 2010:Plate 1, Figure 17). They live in all aquatic habitats, including moist terrestrial ones and some are commensal on other crustaceans and echinoderms (Brusca and Brusca 2003:547–548). Ostracods generally are benthic organisms but some are pelagic. They shed their carapace with each molt as they grow larger and some have seasonal cycles of abundance. Ostracods are sensitive to salinity, water movement, temperature, pH, and depth within the water column. They are most likely to be studied in lake sediments, where they may preserve well (Löffler 1986). Many can be distinguished by sex and age (O'Connor and Evans 2005:171). Their population dynamics provide insights into changes in shorelines and sea level, particularly when studied in combination with sediments, foraminifera, and molluscs (e.g., Scudder 2001). They are also used to provenance construction materials (e.g., Wilkinson et al. 2008, 2010).

Insects (Insecta) outnumber all other forms of life combined (Fig. 4.1; Campbell et al. 2008:688–691). Nearly a million species have been described so far, though people ignore most of these as a general rule. Insects are vectors for spores, pollen, and disease organisms; decompose organic matter; and either consume or are consumed by many organisms, including plants and animals that are prominent in human economies. A few insects, especially in larval stages (grubs, caterpillars, maggots), are eaten intentionally by people, and quite a few are eaten unintentionally. Many insects are associated with plant and animals diseases (e.g., Barnes 2005).

Two insects are among the earliest domesticated animals (ca. 5,000 years ago). One of these is the silkmoth (Lepidoptera: *Bombyx mori*) larva known as the silkworm. Silk, long associated with domesticated silkmoths in China, also was produced from wild silkmoths (*Antheraea*, *Philosamia*) in India at about the same time (Good et al. 2010). Honeybees (*Apis mellifera*) are the other domestic insect. The presence of honeybees at early sites in the Jordan Valley (Israel), combined with texts, wall paintings, and an apiary of at least 30 hives, demonstrates that honeybees were present in this area between the twelfth and early ninth centuries BCE. (Bloch et al. 2010). Morphological analysis suggests these bees were not local, but were closely related to a subspecies now found in Turkey. Either the range of honeybees has changed over the past 3,000 years, or people in the Jordan Valley imported bees from Turkey (Bloch et al. 2010). The presence of this honeybee subspecies so far from its known range is classic zoogeographical evidence of domestication.

Insects are highly diverse animals whose chitinous exoskeletons are not mineralized. They have one pair of antennae, mouthparts modified for chewing, sucking, or lapping, usually two pairs of wings, and three pairs of legs (Campbell et al. 2008:686, 690–691). Their bodies are generally divided into three sections: head, thorax, and abdomen (Fig. 10.12; Brusca and Brusca 2003:602). The thorax is segmented into **prothorax**, **mesothorax**, and **metathorax**, each of which is further divided into four regions composed of one or more sclerites: **notum** (dorsal; plural: nota), **sternum** (ventral; plural: sterna), and a pair of lateral **pleurites** (Brusca and Brusca 2003:605). Thus, a study may indicate that a **pronotum** has been identified, referring to a notum of the prothorax. Insect mouth appendages include mandibles and maxillae (maxillules). A labium may be formed by the fusion of the second maxillary segments (Brusca and Brusca 2003:604). Some mouthparts are modified for

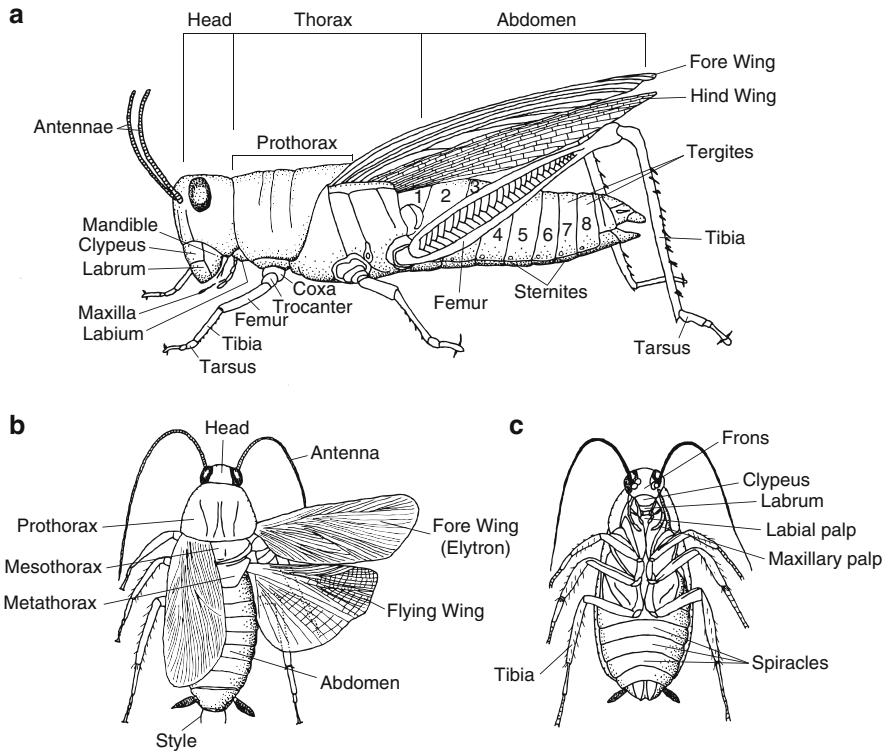

Fig. 10.12 General body plan of insects: (**a**) grasshopper (Orthoptera); (**b**) dorsal view of a cockroach (Blattaria); and (**c**) ventral view of a cockroach. Reproduced from Brusca and Brusca (2003:602, Figure 17.3). Used by courtesy of Sinauer Associates, Inc

piercing, sucking, or both, and may be referred to as a **proboscis** (Brusca and Brusca 2003:611). A plate-like process called the **labrum**, or upper lip, may arise from a sclerite known as a **clypeus** (Brusca and Brusca 2003:603–604). The clypeus is attached to a sclerite known as the **epistome** (or **frons**). In beetles (Coleoptera), one pair of wings is modified to protect the other pair, forming chitinous sheaths known as **elytra** (singular: elytron). In flies (Diptera), the other pair of wings is modified into **halteres**, which provide balance (Brusca and Brusca 2003:608). The head, thorax, and elytra are the major insect components most likely to be preserved in Quaternary deposits (Elias 1994:39).

Myriapoda include centipedes and millipedes (Campbell et al. 2008:687). These are long, worm-like animals with multiple segments and one (Chilopoda, centipedes) or two (Diplopoda, millipedes) pairs of legs per segment. Both have distinct heads, with pairs of antennae, mandibles, and at least one pair of maxillae. Centipedes are carnivores and millipedes are detritivores.

Molluscs generally have a large muscular **foot**, a **visceral mass** that contains most of the internal organs, and a **mantle** or **pallium** (Brusca and Brusca 2003:702;

Campbell et al. 2008:677; Krogh 2009:454). Although some molluscs have no exoskeletons (slugs, squids, octopuses), the mantle in many molluscs secretes a calcium carbonate material to form an exoskeleton with one (**univalve**, Gastropoda, e.g., snails) or two (**bivalve**; Bivalvia, e.g., clams) valves, often termed **shells** (Vermeij 1993:11–15). In bivalves, these form on the lateral surfaces and are designated as left and right valves. Often these are large and durable, forming highly visible components of some archaeological deposits. Most molluscs are marine, but some inhabit freshwater habitats, and a few live in terrestrial habitats. Molluscs have one or two larval stages in addition to an adult stage. Molluscs are discussed in more detail in Chap. 11.

The other major group of symmetrical animals is the bilateral deuterostomes, which include Echinodermata and Chordata. Echinodermata (sea urchins) are radially symmetrical marine invertebrates with endoskeletons (Brusca and Brusca 2003:54 801, 811; Campbell et al. 2008:693–694). Although we may think of these as exoskeletons, they derive from the embryonic mesoderm and thus are endoskeletons (Brusca and Brusca 2003:54; Campbell et al. 2008:693). Chordata (e.g., mammals) are characterized by bilaterally symmetrical endoskeletons; most have bony sheaths protecting their spinal cords (Campbell et al. 2008:698). Deuterostomes are discussed further in Chaps. 11 and 12.

The dominant animals from the perspective of human awareness are some earthworms, crustaceans, insects, molluscs, echinoderms, and chordates (Thomas and Mannino 2001). In addition to food, these animals provide tools, ornaments, fibers, dyes, construction materials, fuels, waxes, mastics, sealants, medicines, poisons, labor, and companionship, in addition to ecosystem services of which we are generally unaware. Animals such as earthworms and pollinating insects contribute to soil formation and crop production, for example. Some hasten decomposition of burials and waste products (e.g., Bianucci et al. 2009) and others are used in the manufacture of leather and other products (e.g., Reed 1972:51). Others are symbols of social affiliations and inspire decorative arts. Today silkmoths and honey bees are prominent among our domestic animals; increasingly crustaceans and molluscs are raised in farms. It is likely that in the past, other insects and some molluscs were at least cultivated in the wild if not fully domesticated (e.g., Good et al. 2010; Whitaker 2008; Williams 2006).

Site Formation Processes

Site formation processes influencing the preservation, recovery, and interpretation of arthropods and other invertebrates are reviewed in this section, excluding molluscs, echinoderms, and chordates, which are discussed in Chaps. 11 and 12. The remains of many arthropods and other invertebrates may be recovered and identified if the depositional context is adequate and care is taken in their recovery. This is particularly the case for animals protected by chitin. Chitin is chemically stable and less vulnerable to decomposition than many other organic materials, though it, too, is subject to oxidation, fungal attack, and mechanical damage (Robinson 2001).

In some cases, chitin may be replaced by calcium carbonate or calcium phosphate after death, which enhances survival of this evidence (e.g., Girling 1979; Robinson 2001). In most cases, survival is best in consistently damp or dry locations.

Platyhelminthes, Nematoda, and Acanthocephala

The soft tissues of platyhelminthes, roundworms, and thorny-headed worms are unlikely to survive in archaeological sites but some have durable ova or zygotes that survive site formation processes and sometimes are recovered in large numbers (Bain 2001:6; Shin et al. 2009; Waldron 2009:111–113). Shells of chitin and **sclerotin** (tough, durable protein) protect some eggs and cysts, enabling them to survive in neutral to alkaline (pH 7.2–8.3) sediments for thousands of years (Bathurst 2005). Cysts of this type are found in palaeofeces, mummified remains, desiccated settings, latrines, cess pits, bodies buried in peat, and similar areas, as well as at high altitudes (e.g., Bain 2001; Leles et al. 2010). Fungi are additional agents of decomposition (Reinhard 1992). In some cases, hosts form cysts of mineralized connective tissues around invading parasites and these may be found with burials (Ortner 2001). Few parasites leave diagnostic skeletal pathologies in their hosts, though some leave indirect evidence of parasite-related anemias and other diseases (Barnes 2005; Bathurst 2005; Larsen 1997:36–37).

People were not universally discriminating about where they disposed of feces. Bathurst (2005) reports finding intestinal parasites in the general matrix of shell-bearing sites, which indicates that either people relieved themselves on the middens or discarded fecal waste there. In other cases, the widespread distribution of these organisms may reflect subsequent redeposition of fecal matter. Shin et al. (2009) report that whipworm eggs are common (100/g) in portions of a moat surrounding Weolseong Palace (Korea). Modifications to the moat may have been designed to manage sewage from the palace.

Annelida

Some annelids live in leaf litter, others construct deep, vertical burrows, and still others burrow horizontally (Fig. 10.13; Canti 2003:137). In the process, they deposit feces, casts, and granules; bury artifacts; alter palaeosols; move small stones; and even build cairns, thereby modifying the stratigraphy of the site. These actions alter the geochemistry of the deposit, affecting the survival of other organic materials. Remains of the worms themselves are less likely to be recovered, but modifications associated with these animals provide indirect evidence of their presence as well as information about palaeosols and soil development at the site.

Annelids do not disperse through the air and have few mechanisms by which to leave an archaeological site once they become established there. Enckell and Rundgren (1988) argue that some earthworm taxa maintain their affiliations with

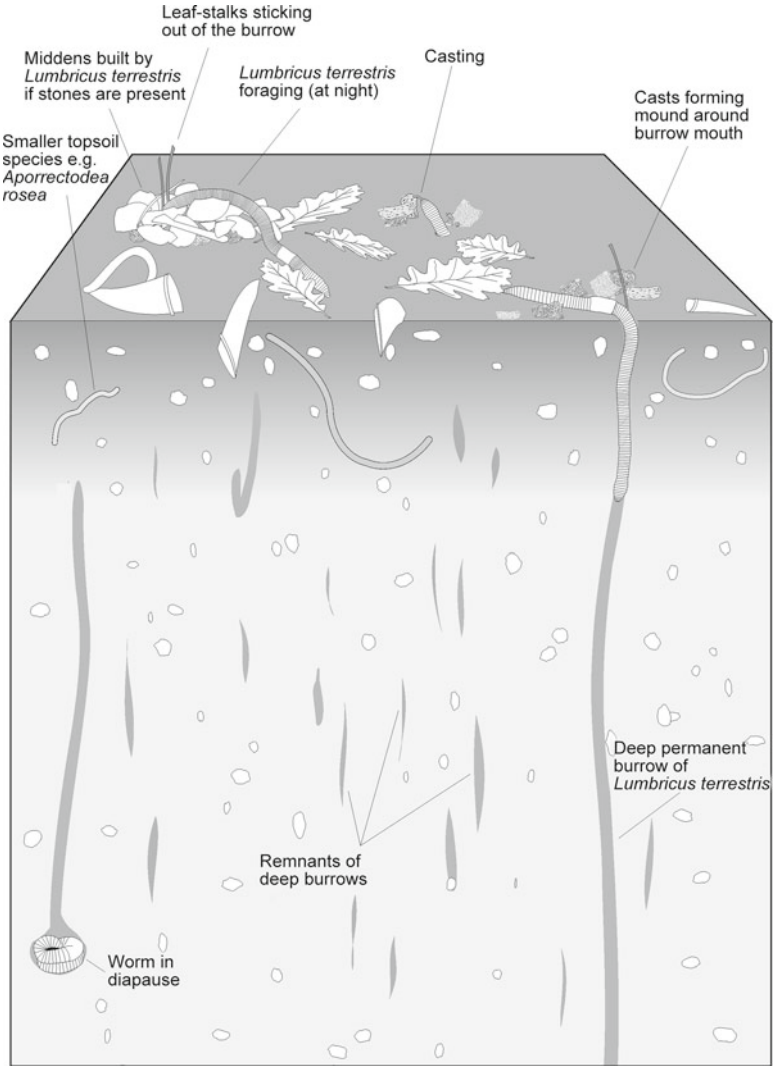

Fig. 10.13 Block of soil showing many of the basic features of earthworm lifestyles. Artifacts depicted prior to earthworm sorting. From Canti (2003:137) and used by courtesy of the author and Elsevier

anthropogenic soils for as long as 600–800 years after human activity has ended. Thus, it may be possible to use modern earthworm compositions at sites as analogues for earthworm populations in the past. These modern earthworm communities can be examined for evidence of former soil quality, environmental conditions, and human activity at the site without actually recovering archaeological remains of earthworms. Enckell and Rundgren (1988) suggest that a similar relationship may exist for millipedes, terrestrial molluscs, and other invertebrates that do not disperse by air.

Arthropoda

Many arthropods are important in ecosystems, but rarely are studied because their exoskeletons seldom are recovered. Although most arthropod cuticles do not contain sufficient calcium carbonate to survive diagenesis, some do. Girling (1979) demonstrates that sometimes exoskeletons of centipedes, millipedes, and wood lice are replaced by calcium carbonate after death. Such replacement fossils may be common where intact cuticle is not, especially in calcareous soils. Thus, calcareous soils or calcified deposits are contexts that may contain arthropod remains otherwise unlikely to survive. Spiders and mites are much less common in archaeological deposits. Mites have a more robust chitinous exoskeleton than do spiders and their remains may be preserved when those of spiders are not. Beetles and crustaceans are the most frequently studied arthropods because they generally are better preserved than other arthropods.

Some parts of crustaceans survive remarkably well because they are strengthened by calcium carbonate. The calcified chelipeds and mandibles of crabs and lobsters preserve best. The dactylus and propodus of the cheliped frequently are found in archaeological samples, generally associated with numerous carapace fragments. Both marine and freshwater crayfish and lobsters are represented by calcified mouthparts. The shrimp (*Penaeus*) element that appears to be most durable is the mandible. Shrimp mandibles have delicate projections (Fig. 10.14a) that usually do not survive under archaeological conditions, so archaeological specimens do not look precisely like modern ones (Fig. 10.14b). Other crustaceans, such as water fleas, are even less visible, though they provide important environmental data when they are studied (Guilizzoni et al. 2002; Szeroczyńska 2002).

Perhaps the most common arthropods in archaeological sites are insects, particularly beetles, lice (Phthiraptera), flies (Diptera; especially non-biting midges [Chironomidae]), true bugs (Hemiptera), ants, bees, wasps (Hymenoptera), moths (Lepidoptera), fleas (Siphonaptera), and caddisflies (Trichoptera; Bain 2001:3; Carrott and Kenward 2001; Girling 1979; Robinson 2001). Insects in archaeological deposits usually are recovered as dissociated plates of the chitinous exoskeleton (Branch et al. 2005:114; Buckland 1976; Elias 1994:17–18; Kenward 1974). The exoskeletons of beetles are remarkably resistant to decay; even beetles eaten by bats, foxes, or owls are recognizable in pellets or feces. Many insects occupy specific habitat types, for example, midges occupy aquatic environments of all sorts, including accumulations in water containers. Midges provide evidence for water quality, pH, salinity, and surface water temperature (Wilkinson and Stevens 2003:103–104) and are particularly useful when combined with sedimentary, palynological, and isotopic data (e.g., Langdon et al. 2010).

Deposits vary considerably in their potential to preserve insects depending upon the animals' rates and modes of deposition. Wells, cess pits, and rubbish heaps frequently contain large quantities of insect remains. Peats, if they have not dried, tend to be rich in insect remains, though these may be difficult to separate from the organic matrix. Fen peats, which are more alkaline and have higher pH levels, often

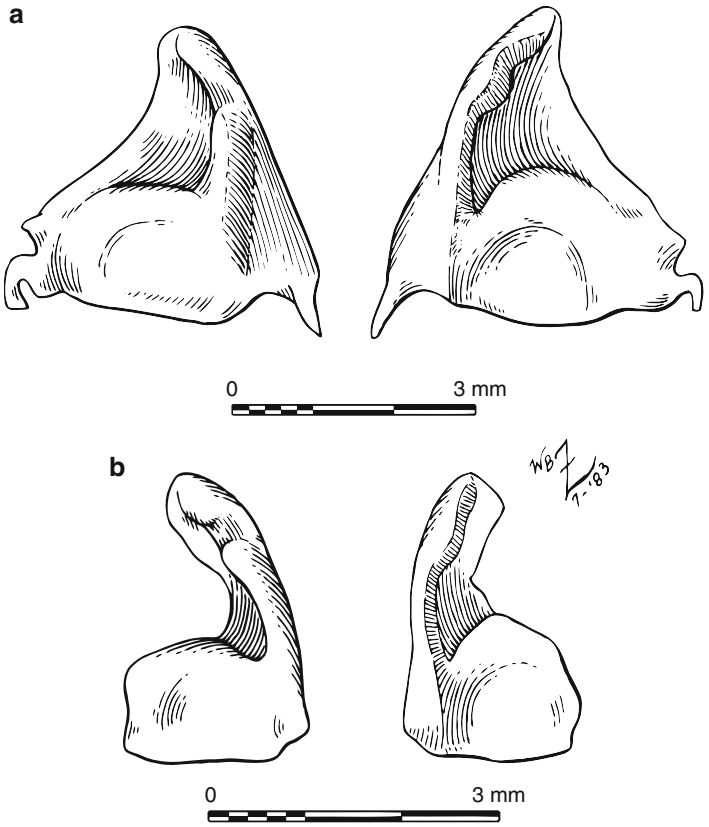

Fig. 10.14 Left and right shrimp (*Panaeus* sp.) mandibles: (**a**) as they appear in a reference specimen; and (**b**) as they appeared in an archaeological deposit. Only the hardest portion of the chewing surface is illustrated. Drawn by Wendy Zomlefer. Used by courtesy of Irvy R. Quitmyer

preserve insects better than do acidic peat bogs, which have lower pH levels. Good insect assemblages may be recovered from anoxic deposits that are permanently waterlogged, conditions that discourage organisms that eat chitin. Insect remains do not survive well in oxic conditions, even when these are damp, though carbonized and desiccated remains may be encountered (e.g., Burleigh and Southgate 1975; Robinson 2001).

The arthropod death assemblage may not represent customary breeding or feeding habitats (Kenward 1975a, b; Kenward and Hall 1997). Although some arthropods are relatively sedentary, others are highly mobile and readily intrude into archaeological deposits. Based on a study of the wingless colydiid beetle *Aglenus brunneus* recovered from Roman and Medieval sites in York (Yorkshire, UK), Kenward (1975a, 1976a) suggests that *A. brunneus* can enter deposits by burrowing. At the Lloyds Bank site (York; Kenward 1976a), a feature containing leather waste intruded into an earlier deposit that was unsuitable as a breeding area for *A. brunneus*.

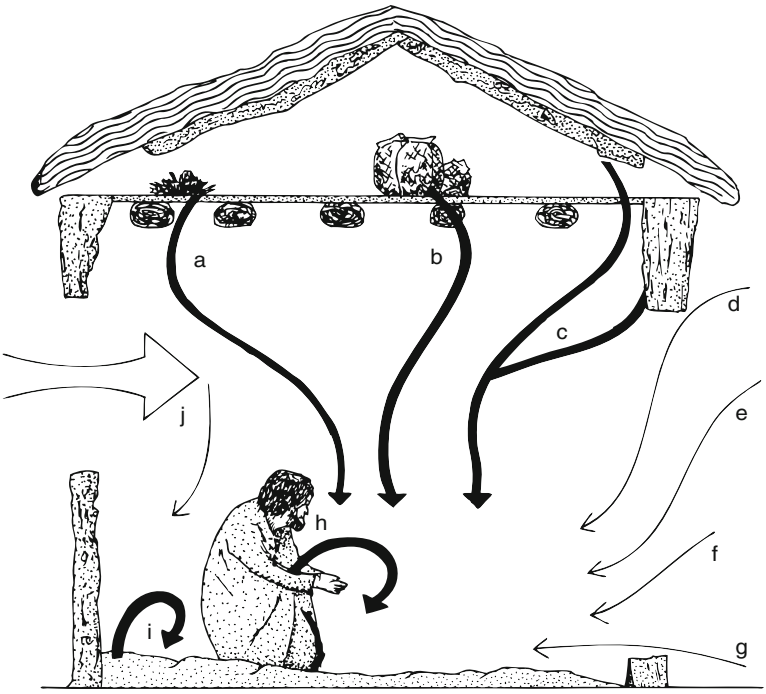

Fig. 10.15 Potential sources of insect remains in dwellings. Broad arrows represent insects originating within the building; slim arrows represent insects originating from outside. Key: (**a**) from nests and droppings of predators; (**b**) from stored products; (**c**) from roof and walls; (**d**) insects seeking habitation sites; (**e**) accidental entry in local flight; (**f**) in imported material, casual transport, or on occupants; (**g**) crawling; (**h**) parasites of occupants; (**i**) from litter; and (**j**) migrating insects. From Elias (1994:109); after Kenward (1985). Used by courtesy of Harry Kenward

The intrusive feature contained abundant beetle remains (32 individuals/kg) as did a sample from below the intrusive feature (13 individuals/kg); but a sample from elsewhere below the intrusive feature contained very few individuals (1/kg). Kenward (1976a) interprets this as evidence that these beetles burrowed into the earlier strata from the intrusive feature and are not contemporaneous with the earlier strata. Modern arthropod contamination also occurs. For example, the Australasian mould beetle (*Aridius bifasciatus*), which has become cosmopolitan because of international trade, can be introduced into archaeological contexts by poor recovery methods (Buckland 1976). Elias (1994:48–49) observes that depositional environments affect the numbers and types of insect body parts represented, noting that some parts are more buoyant than others and will be deposited in different locations in aquatic settings.

Arthropods become part of archaeological collections for many reasons (Fig. 10.15; Elias 1994:109; Kenward 1985). They may be the remains of airborne animals that died as they flew over the site. Some arthropods are transported to the site from distant ecosystems in fodder, dung, trade goods, and building materials

and are mixed with local arthropods and those that served nutritional or economic purposes (e.g., Sveinbjarnardóttir et al. 2007). They may be tracked in by livestock and people. Distinguishing among explanations for the presence of encrusting organisms can be particularly difficult. Barnacles, for example, may be present either because they were attached to some other material or because the barnacles themselves were eaten.

Field Considerations

Systematic and meticulous sampling and handling are necessary to ensure a successful study of invertebrates. Thorough sampling is particularly important for contexts in which they are most likely to be present. It is unlikely that the remains of most small invertebrates will be observed in the field. Promising deposits should be sampled carefully to maximize their recovery and subsequent handling should not undermine sampling. Labeling and archiving of samples must be done with special care to ensure that the opportunity to study these small, fragile remains is not lost through negligence. Often it is chitin that enables these remains to survive and chitin itself attracts fungi and other organisms who view such archaeological materials as food. It may be necessary to develop specific curation and processing protocols for these materials (e.g., Ruiz et al. 2006). Sampling procedures should be developed in consultation with researchers who will study these and other aspects of the same samples.

Small invertebrates are usually studied from samples collected specifically for that purpose, or from samples collected for soil and botanical analyses. In peat and silt, sampling intervals of 50 mm may be sufficient because minor sedimentary structures and bioturbation may mix smaller intervals. Other sampling increments may be more suitable in other depositional environments. Waterlogged deposits are notoriously difficult for archaeological sampling and interpretation. Care must be taken to avoid contamination by intrusive features and field staff (e.g., Shin et al. 2009).

As with other organic samples, a good general policy is for analysts to take their own samples; they are guided by their knowledge of contexts most likely to be productive, the importance of clean tools and stratigraphy, and appropriate sample sizes. If this is not possible, as much material as is practical should be carefully collected, following the protocols for soil and botanical samples, and placed in well-sealed, waterproof, rigid containers. Detailed observations of the in situ samples and procedures used to recover them should be clearly recorded in field notes, which should be transferred to absent analysts along with the samples themselves.

The quantity of small animals present in each sample is highly variable, a factor that cannot be assessed in the field (e.g., Ruiz et al. 2006). For example, a late Bronze Age trackway on Thorne Moor (Yorkshire, UK) produced several thousand insect individuals, whereas a 20 kg block of coarse fluviatile silt of the same age

from the River Don (Yorkshire, UK) yielded fewer than 100 individuals. By way of contrast, Hall and Kenward (1976) report very large quantities of beetles in 5 g samples from a Roman warehouse in York (Yorkshire, UK), which they interpret as evidence that the deposit was a grain warehouse. Sample volumes of 5–10 kg may be a reasonable amount of material. When faced with redundant samples, or ones that are too large for the staff, budget, or time available for the study, subsampling can be done in the laboratory (e.g., Bain 2001:37), but it is rarely possible to return to the deposit for more samples if too little material was collected originally.

Some crustaceans are highly visible in the field during excavation, but their multiple small carapace fragments may be undervalued by field staff. If the field procedure is to collect a "grab" sample, it is unlikely a sample that can be quantified and otherwise meets standard for statistical analysis will be obtained because crustacean fragments often are not sufficiently interesting. Unsystematic, idiosyncratic collections have little to recommend them in environmental archaeology and often bias controlled studies beyond repair. Crustacean remains may be selected from screens, or collected in large bulk samples. In either case, they should be gathered systematically so that their representation in the collection is not biased by field procedures. It may be difficult to collect all of the fragments present. Consultation with the researcher who will study these materials can assist in designing a protocol that will yield samples that can be reliably quantified and analyzed without adding to the field burden.

When soft tissues of plant and animals are encountered, they should be excavated with extreme care and attention to context because commensal and parasitic organisms may be associated with such well-preserved materials. The term "mummy" is applied to animals, usually vertebrates, whose bodies are preserved artificially, such as Egyptian mummies, or by drying or freezing, such as might occur in very dry or very cold locations (Zimmerman 2001). These tissues may contain parasites that were present when the host died. Some organisms are attracted to decomposing tissue and may die in contact with the corpse, suggesting that the corpse was exposed for some time prior to burial (e.g., Huchet and Greenberg 2010). In the case of wrapped bodies, larvae may be from infestations that occurred before the corpse was wrapped; some organisms continue to develop for some time after wrapping. In the case of bog bodies, the presence of **carrion beetles** (flesh-eating) may indicate the body was not submerged completely immediately after death (e.g., Plunkett et al. 2009).

Laboratory Procedures

Studies of invertebrates typically focus on parasitism and environmental conditions, though it is clear that many small animals directly or indirectly reflect human economic activities. None of these interpretations are possible if the samples are inadequately processed and identified in the laboratory (Bain 2001; Zimmerman 2001).

Processing

Procedures for extracting, concentrating, and archiving archaeological samples should avoid contaminating archaeological remains with extraneous ones (e.g., Buckland 1976; Kenward 1974; Kenward et al. 1980; Robinson 2001). Care is needed to recover all fragments to avoid compromising subsequent analysis. Extracting and concentrating small animal remains may require alternating a soaking stage with flotation, chemical treatment, and filtration. Each step must accommodate the chitinous nature of some of these specimens and facilitate the recovery of eggs and cysts (e.g., Bain 2001:38–39). When using flotation, the heavy fraction should be checked to verify that the flotation solution reliably separates animal remains from other materials in the archaeological sample, especially in the case of fibrous peats. The heavy elytra of the larger beetles tend to sink, which can be a significant bias.

In some cases, remains are best processed by hand, usually under magnification. This approach is particularly useful because it allows the person who is sorting the materials to observe when several fragments of the same individual are present, allowing the organism to be extracted more or less intact. Handsorting introduces a subjective bias toward the largest and most obvious materials, a tendency that should be resisted. Many insects are recovered from biogenic sediments such as peat; felted peat may be split along the bedding planes and insects picked out with forceps.

Specimens may be mounted on slides or cards for study. The elytra of some beetles tend to curl, especially those of dung beetles (Scarabaeidae), and these have to be mounted in a viscous medium to maintain their shape as do insect genitalia, wings, and other fragile parts. Unstudied remains may be archived in ethanol.

Identification

As with all other environmental materials, the identification of these remains cannot be learned from descriptions and drawings. The keys and illustrations intended for use with fresh, intact organisms rarely are applicable to archaeological fragments. All items should be attributed to a taxon using reliable reference collections. What is and is not identifiable, with what degree of certainty, can only be learned by practice. The ability to recognize organic remains that are considerably transformed from their appearance in living forms, such as shrimp mandibles, is an important skill. Often these changes conform to specific patterns of transformation learned through experience with such materials. Attributions to the lower taxonomic levels are more useful for environmental and cultural interpretations, but heroic efforts that yield inaccurate identifications are misguided and misleading.

Archaeological remains are compared with materials in the reference collection until the closest match is found, relying on the size, dimensions, and other morphological characteristics of the specimens. Ideally, an archaeological specimen is

compared with a series of specimens consisting of animals with similar behaviors and taxonomic affiliations. Thus, the range of variation within and among species can be assessed, with allowances for deviations associated with site formation processes. Primary reference points are external sculpturing and the shapes of body segments. Calcified or chitinous spicules, plates, and other structures may have diagnostic shapes, textures, microsculptures, coloration, sizes, and positions. In platyhelminthes and nematodes, the ova and cysts are examined. In arthropods, the head, thorax, abdomen, appendages, and genitalia are studied (e.g., Elias 1994:39–54 for insects). Puparia and chrysalises also may be identifiable (e.g., Webb et al. 1998). Some arthropod adults and instars can be attributed to genus or even to the trivial epithet (e.g., Ruiz et al. 2006). Ruiz et al. (2006) caution that early instars may not be represented in samples if the exoskeleton was reabsorbed prior to ecdysis. Archaeogenetic studies of insect remains may improve identifications and analysis in the future (e.g., King et al. 2009).

Crustaceans are more frequently studied in archaeological materials than are other arthropods. Mandibles and chelipeds of crabs and lobsters are examined most frequently because carapace fragments, when present, can be extremely abundant and unhelpful in terms of taxonomic identifications. Losey et al. (2004) focus only on crab propal and dactyl fragments that are over 50% complete because they find these are more likely to be identifiable to environmentally sensitive taxa. This compromise may be necessary to make the best use of staff, time, and funds. It is consistent with the philosophy of a standard count that guides many laboratory sampling decisions. For ostracods, carapaces are examined; these may be plain or ornamented and are hinged along the dorsal margin, offering a left and right lateral view (Fig. 10.11). Ostracods can be separated by age, sex, and habitat preferences. Barnacles are identified from the plates protecting the sessile adult forms (Fig. 10.10).

In some cases, identifications of small animal remains are aided by indirect evidence. Marguerie and Hunot (2007), for example, report finding tunnels and other signs of insect infestations in wood, in conjunction with the remains of the insects themselves. Such indirect evidence can provide guidance that may narrow the search for a direct identification of the accompanying insects.

Analytical Procedures

Distinguishing between organisms that were part of a local ecosystem or originated in more distant locations is a fundamental analytical step and may aid in determining the source and mode of transport for these animals. A death assemblage may contain animals from several different habitats, some local and others regional. Some of these organisms entered the site because people intended for them to do so, others were transported unintentionally because they were attached to other materials, such as hay. Still others were attracted to the location because of stored grains. Sveinbjarnardóttir et al. (2007) interpret sheep ectoparasites at a high status Icelandic farm as indirect evidence of wool processing, an interpretation strengthened by the

presence of wool-processing tools. They interpret ants in the assemblage as evidence that grain was imported, because ants are not indigenous to Iceland. Referring to insects, Kenward (1976b) termed some non-local animals as background fauna, comprising an insect rain similar to pollen rain. Background fauna include, for example, airborne animals and those that enter the death assemblage in the droppings, pellets, and feces of other animals. Background fauna may not be evidence of nearby, local habitats; or even be contemporaneous with the archaeological time period that is the focus of the study. Even the presence of arthropods and other invertebrates in anthrosols does not eliminate the problem of spatial and temporal origins, behavioral associations, and contemporaneity (e.g., Enckell and Rundgren 1988).

Kenward (1976b:15) argues that "The abundance of a group of species with similar requirements may be used as sure evidence of the importance of their habitat at or close to the point of deposition, as long as the total fauna is large." He suggests that sample sizes of several hundred specimens are needed to distinguish between animals brought to the site intentionally and background animals (Kenward 1976b). This recommendation underscores the importance of systematically collecting large samples from as many different contexts as possible.

Analysis relies on quantifying presence and abundance. The primary form of presentation is a taxonomic list documenting the taxa present in various contexts at the site. In some cases, the list includes the number of identified specimens (NISP) or weights for individual taxa or groups of taxa. NISP or the weights of identified specimens enable taxa associated with specific habitat preferences to be summarized and compared in various ways. In many cases, results are presented following the style of pollen diagrams (Fig. 10.16; Ruiz et al. 2006:21). In other cases, the number of specimens from distinct cultural or ecological contexts may be compared.

In some cases, the **minimum number of individuals** (**MNI**) is estimated, an approach that relies on radial or bilateral symmetry. Thus, for example, the presence of two left propal of a specific crab species may be interpreted as indicating that the remains of at least two individuals are present in the sample, whereas the presence of one left and one right propodus of similar size suggests the presence of the remains of one crab individual. In cases of unique elements, such as the head capsule of a beetle, the number of head capsules may be used to infer the number of individuals represented in the sample. For example, Hellqvist and Lemdahl (1996:879) compare habitat preferences of beetles present during four settlement phases at Medieval Uppsala (Sweden) using the number of beetle taxa and the number of beetle individuals (Fig. 10.17). In other cases, the total count of an element that is paired in the organism (e.g., the scutum of barnacles) may be divided by two instead of assessing actual symmetry. MNI is more commonly used in analyses of molluscs, echinoderms, and vertebrates and is discussed in more detail in Chap. 11.

Measurements of dimensions that elaborate upon shapes and verify impressions of size are used to identify taxa and interpret invertebrate data. For example, mean dimensions of ova are associated with specific developmental stages. Studies of crustaceans may involve measuring maximum widths or lengths of the instars. Because crabs grow incrementally throughout their lives, these measurements provide an estimate of the age classes represented in the archaeological collection,

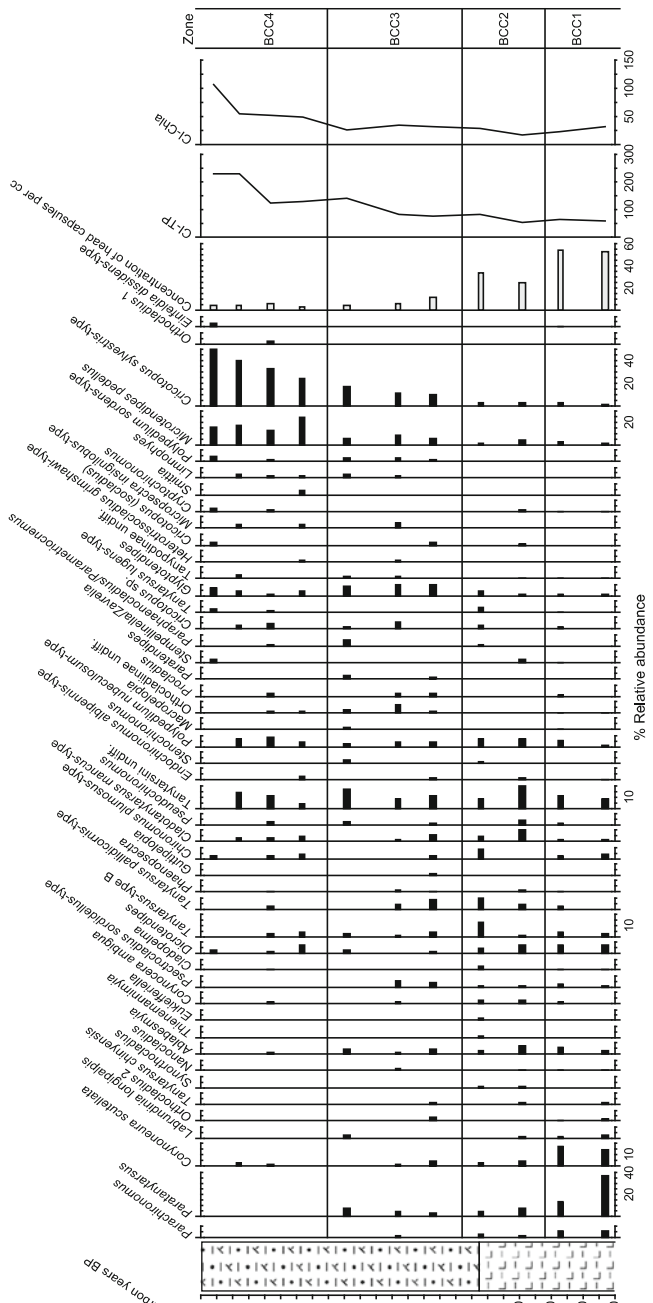

Fig. 10.16 Stratigraphy of midge (Chironomidae) remains from Ballywillin Crannog (Ireland), including chironomid-interred total phosphorus (Cl-TP) and chlorophyll-*a* (Cl-Chl*a*) reconstructions. Dates in *parentheses* are considered less reliable than the other two dates. Midge taxa are arranged to emphasize up-profile shifts in community composition and structure. From Ruiz et al. (2006:21) and used by courtesy of the authors and Elsevier

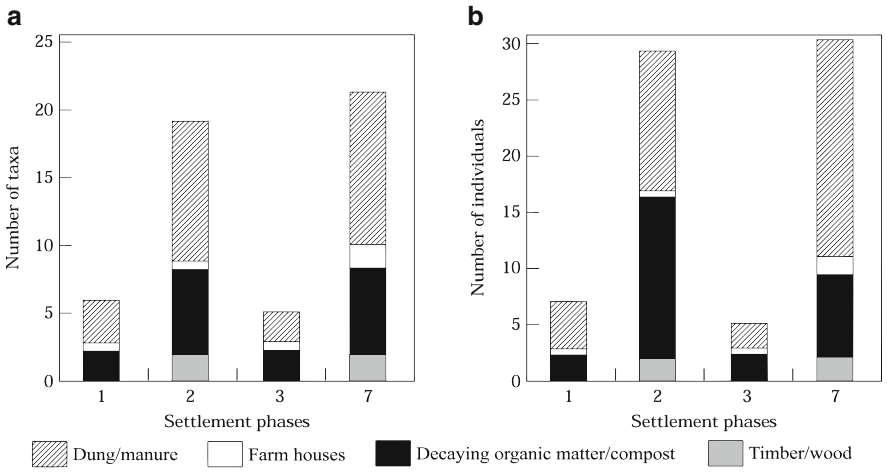

Fig. 10.17 Habitat preferences of beetles (Coleoptera) in dung/manure, farm houses, compost, and wood deposits during four settlement phases in Uppsala (Sweden) from AD 1100 (bar #1) to the first part of the fifteenth century (bar #7). The calculations are based on: (**a**) number of taxa; and (**b**) number of individuals recorded in samples from each settlement phase. From Hellqvist and Lemdahl (1996:879) and used by courtesy of Elsevier

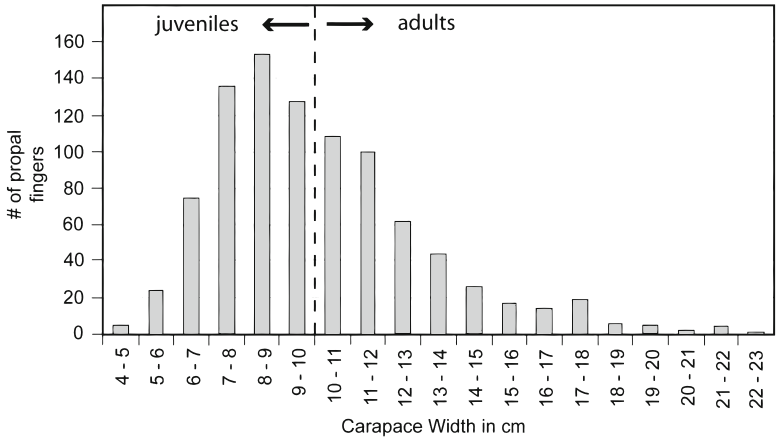

Fig. 10.18 Mortality profile for archaeological Dungeness crabs (*Cancer magister*) from Netarts Sandspit Village (Oregon, USA) based on allometric scaling of the greatest width of the carapace to propal finger length (Fig. 10.9). Profile is based on measurements of 931 propal fingers. From Losey et al. (2004:1609) and used by courtesy of the authors and Elsevier

larger crabs of a species being older than smaller members of that same species. These data can be used in mortality profiles, as Losey et al. (2004) do by equating age with measurements of propal fingers of juvenile and adult Dungeness crabs (*Cancer magister*; Fig. 10.18; Losey et al. 2004:1609).

Table 10.2 The abundance of beetles (Coleoptera) and true bugs (Hemiptera) from various habitats in an assemblage from a modern drain sump and the proximity of those habitats to the sump[a]

Habitats	Number of species	MNI	Proximity of habitat to sump
Aquatic and aquatic marginal	5	9	Not recorded within 250 m
On open ground	7	12	Some habitat for most species within 10 m
At roots of low vegetation	24	34	Scattered isolated plants present within 30 m
Phytophages	15	28	Hosts of some are recorded within 100 m, but are rare
In rotting plant matter	41	110	Absent within 10 m, probably some accumulations within 250 m
In dung or exploit dung	12	25	Absent within 250 m, probably very rare within 1 km
In dead wood exclusively	4	22	Present within 2 m
Synanthropic	20	63	Entire study area

[a]The study includes a total of 259 specimens of 115 species, many of which fall into two or more habitat classes and all of which are found in areas disturbed by people. Based on data from Kenward (1975b, 1976b)

Much analysis relies on groups of species (species associations) instead of single species (Table 10.2; Kenward 1976a, b). In some cases, it is possible to reconstruct former community affiliations based on such species associations (Elias 1994:74–79; Kenward and Carrott 2006). Hellqvist and Lemdahl (1996) incorporate the **Mutual Climatic Range** (MCR) concept into their study of arthropods from Uppsala. This approach groups identified organisms in terms of modern ecological preferences, generally temperature range and maximum temperature, to define areas of overlap that might indicate conditions in the past (Fig. 10.19; Atkinson et al. 1986). In the Uppsala study, MCR is used to reconstruct temperatures prevailing when the insect assemblage accumulated (Table 10.3; Hellqvist and Lemdahl 1996:879). The geographical range is defined by the mean warmest month (TMAX) and the mean coldest month (TMIN) preferred by the organism today. Kenward and Carrott (2006) use detrended canonical correspondence analysis (DCCA) to define membership in groups of affiliated insect species that form death assemblages in specific types of deposits.

Invertebrates and Disease

Parasitism is reviewed in a general way, and specifically for viruses, protists, and fungi, in Chap. 6. Some animals are parasites, using people as vectors or hosts. In some cases, these parasites do not afflict people, but may do serious harm to organisms upon which people rely, particularly to crops, livestock, and stored goods (e.g., Buckland 1976; Claassen 1998:31–37; Sveinbjarnardóttir et al. 2007). In other cases, the relationship may be **pseudoparasitic**, which occurs when a person eats diseased tissues and becomes infected by organisms that normally would parasitize

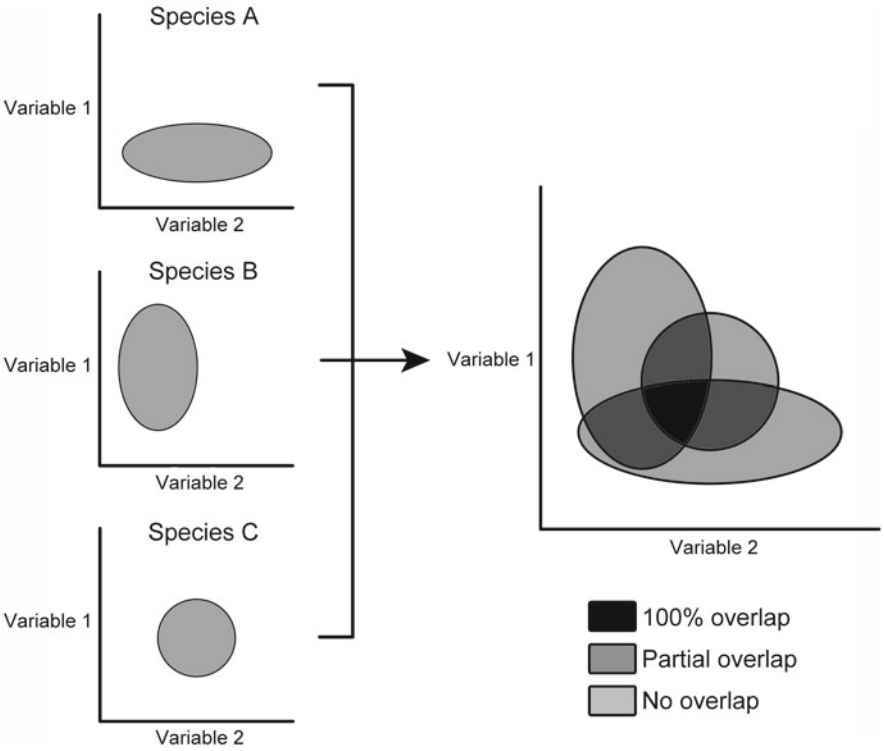

Fig. 10.19 Mutual climatic range (MCR) defined by the area of overlap between two environmental variables, such as maximum temperature and temperature range, for three hypothetical species

Table 10.3 Climatic reconstructions for three settlement phases in Medieval Uppsala (Sweden) based on mutual climate range (MCR) of selected beetle taxa[a]

Settlement phase	t_n	TMAX	TMIN
1	2	12–29 (20.5)	−23 to 14 (−4.5)
2	19	16–18 (17)	−12 to 6 (−3)
7	8	16–18 (17)	−20 to 5 (−5)

[a]TMAX and TMIN are the reconstructed ranges of mean July and mean January temperatures in °C. t_n is the number of species included in the calculation. From Hellqvist and Lemdahl (1996:879) and used with permission of Elsevier

other animals. People share some parasites with their companion animals, such as dogs, and other parasites are shared among domestic animals (Barnes 2005; Bathurst 2005; Waldron 2009:111–113). The life cycles of parasitic animals can be extremely complex, often driven by the challenges of surviving transmission from one host to another by making use of vectors or resistant dormant stages that can be passed from one host to another (e.g., Matthews 2011). The relationship between invertebrate vectors and parasites during transmission cycles is an active focus of parasite

research and demonstrates the complexity of this process. Very little direct evidence of most parasites is found in the archaeological record. Most evidence is indirect, derived from observing symptoms of disease in plant and vertebrate remains.

Platyhelminthes often have complex life cycles that involve people and other animals (Barnes 2005:99–113). The liver fluke (Trematoda: *Fasciola hepatica*) of sheep infects other mammals and occasionally people. This fluke uses aquatic snails as intermediate hosts, though humans may be infected through infested water. Blood flukes of the genus *Schistosoma* cause diseases such as bilharzia and schistosomiasis in people and the animals that live with them (Barnes 2005:111–112). Tapeworms infect many animals and must obtain nutrients from their host because they have no digestive tracts. Some species feed on their definitive host for decades (Barnes 2005:40–41). In a healthy person, a single tapeworm is not fatal, but it lowers resistance to other diseases and produces severe weight loss. Perhaps the most common tapeworms identified in archaeological contexts are beef tapeworms (*Taenia saginata*) and pork tapeworms (*Taenia solium*). Another tapeworm, *D. latum*, has two secondary hosts, the first is a water flea and the second is a freshwater fish; people and other fish-eating animals are definitive hosts.

Some nematodes are parasites of domestic animals and people (Barnes 2005:58–61; Brusca and Brusca 2003:359–361). Trichinosis is associated with a roundworm known as trichina worm (*T. spiralis*) that infects the host when meat containing viable cysts is eaten; the walls of the cysts are digested in the intestine, releasing the young roundworms (Barnes 2005:39; Brusca and Brusca 2003:360). Infected pork may contain as many as 3,000 cysts/g (Shackley 1981:155). Other nematode parasites are hookworms (e.g., *Ancylostoma duodenale*), roundworms (e.g., *Ascaris lumbricoides*), whipworms, and filarial worms (Filarioidea; Barnes 2005:59–62, 130–134).

Ectoparasites include some animals that are very familiar to us: fleas and lice (singular: louse). Fleas are common bird and mammal ectoparasites; over 1,000 species are known. Fleas usually have little effect on health, with a few notable exceptions. The common flea (*Xenopsylla cheopis*), an ectoparasite of the black rat (*Rattus rattus*), transmits the plague bacillus *Yersinia pestis* (Barnes 2005:242). Lice are intriguing ectoparasites because people and apes are infected by the same genus (*Pediculus*), indicating their shared ancestry (Barnes 2005:36). Three types of lice afflict people, a head louse (*Pediculus humanus capitus*), an upper body louse (*Pediculus humanus humanus*), and a pubic louse (*Pthirus pubis*). The head and body lice have different morphological, behavioral, and ecological characteristics. Head lice required hair, but body lice can live in clothing. The divergence between the head and body lice likely began as humans lost body hair and began to use clothing regularly (Toups et al. 2010). Human lice can be carriers of rickettsiae (*Prowazekii typhus*) associated with epidemic typhus (Barnes 2005:252, 255–256). In the case of louse-borne typhus, lice also sicken.

Some flies, mosquitos, ticks, and mites are vectors for disease-causing organisms (Barnes 2005:251–268). Yellow fever is caused by a virus transmitted by a mosquito (*Aedes aegypti*) and is particularly associated with settlements and lands cleared for fields and pastures (Barnes 2005:300). Insect bites transmit tiny

microfilaria nematodes that cause river blindness, elephantiasis, and other diseases in tropical areas (Barnes 2005:130–134). Tsetse flies (*Glossina*) are vectors for parasitic protozoa known as trypanosomes (e.g., *Trypanosoma brucei*) associated with sleeping sickness in people and causing disease in many other animals (Barnes 2005:117–122). Chagas' disease in the Americas is caused by trypanosomes transmitted by kissing bugs (Reduviidae: *Triatoma*).

Applications

Site formation processes are of considerable importance for many arthropod assemblages, but Schelvis (1990) argues this is not the case for moss mites (Acarina: Oribatida) because they are flightless, too small to attract human attention, and completely encased in an exoskeleton composed of chitin. Schelvis (1990) defines 20 ecological groups of mites based on shared habitat preferences and uses these ecological groups to analyze materials deposited during the eleventh century AD at the rural site of Oldeboorn (The Netherlands). The ecological groups are defined by the tolerance of members of each group to different levels of soil moisture. Some mites formed a group with no obvious habitat preference and others form a synanthropic group associated with deposits rich in decaying organic matter. The groups range in richness from 1 to 14 taxa. To compensate for uneven group size, Schelvis (1990) counts the number of individuals for each taxon (e.g., 98), multiplies this by an index obtained by dividing the number of taxa actually recovered (e.g., 3) by the number of taxa in the ecological group (e.g., 7), producing a value of 42. This yields a weighted distribution that emphasizes the completeness of each ecological group instead of the number of individuals in each group and enables the relative importance of ecological groups in the overall assemblage to be assessed (Fig. 10.20; Schelvis 1990:564). Schelvis (1990) reports that the majority of the Oldeboorn mites are from moist, fresh or salty grasslands (Group XIII), or from salty grasslands only (Group XIV), suggesting that the environment near the site was open, dominated by grasslands, and exposed to the sea in the eleventh century.

The extent of forests and woodlands is an important aspect of landscape and cultural transformations. Evaluating changes in forests and woodlands requires considering evidence for complex relationships among habitat preferences, habitat successions, taphonomic pathways, and death assemblages (Carrott and Kenward 2001; Kenward 2006; Kenward and Carrott 2006). People alter landscapes by using fire to improve pasturage for wild and domestic herbivores, expanding fields, and collecting wood for fuel and construction projects (e.g., Innes and Blackford 2003). Insects offer important perspectives on these activities because of their close associations with trees, grasslands, crops, or wetlands. Some sites contain abundant evidence for trees, but little or no evidence for the insects that should be associated with those trees (Fig. 10.21; Kenward 2006:1373). Kenward (2006) explores this apparent contradiction by analyzing insects collected from modern deposits in woodlands, woodland margins, and non-woodlands in York and Kent (UK). He reports that associations

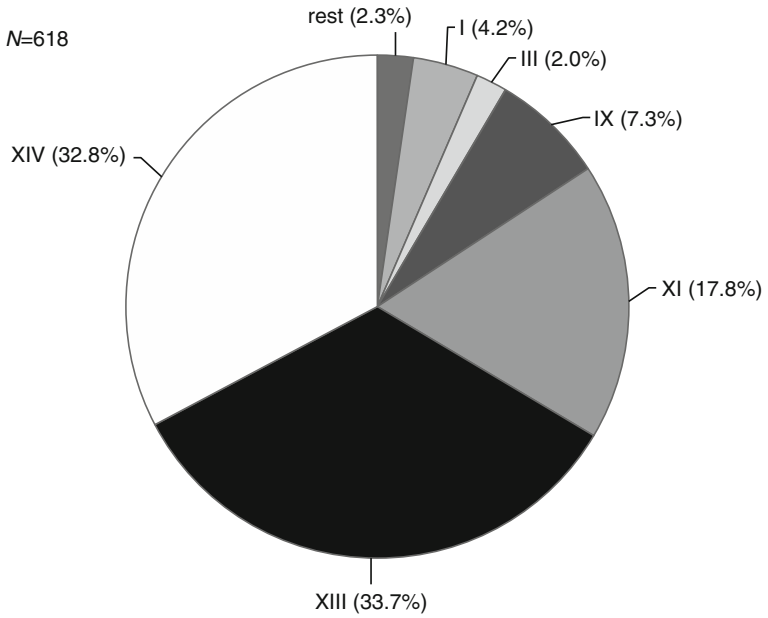

Fig. 10.20 Spectrum of the ecological groups of oribatid mites (Oribatida) based on the remains of 618 mites from the eleventh-century Oldeboorn (The Netherlands) sample. Roughly summarized, the groups are: Group I, mites associated with moss, lichens, and litter on dry sandy soil, moist soil in moorland, and dry woodland soil; Group III, mites found on dry and moist litter and moss in woodlands; Group IX, mites associated with wet moorland, grassland, and swamp woodland; Group XI, mites found in constantly wet mosses, especially *Sphagnum* moorland; Group XIII, mites found in moist and wet, fresh or salty grassland; and Group XIV, mites found only in salty grasslands. For more details of these groups see Schelvis (1990). From Schelvis (1990:564) and used by courtesy of the author and Elsevier

between trees and insects vary greatly. Although the proportion of woodland insects does decline as one gets further from trees, tree-affiliated insects may not be common even next to trees. Kenward (2006) concludes that the absence of tree-associated insects may not be evidence of deforestation for a number of reasons associated with site formation processes. Nonetheless, Kenward and Carrott (2006) report a broad consistency in species associations among deposits with similar usages or offering similar habitats. Some suites of insects reflect patterns in habitats, activities, and deposit types; forming indicator or ecological groups that may distinguish among farm houses, granaries, stables, compost, and open landscapes. They interpret this to mean that some taxa coexist in the same or adjacent habitats, or enter deposits through similar processes or disposal routes. Kenward and Carrott (2006) caution that death assemblages are not evidence that all of the insects in the assemblage had the same habitat preferences throughout each animal's range, only that they may occur together because of overlaps in habitat preferences and taphonomic pathways that merge life, death, deposited, archaeological, and study assemblages.

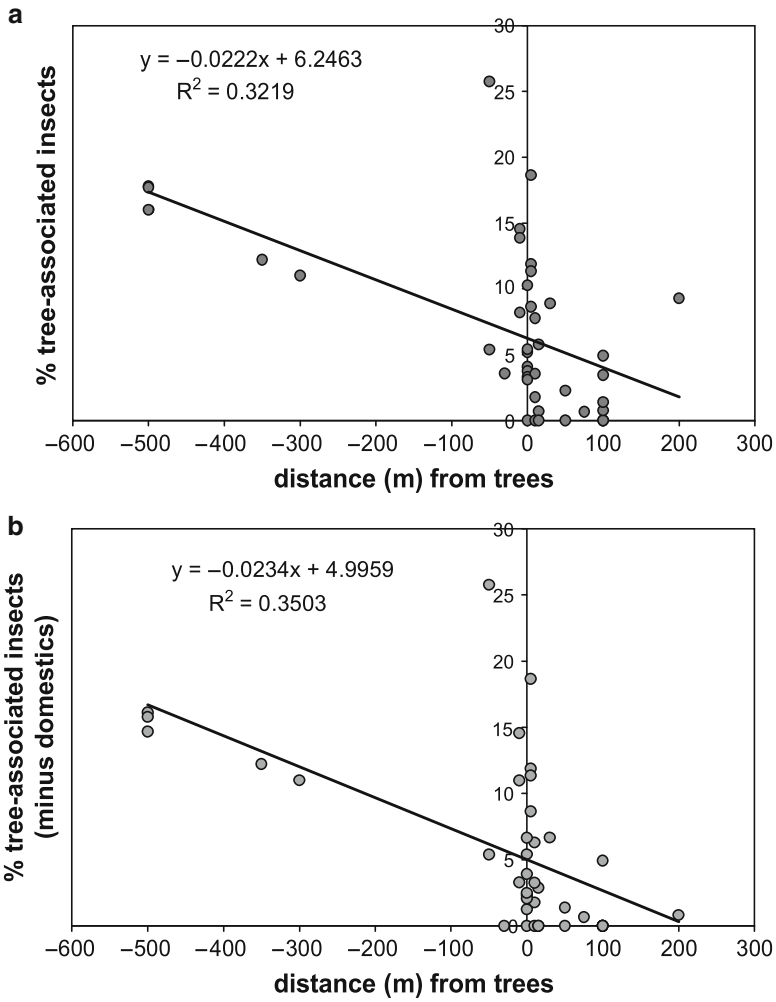

Fig. 10.21 Scattergrams showing the percentage of tree-associated adult beetles (Coleoptera) and true bugs (Hemiptera) against nominal distance from trees in a series of modern deposits: (**a**) including synanthropic wood borers; and (**b**) excluding synanthropic wood borers. Aquatic taxa are excluded in both cases. Nominal distance is negative within woodlands. From Kenward (2006:1373) and used by courtesy of the author and Elsevier

Arthropods provide insights into human behaviors such as burials and trash disposal (e.g., Huchet and Greenberg 2010; Panagiotakopula et al. 2010). They also suggest functions of buildings and activity areas. The variety and quantity of arthropod remains at Weier II (Canton Schaffhausen, Switzerland), a bog settlement, provide evidence for such functions as well as for an integrated management of crops and animals. Nielsen et al. (2000) found 54 arthropod taxa in a sample of 533 specimens from the site. They use these specimens to test the hypothesis that a

structure dated to ca. 3600 BC was a **byre** (a roofed stable). Approximately 30 cm of compressed, decomposing manure, twigs, leaves, and other organic debris was found inside the structure between three floors of whole and split tree trunks. The deposit probably was much thicker, but some of it has decomposed over time. Lesser dung flies (Sphaeroceridae, e.g., *Thoracochaeta zosterae*) dominate the assemblage, which includes house flies (*Musca domestica*), mites, and 37 taxa of adult beetles (Coleoptera). Flies are represented only by puparia and some larvae, indicating that flies were breeding and laying eggs inside the structure. The beetles may be background fauna attracted to the decomposing plant materials, but they also may be autochthonous as few were definite "outdoor" taxa. The identification of cattle remains, liver fluke (*F. hepatica*) eggs, and biting lice (*Damalinia bovis*), a cattle ectoparasite, indicate that cattle sheltered in the structure. The authors conclude that cattle may have been over-wintered in the byre, which was mucked out only in the spring when manure was needed to fertilize fields.

Porotic hyperostosis and cribra orbitalia are sieve-like lesions found on some human skulls. Porotic hyperostosis is observed on flat elements of the cranial vault and cribra orbitalia occurs within eye orbits (Larsen 1997:31–32). These pathologies are attributed to iron deficiency anemia or to hereditary diseases such as sickle cell anemia, but may have different origins (Walker et al. 2009). Cribra orbitalia, in particular, may be evidence of parasitic infestations (e.g., Okumura and Eggers 2005; Waldron 2009:136–137). Although skeletal lesions associated with anemia are observed at sites in the Pacific Northwest coast, there is little evidence linking parasites to these lesions because coprolites, mummified remains, and latrines are rare in the area (Bathurst 2005). Bathurst (2005) reports empirical evidence for parasites at Pacific coast shell-bearing sites (Fitz Hugh Sound, British Columbia, Canada). The ages of the sites range from 10,000 years ago into the eighteenth century AD. Throughout this time, people were fishers and foragers with limited residential mobility and dense human populations, conditions often associated with high levels of parasitism. Fecal deposits are rare in the study area; thus, Bathurst (2005) sought parasites in the sediments themselves, finding parasite eggs in samples from 11 of the 15 sites studied; the oldest sample dated to 5650–5440 cal BP. Two parasitic genera are abundant: the fish tapeworm (*Diphyllobothrium*) and the human roundworm (*A. lumbricoides*; Figs. 10.22 and 10.23; Bathurst 2005:117, 118). The length and width of the tapeworm eggs indicate that a single tapeworm taxon is present in the material, but are not adequate for an attribution to a specific epithet (Fig. 10.24; Bathurst 2005:119). The fish tapeworm is associated with pernicious anemia in people. The larval stage of the tapeworm begins in copepods; fishes are secondary hosts; and birds and mammals are definitive hosts. When raw or undercooked fish or hard **roe** (mass of fish eggs) are consumed by a definitive host (i.e., a person), the tapeworm matures and produces eggs that pass with the feces into water or moist conditions, where the cycle resumes. The human roundworm is specific to human hosts and is transmitted via foods or beverages containing fertilized eggs. Eggs hatch within the human host, where the roundworm reproduces. Eggs are passed with the feces and subsequently are ingested by another human host. Bathurst's (2005) results support the hypotheses that shell-bearing deposits with

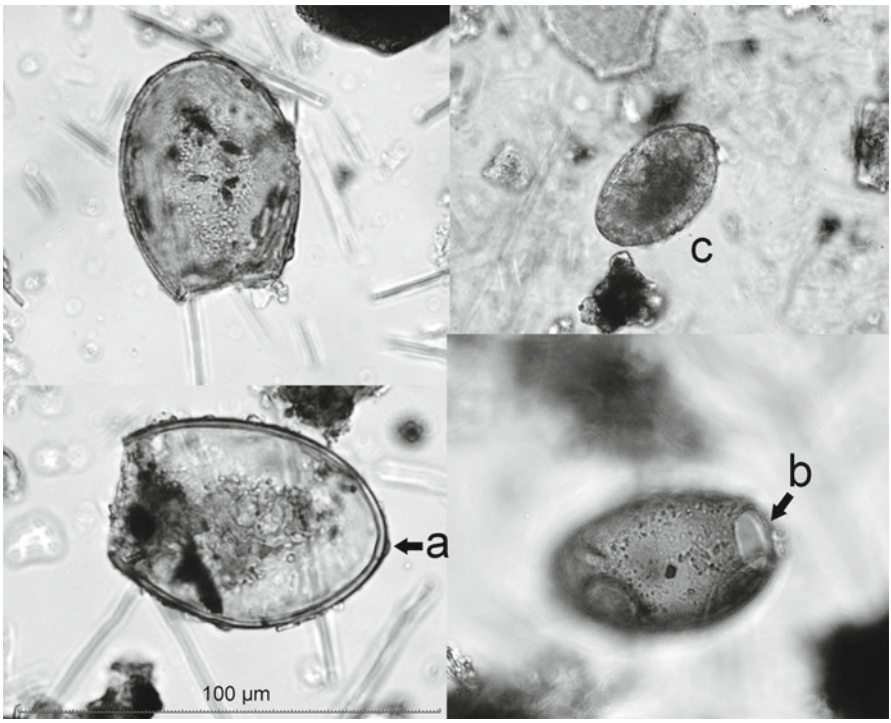

Fig. 10.22 Fish tapeworm (*Diphyllobothrium*) eggs recovered from Fitz Hugh Sound sites (British Columbia, Canada) displaying: (**a**) characteristic abopercular knob; (**b**) operculum; and (**c**) intact unembryonated eggs. Magnification ×400. From Bathurst (2005:117) and used by courtesy of the author and Elsevier

neutral to alkaline (pH 7.2–8.3) sediments may contain parasite eggs. These results suggest that parasitic infections may be a source of iron deficiency found in human skeletal remains and a factor contributing to anemia even among people who do not farm. The probability that intestinal parasites are present in general site matrix creates yet another demand for well-collected soil samples.

Increasingly, environmental archaeologists use archived museum specimens to demonstrate new methods or test new theories. A slightly dirty archaeological specimen does not conform to a museum's integrated pest management plan and most archaeological objects are cleaned shortly after they are excavated. Sometimes, however, residue eludes even vigorous cleaning and is available for study. Fugassa et al. (2008) report on their examination of sediments adhering to human **sacra** (the lower portion of the spinal column forming the dorsal wall of the pelvic girdle) from sites in Santa Cruz and Tierra del Fuego provinces (Argentina). The sacra contained eggs from two nematode taxa (*Capillaria*, *A. lumbricoides*). The eggs had accumulated in the sacra as the bodies decomposed. Some sacra contained fungal spores. *A. lumbricoides*, found in only one individual, is more frequently associated with

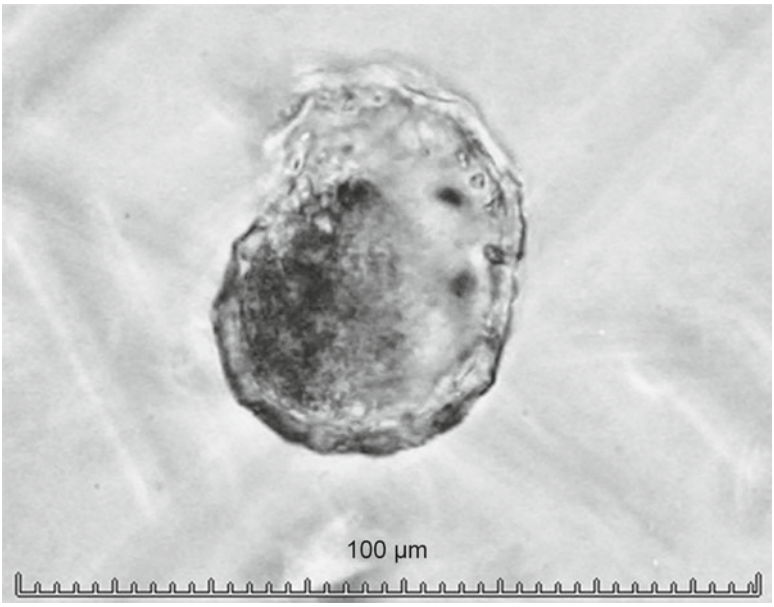

Fig. 10.23 Human roundworm (*Ascaris lumbricoides*) egg displaying characteristic thick, mammillated outer shell. Magnification ×400. From Bathurst (2005:118) and used by courtesy of the author and Elsevier

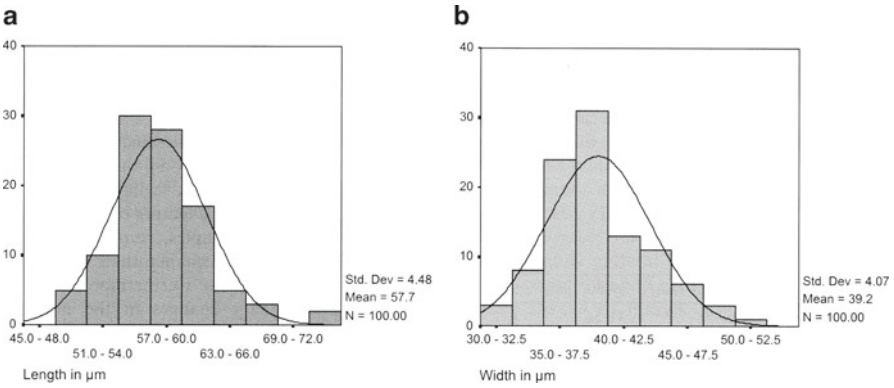

Fig. 10.24 Fish tapeworm (*Diphyllobothrium*): (**a**) length; and (**b**) width measurements. From Bathurst (2005:119) and used by courtesy of the author and Elsevier

Europeans and subsequent molecular study of the human skeleton confirmed its European origin. Although thorough cleaning is a standard, and important, museum protocol, Fugassa et al. (2008) urge museums to collect and archive adhering debris for future studies instead of discarding what appears to be troublesome dirt.

Many archaeological interpretations test associations among foraging strategies, prey ranking systems, settlement patterns, and subsistence technologies. High-ranking prey species often are defined as large-bodied animals. Small-bodied animals, however, may not be recovered because of inappropriate field methods or may not be studied; thus, their role in many economies is untested. Losey et al. (2004) report on their study of one small-bodied, under-studied animal, Dungeness crabs, recovered from Netarts Sandspit Village (Oregon, USA). The village is located on the Pacific coast overlooking what is now a shallow saline lagoon. Its wood-plank houses and dense shell middens were used from ca. AD 1300 until the late 1700s. Dungeness crabs are one of the larger crabs in the study area, with typical carapace widths of 180 mm. Crabs reach sexual maturity between 2 and 3 years of age, live about 8 years, and grow larger with each molt. The relationship between size and age makes it possible to construct a mortality profile for these crabs (Fig. 10.18; Losey et al. 2004:1609). People at the village harvested a wide range of size classes, but many crabs were small, young individuals. Losey et al. (2004) conclude that juveniles and young adults were obtained through mass-harvesting techniques (e.g., raking) and that larger, adult, crabs were collected using individual capture methods (e.g., by hand). They note that raking shallow, subtidal estuarine habitats requires less time than do individual capture methods. Their interpretation is supported by the identification of four species of molluscs whose habitat preferences are similar to those of the smaller crabs. Small crabs and cockles (*Clinocardium nuttallii*), for example, could be harvested using rakes from the same location at the same time. The authors observe that all of the major shellfishes used at the site could be collected during a single tidal cycle. Losey et al. (2004) argue that this strategy combines efficient mass-harvesting technology with an abundant, dense, small-bodied prey taxa whose capture requires minimal search time, thereby compensating for the small size of individual crabs.

Summary

Animals play specific roles within communities and provide insights into site formation processes, habitats used, seasonal aspects of human behavior, and functions of buildings and activity areas. Many of animals reviewed in this chapter are sensitive to climate, vegetation, aquatic systems, ecological processes, and related environmental attributes. Some are significant components of site formation processes and others provide direct or indirect information about human resource use and landscape transformations. A few of the animals reviewed in this chapter have significant dietary roles and provide insights into exploitation strategies or other economic features. Others have far-reaching impacts as parasites or vectors of parasites.

Multi-proxy studies are especially important in environmental archaeology because some proxies compensate for weaknesses in other proxies or elaborate upon interpretations derived from other sources. The arthropods and other invertebrates reviewed in this chapter are particularly valuable when used to expand, support,

or refute interpretations derived from other classes of data. Of particular importance are the biogeographical and cultural interpretations made possible by associations among indicator taxa, groups, or packages, especially those based on species that are either stenotopic or synanthropic. Interpretations are further enhanced by studies of molluscs, echinoderms, and vertebrates, groups reviewed in the next two chapters.

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Chapter 11
Molluscs and Echinoderms

Three invertebrate groups (Crustacea, Mollusca, Echinodermata) are of particular importance in multiproxy studies because many were widely used by people, often are abundant, or at least highly visible, in archaeological deposits, and are sensitive to environmental conditions. Crustacea are discussed in Chap. 10 with other arthropods. In this chapter, Mollusca and Echinodermata are reviewed.

Molluscs and echinoderms are sensitive to changes in oxygen, temperature, and other aspects of aquatic environments such as siltation, energy level, water depth, sea level fluctuations, and transformations of aquatic, and in some cases, terrestrial habitats. Some of these animals have distinctive patterns of episodic or incremental growth which can be associated with growth habits and may indicate the age of the animal at death. Stable isotopes of oxygen in these episodic growth structures are commonly used as proxies for temperatures prevailing during each growth episode. These palaeotemperatures are associated with climatic regimes, weather patterns, biogeography, and seasonal aspects of human activity such as residential patterns and scheduling decisions.

Environmental archaeologists can assess the dynamics of human and prey populations by examining which organisms people used, in what manner, as well as the intensity, methods, and timing of use. A change in a species' growth habits, growth rates, and body sizes over time may indicate that human predation shifted to a different age cohort or habitat or employed a different collection technology. Some animals were so widely used that resource management strategies, or environmental degradation through overuse, were possible. Nutritional value might guide decisions made by people about which resources or resource areas to use, how much effort to expend in searching for and acquiring a specific resource, and which portions of the resource to transport over what distance. Estimates of dietary contribution are important for assessing the roles of plant, invertebrate, vertebrate, terrestrial, and aquatic resources in economies and in other aspects of human behavior.

Molluscs and echinoderms have important nondietary uses as tools, dyes, ornaments, architectural elements, and raw material in ceramics and tiles. Some are traded over vast distances because of their ritual and social value; thus,

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environmental interpretations must consider both local and nonlocal origins in addition to nonenvironmental and nondietary reasons for any changes observed in assemblages of archaeological specimens.

The calcium carbonate in molluscs contributes to the preservation of some organic materials and advances the decay of others. Molluscs, echinoderms, and crustaceans sometimes are found in large deposits associated with coastal, riverine, and lacustrine ecosystems. If a deposit contains more than ca. 30% shell, the accompanying sediments, material culture, and biological constituents often are inconspicuous by comparison and the deposit appears to be primarily shell. Such deposits may be referred to as shell middens or shell mounds. These names are confusing because they are applied both to archaeological deposits composed almost entirely of molluscs and to ones in which molluscs may be less common or present in only a few contexts. A difficulty with the term "shell midden" is that the deposit may not be a midden, a term that implies refuse generated by secular, residential, or domestic activities. "Shell mound" may be inappropriate because the deposit may not form a mound, however densely the shell may be packed. Some shell-bearing deposits were originally mounds of densely packed shell, but at the time of excavation they may be less than a meter above the ground surface, or not visible above ground at all. Due to broad differences in quantities, functions, and physical organization of shell in shell-bearing deposits, some argue that such contexts should be referred to as shell-bearing or shell-matrix sites instead of shell middens or shell mounds. Even this may be problematic because the deposit matrix usually contains materials other than shell. The term "shell" itself may be technically incorrect when the specific organisms are considered. Often the term "shell" is used exclusively for molluscs, but not all molluscs have "shells."

Embedded in this semantic discussion are important research objectives: resolving the structure, function, and formational history of each deposit and the environmental and cultural roles of organisms. In this chapter, molluscs and echinoderms are reviewed independently of the functional context in which they are found to emphasize that they are recovered in many situations other than "mounds" or "middens" and that they have numerous uses beyond food. Nonetheless, most sites, or locations within sites, that contain large quantities of molluscs are generally referred to in English as shell mounds or middens, regardless of the deposit's structure, function, or history (e.g., Eggers et al. 2008; Okumura and Eggers 2005; Rodrigues et al. 2009).

Two spellings of the vernacular name for Mollusca appear in the English literature. "Mollusc" is considered the British spelling; "mollusk" is more common in the United States. One leading American authority on this phylum uses the term "mollusk" (Turgeon et al. 1998); however, another uses "mollusc" (Brusca and Brusca 2003). Brusca and Brusca (2003:702) note that the convention in biological nomenclature is to obtain the vernacular name directly from the Latin scientific name. Thus, we use mollusc as the vernacular form, which also is the more widespread spelling.

Nomenclature

Molluscs (Table 11.1; Brusca and Brusca 2003:703–715) and echinoderms (Table 11.2; Brusca and Brusca 2003:804–806) have neither teeth nor vertebrae, but they do have either exoskeletons or endoskeletons. A defining characteristic of molluscs is the presence of a mantle (Fig. 11.1; Brusca and Brusca 2003:717; Krogh 2009:454). The mantle (or pallium) is a layer of skin that secretes a calcium carbonate material to form the protective skeleton. This skeleton may consist of spines, spicules, sclerites, or plates in the body wall, or solid shells (**valves**) that are either external or internal (Brusca and Brusca 2003:717, 720).

Shells and valves consist of calcium carbonate, usually in the form of calcite or aragonite, arranged in layers. These layers generally include an outer, chalky **prismatic** or **palisade layer** and an inner, pearly **lamellar** or **nacreous layer** and may be covered by a thin organic membrane (**periostracum**). Additional layers may be present and some molluscs have lost the lamellar layer (Brusca and Brusca 2003:720). An organic protein (**conchin** or **conchiolin**) may bind the calcareous crystals in the layers together. The nacreous layer, if present, always contains conchin. The nacreous layer in particular may confer a distinctive sheen or color that gives some shells value as ornaments or currency. In some molluscs (e.g., slugs, squids, octopuses), the number of valves is reduced or they may be absent (Brusca and Brusca 2003:714, 719). Evidence for molluscs that lack valves is rare in archaeological deposits, though this is not proof that the animals themselves were not present.

Many molluscs feed using a rasping tongue-like strap (**radula**) that bears radular teeth (**cuticula**; Brusca and Brusca 2003:717, 733). The radula is a uniquely molluscan feature. "Teeth" in this context refers to small chitinous structures lining the edge of the radula (Fig. 11.2; Holden 2001:405). These teeth have a wide variety of shapes, sizes, and arrangements (Brusca and Brusca 2003:734–735), but are not homologous with vertebrate teeth.

Polyplacophora (chitons) are bilaterally symmetrical, mobile marine animals that use their ventral foot to cling to rocks along coastal intertidal regions, where they use radular teeth to feed on algae (Fig. 11.3; Brusca and Brusca 2003:703, 708; Reitz and Wing 2008:373). The vernacular name for these animals (chiton) should not be confused with chitin, a complex carbohydrate found in other organisms. Chitons do not look like other molluscs because they are flattened ovals and their protective valves consist of seven or eight overlapping dorsal plates. The first anterior (**cephalic**) and the final posterior (**anal**) plates are particularly distinctive.

Gastropoda (e.g., snails) live in marine and freshwater habitats and include the only terrestrial molluscs. Most gastropods have a single, asymmetrical shell or valve, hence the common reference to them as univalves (Fig. 11.4; Brusca and Brusca 2003:703, 709, 722–725; Campbell et al. 2008:678–679). The valve may be either aragonite or calcite, though aragonite is more common (Brusca and Brusca 2003:724; Vermeij 1993:45–53; Weiner 2010:160). Most gastropod valves show **torsion**, coiling around an opening (**aperture**) at the anterior end of the animal.

Table 11.1 Classification of some molluscs[a]

Category	Examples
Polyplacophora	
Chitonidae	Chitons
Gastropoda	
Prosobranchia	
Haliotididae	Abalones
Fissurellidae	Limpets
Trochidae	Topsnails
Neritidae	Nerites
Cerithiiidae	Ceriths
Littorinidae	Periwinkles
Strombidae	Conches
Calyptraeidae	Slippersnails
Naticidae	Shark eyes
Muricidae	Murexes
Buccinidae	Conchs, whelks
Melongenidae	Whelks
Nassariidae	Mudsnails
Pyramidellidae	Odostomes
Opisthobranchia	Sea slugs
Pulmonata	Land snails, slugs
Stylommatophora	Snails
Bulimulidae	Treesnails
Polygyridae	Woodland snails
Bivalvia (= Pelecypoda)	
Arcidae	Arks
Pectinidae	Scallops
Spondylidae	Thorny-oysters
Ostreidae	Oysters
Unionidae	Freshwater clams
Chamidae	Jewelboxes
Donacidae	Coquina
Mactridae	Rangias
Solecurtidae	Tagalus
Dreissenidae	Zebra mussels
Corbiculidae	Marshclams
Veneridae	Venus clams
Scaphopoda	
Dentaliidae	Tusk shells
Cephalopoda	
Spirulidae	Squids
Octopodidae	Octopus

[a]Following Brusca and Brusca (2003:703–715), Campbell et al. (2008:678), and Turgeon et al. (1998)

Table 11.2 Classification of some echinoderms[a]

Category	Examples
Crinoidea	Sea lilies, feather stars
Asteroidea	Sea stars
Ophiuroidea	Brittle stars
Echinoidea	Sand dollars, sea urchins
Holothuroidea	Sea cucumbers

[a]Following Brusca and Brusca (2003:804–806) and Campbell et al. (2008:694)

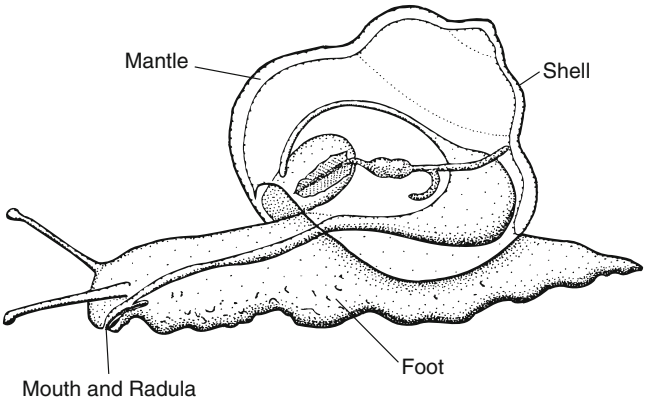


Fig. 11.1 Generalized mollusc, represented by a gastropod

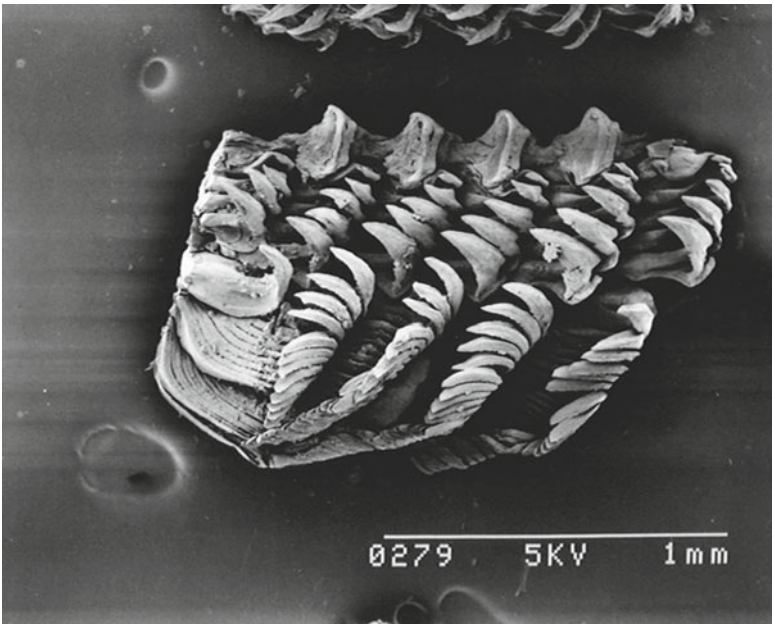


Fig. 11.2 Scanning electron micrograph (SEM) of a fragment of the radula from a marine mollusc (*Chlorostoma*), from El Morro, northern Chile. From Holden (2001:405) and used by courtesy of the author and Wiley-Blackwell

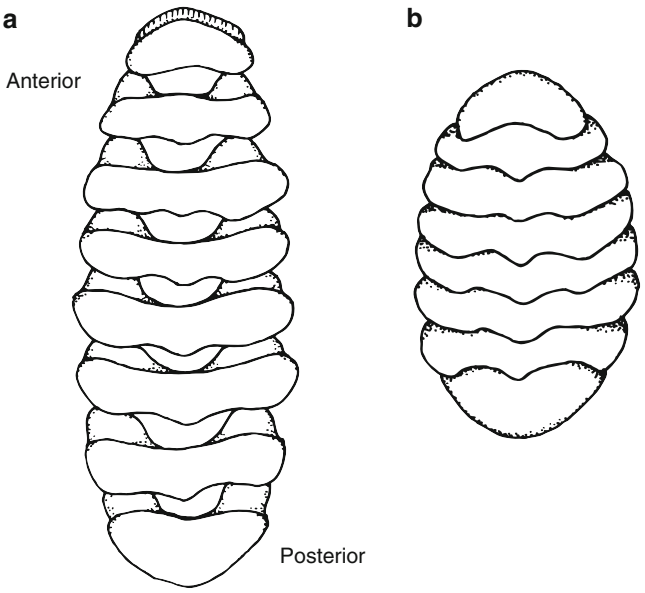


Fig. 11.3 A West Indian fuzzy chiton (*Acanthopleura granulata*): (**a**) with its plates expanded so that the shape of each is visible; and (**b**) as it is in life. Drawn by Virginia Carter Steadman. From Reitz and Wing (2008:373) and used by courtesy of Cambridge University Press

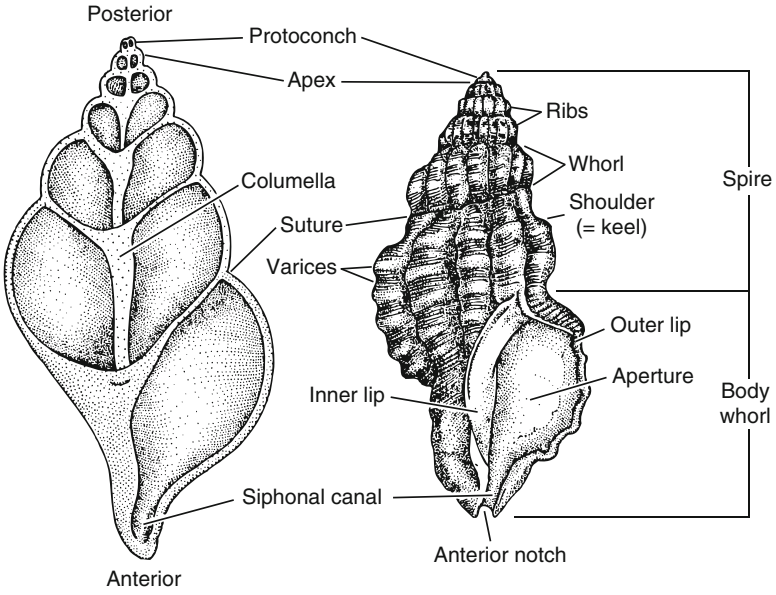


Fig. 11.4 Internal and external features of a spiral gastropod shell. Reproduced from Brusca and Brusca (2003:722, Figure 20.16g). Used by courtesy of Sinauer Associates, Inc

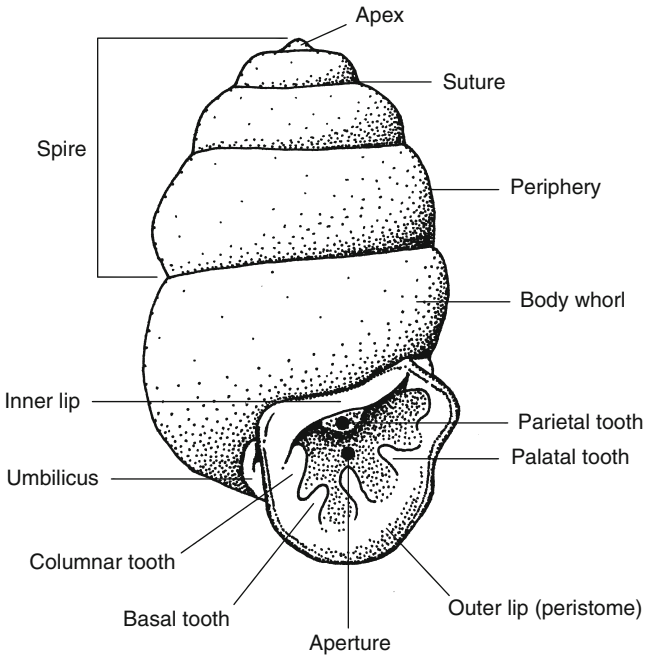


Fig. 11.5 Landmarks as they appear in a crested vertigo (*Vertigo pygmaea*), a terrestrial gastropod. Modified from Evans (1972:47)

Some gastropods have a calcareous flap or plate (singular: **operculum**; plural: opercula) that closes over the aperture to protect internal organs. The lip of the aperture may be reinforced with a thick pad or **callus**. **Denticles**, sometimes referred to as teeth, may be arranged along the lip of the aperture. The number, shape, and arrangement of radular teeth are additional diagnostic features. Many Opisthobranchia (sea slugs) and some of the Pulmonata (land snails, slugs) have no valves.

Valve shapes range from a cone or spire (**spiral**) to a flattened disk (**discoidal**; Brusca and Brusca 2003:723–724). The top of the spire or center of the disc is generally known as the **apex** (Fig. 11.4). The animal moves forward from the aperture and the apex is at the posterior end, a distinction that is more obvious in cone-shaped gastropods than in disc-shaped ones. Each turn of the spire or disk forms a **whorl** demarcated by lines known as **sutures**. The largest whorl forms the **body whorl**. The central axis of coiling is termed the **columella**. This is a solid structure in some species; in others it opens basally to form an externally visible **umbilicus** (Fig. 11.5; Evans 1972:47). An umbilicus can be wide or narrow, shallow or deep, open or plugged. Coils may be clockwise (**dextral**, right) or counterclockwise (**sinistral**, left), though some species coil in either direction. The anterior end of the valve may have an **anterior notch** or an anterior canal (**siphonal canal**). Valves may bear nodules, beads, or ribs. The valves of two gastropod families (abalones [Haliotididae] and limpets [Fissurellidae]) are flat and do not appear to coil.

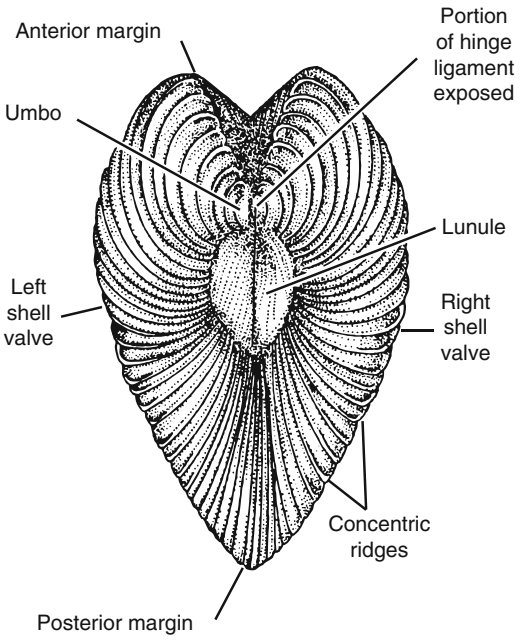


Fig. 11.6 Dorsal view of a clam (Bivalvia). Reproduced from Brusca and Brusca (2003:722, Figure 20.16k). Used by courtesy of Sinauer Associates, Inc

Bivalvia (e.g., mussels, sometimes referred to as Pelecypoda) are so named because they have two valves that articulate with one another along the dorsal surface (Fig. 11.6; Brusca and Brusca 2003:712, 722–724). Bivalves are found in both marine and freshwater locations. Most bivalves are bilaterally symmetrical, such as mussels (e.g., Mytilidae), though some are asymmetrical, such as oysters (e.g., Ostreidae). The calcareous layers may be aragonite or a mixture of aragonite and calcite and may include a substantial organic component (Brusca and Brusca 2003:723). The mantle attaches to the interior portion of each valve along the **pallial line** (Fig. 11.7; Brusca and Brusca 2003:722–723). The left and right valves articulate along a dorsal **hinge** at the thickest part of a valve, near a protuberance known as the **umbo**. This part of the valve is the oldest portion. Hinges are held together by ligaments and **hinge teeth**. These teeth strengthen the link between the two valves and are quite different from radular teeth. The foot is attached to the valves very firmly, forming **muscle scars** on the valves. Some bivalves have only one muscle and others have two. Bivalves do not have radula; they are **filter feeders**, consuming food trapped in gills as water flows through them. Some are sessile (e.g., oysters), at least as adults, while others (e.g., scallops [Pectinidae]) are mobile both as larvae and as adults.

Cephalopoda are carnivores that, with a single exception, have reduced internal shells (e.g., squids) or none at all (e.g., some octopuses; Brusca and Brusca 2003:714–715; 723). The nautilus (*Nautilus*) is the only living cephalopod genus with an external, protective shell. Some cephalopods have a radula and a chitinous beak. Cuttlefishes (Sepioida) have a hard, brittle internal structure (**cuttlebone**)

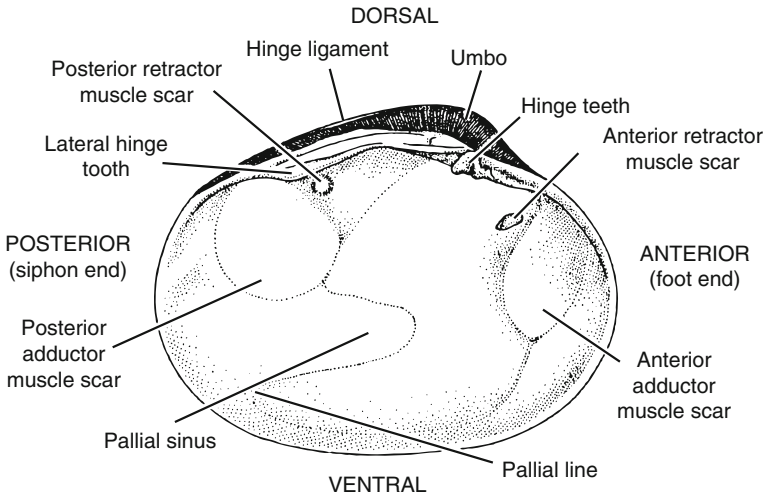


Fig. 11.7 Internal view of the left valve of a clam (Bivalvia). Reproduced from Brusca and Brusca (2003:722, Figure 20.16j). Used by courtesy of Sinauer Associates, Inc

composed primarily of aragonite. For this reason, cuttlefishes are recognized in archaeological deposits more frequently than other cephalopods, which does not necessarily mean they were more commonly used than squids and octopuses.

Scaphopoda (e.g., tusk shells) have a single, hollow, tubular valve that is open at both ends (Brusca and Brusca 2003:714; Vermeij 1993:15). The primary mineral is aragonite (Weiner 2010:160). The mantle of a scaphopod fits entirely within the valve. The foot extends from the larger end of the valve and is used to burrow through the substrate. Tusk shells feed using radular teeth.

Most Echinodermata are radially symmetrical. Some have flexible arms (e.g., sea stars [Asteroidea]) and others have globular or flat shapes without arms (e.g., sea urchins, sand dollars [Echinoidea]). Some endoskeletons consist of simple skeletal plates that are unfused and others have plates that fuse to form a test (Figs. 11.8–11.10; Brusca and Brusca 2003:805, 808, 811, 819; Campbell 2008a:17–19). Echinoderm tests consist of fused calcite plates (**ossicles**) that may be covered with spines and perforated by pores through which tubular feet protrude. The test is covered by circular bumps (**tubercles**) where spines are attached. Some Echinoidea have a complex feeding apparatus known as **Aristotle's lantern**. This calcium carbonate structure consists of five triangular-shaped plates called **hemipyramids**. Each pyramid bears a canal to accommodate a tooth that superficially resembles a rodent incisor and functions in much the same way. Teeth grow at their internal ends as the external ends wear down through use. The lantern also contains five pairs of **epiphyses**, five **rotula** (singular: rotule), and five **compasses**. All of these diagnostic parts are recovered from archaeological sites.

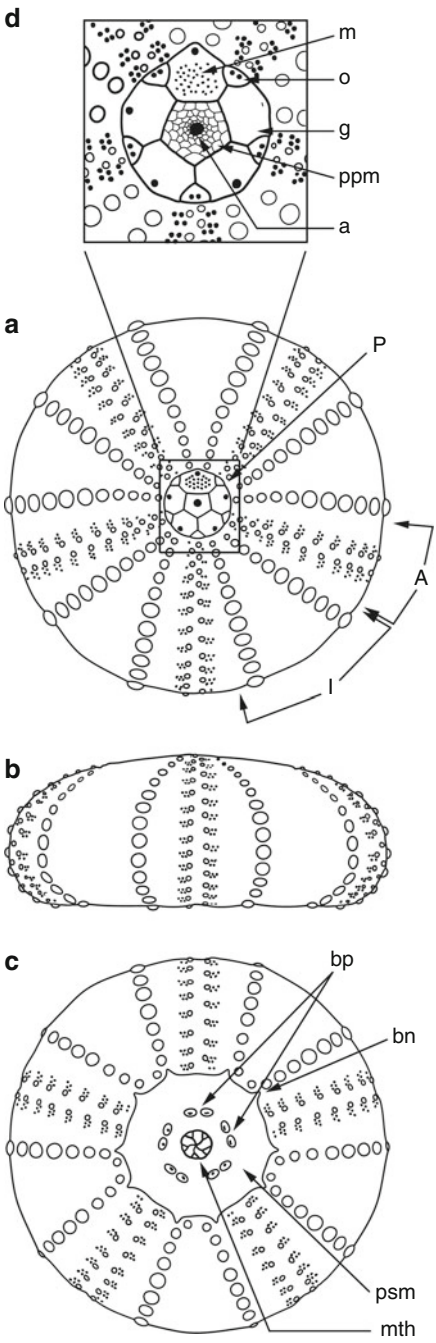


Fig. 11.8 Simplified diagram of a generalized Echinoidea (sea urchin) test with patterns of tubercles (*circles*) and pairs of pores (*dots*) much simplified: (**a**) top view, with anus central: *P*, periproct with apical disk; *A*, one of the five ambulacral zones; *I*, one of the five interambulacral zones; (**b**) side view, directly facing an ambulacral zone; (**c**) base view, with peristome central: *mth* mouth; *psm* peristomal membrane; *bp* buccal plate; *bn* buccal notch or gill slit; and (**d**) magnified view of periproct, showing apical disk of specialized plates: *a* anus; *ppm* periproctral membrane with closely packed plates; *g* one of the genital plates; *o* one of the five ocular plates; *m* madreporite. From Campbell (2008a:17) and used by courtesy of the author and *Canadian Zooarchaeology*

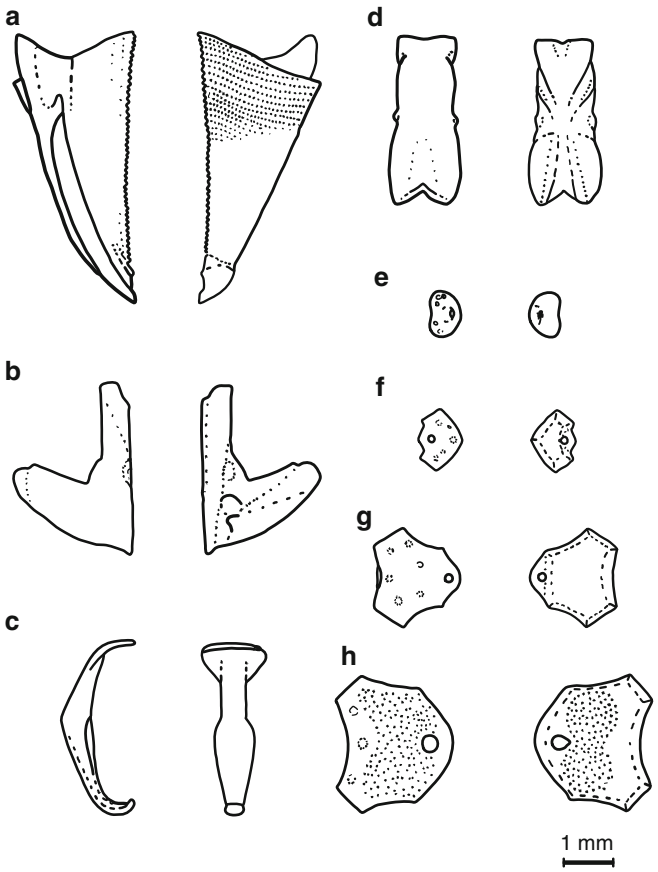


Fig. 11.9 Elements from Aristotle's lantern and other nontest elements of a purple sea urchin (*Paracentrotus lividus*). *a* the hemipyramid; *b* epiphysis; *c* compass; *d* rotula (singular: rotule); *e* buccal plates from the membrane around the mouth; *f* ocular plates; *g* genital plates; *h* madreporites from the periproct at the top of the test. From Campbell (2008a:18) and used by courtesy of the author and *Canadian Zooarchaeology*

Episodic or Periodic Growth in Animals

Animals with indeterminate growth grow episodically or periodically at specific intervals in response to favorable conditions, perhaps to manage the costs and risks of growth (Vermeij 1993:36, 39–40). Episodic growth produces accretionary structures seen as increments (rings, lines, zones, laminae, layers, bands) in mollusc valves (Andrus and Crowe 2000; Deith 1983; Hallmann et al. 2009; Milner 2001) and in the skeletal and dental elements of vertebrates whose growth is indeterminate (Wheeler and Jones 1989:89). Episodic growth also occurs in some vertebrates with

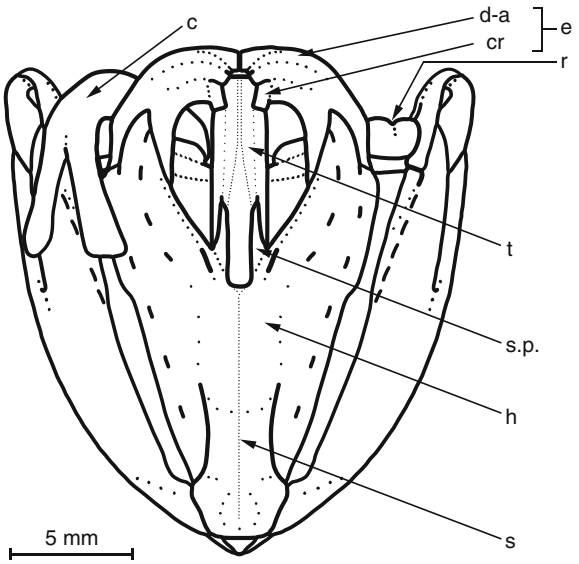


Fig. 11.10 Side (abaxial) view of the jaw or lantern of a red sea urchin (*Strongylocentrotus fransiscanus*) oriented as in life. *c* compass (which is removed from the right side of the figure); *e* epiphysis; *d-a* demi-arc; *cr* crest; *r* rotule; *t* tooth, visible through the foramen magnum; *h* hemipyramid; *s.p.* styloid process; *s* suture along which mirror-image pairs of hemipyramids are joined, surrounding the lower part of tooth. From Campbell (2008a:19) and used by courtesy of the author and *Canadian Zooarchaeology*

determinate growth (Hillson 2005:159–168, 247–252). Growth in gastropods is primarily around the aperture. Growth in bivalves is accomplished by deposition of new layers at the edge of the valve, with growth along the entire circumference of each valve (e.g., Quitmyer et al. 1997). Patterns of incremental growth and geochemical analyses of the increments can be used to assess human environmental impacts, and former environments.

Episodic growth is recorded in hard tissues as alternating broad and narrow increments. To observe increments in bivalves, for example, a valve is cross-sectioned along the axis of greatest growth: a line from the umbo to the ventral margin (Fig. 11.11; Cannon and Burchell 2009; Quitmyer and Jones 1992:248, 249). Under reflected light (incident illumination), increments appear to be alternating wide, light bands and narrow, dark ones. Under polarized transmitted light, they look like alternating wide, opaque bands and narrow, translucent ones. Thus, growth increments are described in terms of contrasting pairs that are wide or narrow, translucent or opaque, white or black, dark or light. These differences reflect the mineral density and organizational structure of the increments and are interpreted as evidence of alternating cycles of fast and slow growth. As in wood, a pair of adjacent narrow and broad increments may be referred to as an annulus (e.g., Carré et al. 2009; Claassen 1998:152–174; Chap. 8). Confusion in the characterization of increments reflects differing procedures that use either reflected or polarized transmitted light to examine stained or unstained specimens, as well as traditions at specific laboratories and among the disciplines that study these phenomena.

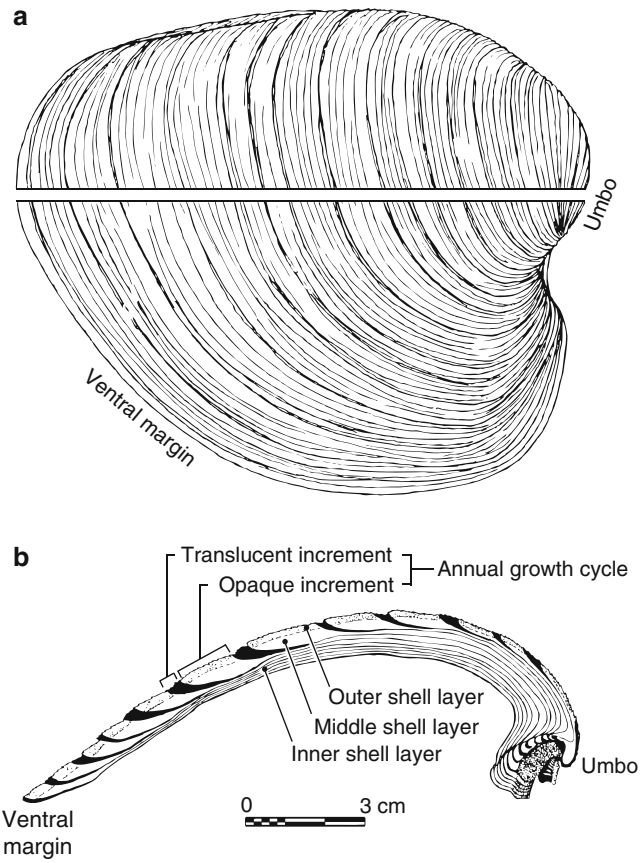


Fig. 11.11 A southern quahog (*Mercenaria campechiensis*) showing: (**a**) where it was sectioned; and (**b**) a side view of the section. The section shows the narrow (translucent) growth increments associated with slow growth and broader (opaque) increments associated with more rapid growth, as seen under transmitted light. These represent an annual growth cycle. Drawn by Merald Clark. Reproduced from Quitmyer and Jones (1992:248, 249); used by courtesy of Irvy R. Quitmyer and William H. Marquardt

Growth is not constant; it responds to tidal, daily, seasonal, and annual rhythms; physiological stresses related to reproduction and predation; changes in salinity, oxygen, turbidity, and suspended sediments associated with floods and droughts; biomechanical stresses; migration patterns; latitude; and nutritional status (Andrus 2011; Jones et al. 1989). At a broad level, increments appear to reflect episodic environmental conditions that are repetitive, patterned, and associated with temperature and temperature-sensitive variables. Variations occur among individuals within the same species and among populations, reflecting responses to local conditions and clinal differences. Older individuals tend to display less distinct growth patterns compared with younger ones (e.g., Jones et al. 1989).

True annuli correspond to a prolonged period of reduced growth, or a lengthy resting state, alternating with a period of increased growth. They are continuous

over extended portions of the specimen and lack fine, undulating lines. False annuli, incomplete annuli, annuli reabsorbed later in life, and irregular annuli in older animals all complicate such characterizations, just as they do in woods and other structures that grow episodically. Some of these are records of smaller growth cycles within each major episode as the animal responds to events of shorter duration, such as tidal cycles.

Major increments often are discussed as though they were entirely seasonal and referred to by terms that reflect this assumption (Culleton et al. 2009). In the northern hemisphere, for example, broad bands may be referred to as "summer" increments and narrow ones as "winter" increments. Environmental conditions favoring growth in cold, temperate, and tropical environments may differ considerably; some organisms find cool conditions more optimal for rapid growth than warm ones. A more neutral approach refers to increments in terms of fast and slow growth. Although caution needs to be exercised when equating increments with temperature and season, the relationship between water temperature and growth is verified in many aquatic species by examining the oxygen isotopic composition of calcium carbonate, such as those in the increments of mollusc valves and fish **otoliths** (aragonitic ear structures; e.g., Andrus 2011; Hallmann et al. 2009; Chap. 13).

Average temperature and precipitation regimes are two features that define seasons and climates (Andrus 2011). These vary from 1 year to the next within a broader range; warm or dry weather can persist well into a season that might normally be cool or wet, for example. Calendrical seasons based on lunar cycles may not precisely match average temperatures and humidity for that season. Seasonal definitions are problematic because of the loose association between calendrical dates and dynamic cycles of warmer/cooler or wetter/drier conditions. Although growth can be broadly associated with calendrical months in modern studies, even these studies find individual variations and strong deviations from seasonal averages (e.g., Culleton et al. 2009). Carré et al. (2009), however, are able to correlate growth during tidal cycles with the lunar cycle in archaeological specimens from Quebrada de los Burros (Peru). This enables them to determine the months when molluscs were gathered, an interpretation verified by oxygen isotopic profiles.

In some cases, the number of annuli correlates with the age of the animal, and characteristics of the final increment may indicate the growth stage the animal was in when it died (e.g., Cannon and Burchell 2009; Claassen 1998:25–26; Quitmyer et al. 1997). Age is estimated by counting the major pairs of fast growth and slow growth increments. The very earliest growth increments may be disorganized due to rapid juvenile growth, but a larger problem lies with annuli at the end of life, such as those along the outer, ventral margin of a mollusc valve. Growth in older individuals may be so slow or erratic that the final increments cannot be assessed. Some organisms may not grow each year or may grow throughout the year. In archaeological specimens, the exposed margin may be eroded by physical and chemical site formation processes and further damaged during excavation and subsequent handling. When this is the case, it may be impossible to assess age at death or characterize the last stage(s) of growth.

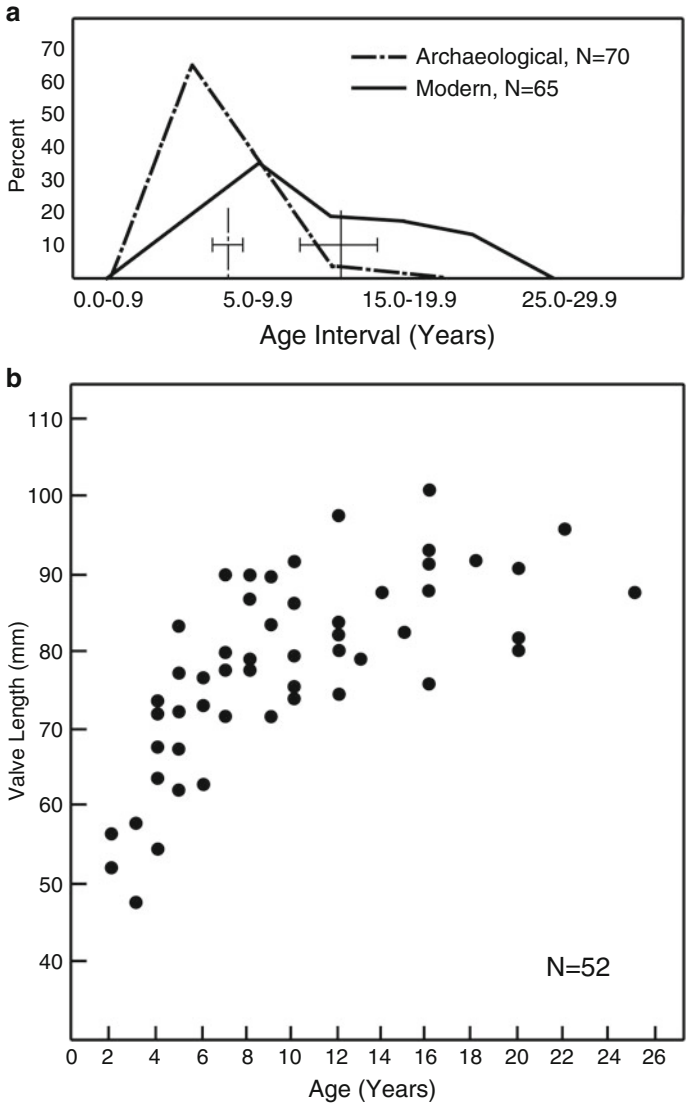


Fig. 11.12 Characteristics of northern quahogs (*Mercenaria mercenaria*) based on increment counts and measurements of modern and archaeological (AD 1000–1500) clams from Kings Bay, Georgia (USA): (**a**) age intervals based on increment counts of modern clams compared with archaeological ones (*vertical bars* indicate means and *horizontal ones* indicate one standard deviation); and (**b**) scatter diagram showing the relationship between valve length and age. Modified from Quitmyer et al. (1985:34); © 1985 by the Southeastern Archaeological Conference and used by courtesy of the authors and *Southeastern Archaeology*

The number of increments may be a more reliable indicator of age than the size of the animal (Fig. 11.12; Quitmyer et al. 1985:34). Size can reflect life history strategies in specific habitats reflecting reproductive status, parasitism, population density, mortality rates, capacity for individual plasticity, competition, mutualism, nutrition, predation, and other parameters that affect growth in populations and individuals within populations. Growth may be quite different at the margins of an animal's range compared with a more optimal part of the range; or from 1 year to the next. Individuals may stop growing if conditions are too stressful, a habit that affects not only the association of age with size, but also that between age and the number or form of annuli.

Site Formation Processes

Site formation processes affect relationships between life and study assemblages of molluscs and echinoderms (Davies 2008:2–3; Evans 1972:15–24; Wolverton et al. 2010). The study assemblage is not a controlled sample of the life assemblage in the way that a modern field sample of a living community would be. Several questions must be asked. Was the organism part of the local community? Was it brought to the site intentionally or was it attached to something? If it was brought to the site intentionally, was it dead or alive? What was the cultural role of each specimen? In what way has time-averaging affected the deposit?

Many processes deposit, move, damage, and destroy mollusc and echinoderm remains. Accumulations of these animals often are found along lakeshores, riverbanks, and coastlines. In these dynamic settings, the composition and location of such deposits may be altered. One issue associated with these accumulations is whether they are produced by natural processes or by human behavior. Are they in situ communities that now lie above the water line; are they accumulations from a wider area, left by rising (or falling) sea levels, tides, storms, currents, wind, and waves; or is the accumulation an archaeological site? Sometimes the organization of valves within the matrix (e.g., articulated valves) and other components can clarify the processes that formed or altered a deposit (e.g., Rosendahl et al. 2007). Resolution of these questions benefits from knowledge about sediments and soils as well as analysis of the associated material culture.

Readers familiar with the huge mounds of molluscs found in some locations (e.g., Brazilian sambaquis; Okumura and Eggers 2005) may equate molluscs with excellent preservation of other organic materials that require alkaline conditions. In reality, molluscs decompose and the survival of other organic materials is linked to the dissolution or conversion of calcite and aragonite, which in turn reflects the chemical environment. Calcite is more common than aragonite, less soluble and more stable at ambient temperatures, and less dense (lighter; Vermeij 1993:45; Weiner 2010:76–77). After death, aragonite converts to calcite at temperatures below 30°C and may be replaced by other minerals (Claassen 1998:60–61). The shells of freshwater molluscs and terrestrial gastropods are mainly aragonite

(Weiner 2010:80), one explanation for their sometimes poor preservation. Calcite dissolution is associated with cold waters, acidic waters, and high salinities (Vermeij 1993:47–48). Aragonite structures dissolve more quickly than calcite ones in such settings. At high temperatures, the reverse occurs (Weiner 2010:78).

Heating, especially direct exposure to heat (e.g., cooking), alters chemical and structural properties of these materials. This makes specimens exposed to heat unsuitable for isotopic or incremental growth studies (Claassen 1998:61–66, 96; Weiner 2010:78, 80). Calcium carbonate materials exposed to fire may be very fragile and chalky.

Concentrations of molluscs may confound multiproxy studies by contributing to pH levels that preserve some organic materials and destroy others. Calcite and aragonite reach equilibrium in water at approximately pH 8.2 (Weiner 2010:77). Their dissolution maintains a buffered environment with high pH that enhances the preservation of organic materials requiring alkaline environments to survive, such as vertebrate skeletal and dental materials. This prolongs the preservation of vertebrate remains, for which large aquatic shell deposits are famous. It works against the preservation of organic remains that survive best in acidic conditions, however. Pollen and phytoliths are poorly preserved in contexts saturated with carbonates or with a very high pH, conditions often found in deposits containing molluscs. Pollen grains and phytoliths are particularly vulnerable to decay when high carbonates and high alkalinity occur in conjunction with high temperatures and rainfall, conditions found at many tropical and subtropical sites. Calcite skeletons with high percentages of magnesium, such as those of echinoderms, are particularly unstable (Claassen 1998:60–61). The poor preservation of some terrestrial gastropods is attributed to their thin periostracum, which may be destroyed in oxic conditions but survive in anoxic ones (e.g., wells, ditches, peat deposits; Carter 1990). The apparent regional distribution and abundance of terrestrial gastropods may be functions of such soil conditions.

Mollusc valves, which may be very large objects, keep deposits open-textured, which facilitates drainage and atmospheric permeation, as well as permitting smaller items to filter downward. Consequently, shell-rich deposits tend to be well-oxidized and leached; and small items may be clustered in the lower levels.

Physical attributes, such as shape and structure, are associated with survival potential (Claassen 1998:54–66; Vermeij 1993:45). Mechanical damage is caused by trampling, abrasion, and compression as the weight of overlying sediments increases over time. Postdepositional fluctuations in temperature and moisture are never optimal for the survival of organic materials, including mollusc and echinoderm remains.

Distinguishing between anthropogenic and nonanthropogenic modifications and deposition requires familiarity with both the archaeological context and the outcomes of human and nonhuman activities (e.g., Claassen 1998:55–60, 71; Rigaud et al. 2009). Mollusc and echinoderm specimens are modified by predators and parasites, which include algae, crustaceans, and vertebrates, in addition to other molluscs and echinoderms. Some animals, such as hermit crabs (*Coenobita clypeatus*), modify shells to live in them. Other animals, such as worms, arthropods, birds, and

mammals, accumulate or move shells for other reasons. Some alterations may be the cause of death (e.g., boring) or occur after death (e.g., boring, root etching). These processes not only modify specimens, but mix and sort them, destroying their temporal, spatial, and ecological associations (e.g., Carter 1990).

Distinctions between autochthonous and allochthonous organisms are important when interpreting molluscs and echinoderms for environmental information. Terrestrial snails are good examples of this distinction. They live in soil, in leaf litter, on herbaceous plants, in tree canopies, and on walls, among other settings. At death, most of these snails, irrespective of the habitat they preferred during life, fall to the ground and become what may appear to be members of the soil community. This can alter the environmental interpretation because these dead snails are not recovered from the habitat or the community they occupied in life. Although some terrestrial snails have very specific habitat preferences, others are able to live in a variety of conditions, masking synchronic and diachronic distribution patterns related to environmental change and land use (e.g., Davies 2008:159–179).

People use these animals for many purposes, many of which are not obvious from the taxonomic identification itself and some of which have little or nothing to do with human diet. The same species can be a source of foods, ornaments, and dyes. Shells from abalone (*Haliotis midae*) were used to produce and store a liquefied ochre-rich mixture at Blombos Cave, South Africa, in tool kits that included bone, charcoal, and lithic materials (Henshilwood et al. 2011). Molluscs often are used in building materials such as **tabby** (a shell, lime, and water mixture that dries into a concrete-like substance), in lime production, or in gardens, pathways, and ceramics. This does not preclude the possibility that the meat was eaten before the shell was used for these other purposes. Fossil shells may be brought to the site as curios or embedded in limestone used in buildings. They may come from sediments underlying the site. People, of course, remove shells from older sites to reuse them elsewhere, much as they do timbers, stones, and bricks. Long-distance trade in ornamental shells was, and continues to be, active. Though these uses are intrinsically interesting, the resulting deposited assemblage may not be appropriate for environmental or dietary studies.

Other anthropogenic processes affect molluscs and echinoderms. Handling and processing in the past influences the materials, as does subsequent discard., excavation, and analysis. The study assemblage generally represents only part of the acquisition, processing, consumption, and disposal continuum. Mollusc valves, for example, may be discarded at the collection location and only the meat transported to the consumption site; or the meat may be consumed at ephemeral, special use sites, such as dinner-time camps (Meehan 1982). Shell ornaments may have been manufactured at a distant location so that the manufacturing stages are not represented at the site from which the object is recovered. In other cases, molluscs were collected from habitats that were considerable distances from residential sites, but were brought back to the residential site intact, even though the primary use was as food (e.g., Andrus and Thompson 2012).

At least some molluscs and echinoderms were originally collected intentionally as live animals; others are encrusting organisms (**epibionts**) or accidental inclu-

sions. Symbiotic organisms may be brought to the site unintentionally because they were attached to plants or animals brought to the site. For example, when clumps of molluscs, such as oysters, are brought to the site, some of the oysters and other animals may be alive and some may be dead. Only the living oysters may be used as food, but the encrusting organisms and the dead oysters will both be discarded at the site, perhaps in the same context. All may subsequently be used to establish a walkway or build a courtyard. In other cases, dead animals may be brought to the site intentionally to be used in adornments, lamps, net weights, architectural features, and other applications (e.g., Deshpande-Mukherjee 2005; Rigaud et al. 2009; Wilkens 2005).

Field Considerations

Crustaceans, molluscs, and echinoderms can be very common in coastal and freshwater sites, representing a considerable challenge to time, facilities, and funds. It is far better to anticipate the logistical problems huge quantities of shell pose and to develop an appropriate strategy in advance that will facilitate rather than hamper quantification and analysis. To assess the cultural and environmental roles of these animals, it is important that the ability to combine invertebrate and vertebrate evidence not be compromised.

Because their recovery and processing can be costly, the tendency is to ignore them, to take a subsample, or to take a "random representative sample" or a "grab" sample. Unsystematic, idiosyncratic recovery is particularly problematic because it generally means that only specimens attracting someone's attention are collected. Analysis is hampered by such incomplete or inconsistent sampling and processing methods. Subsequent researchers may not know that "random" in this sense does not meet the statistical definition of random sampling. This approach leaves a large portion of the environmental and cultural evidence unexplored. Biased sampling strategies preclude quantitative analysis and may lead to incorrect interpretations.

Opportunities for interpretation are further limited by inadequate descriptions of the contexts from which the remains are recovered. It is difficult to interpret mollusc and echinoderm remains if detailed information about the archaeological context of the study assemblage is unavailable from maps, profiles, field notes, and other descriptions. In the lab, a sample of shells from a pavement made of clam valves may look like any other bag of clams without such notes.

Many of these animals are small and even some large ones, such as chitons and echinoderms, separate into much smaller segments once the animal dies. Plates, tests, valves, and Aristotle's lanterns decompose into dozens of small specimens that will not be recovered using typical screen sizes. Many of these specimens are too small to be recovered during normal dry-screening. Mollusc and echinoderm fragments of every size may sink or float in unpredictable ways when the flotation protocols typically used for botanical remains are relied upon for recovery of all

small materials. Assemblages of molluscs and echinoderms in flotation samples generally are considered unreliable for most interpretations.

Often soil samples are used as the primary way to recover small molluscs and many echinoderm fragments. In the case of terrestrial gastropods, soil samples should be taken from both the archaeological site and the surrounding area to assess anthropogenic influences on these organisms and to distinguish between animals from nearby habitats and those from more distant ones. Point sampling is recommended for contexts that are particularly likely to produce terrestrial gastropods. Boring generally is not advisable because of the damage done to specimens and mixing that may occur, but, in some cases, the deposits are too deep for any other approach.

Intact mollusc valves should be handled with care because undamaged margins are necessary to estimate age and growth stage at death and to observe wear that might be associated with use. The margin is the preferred location for some isotopic analyses. If the margin is damaged, as it often is, it may not be possible to pursue studies that require intact margins.

Environmental archaeologists working with large animals often approach field sampling from a fundamentally different perspective than do those working with fungi, plants, and small animals such as arthropods and terrestrial snails. Studies of large invertebrates and vertebrates often rely on very large samples taken from a few contexts, perhaps from only one or two column samples. Studies of smaller organisms often are based on many small samples taken from multiple contexts, such as pinch samples and point samples. Both approaches are compromises associated with considerable biases (e.g., Orton 2000:153–154). All environmental archaeologists would prefer to study large samples from the full range of functional, spatial, temporal, and behavioral contexts, but have developed different strategies to accommodate limited time, funds, and skilled staff. The inability of what are usually only a few column samples to test the full range of archaeological contexts at a site is yet another obstacle to multiproxy studies, which are highly desirable in theory but difficult to achieve in practice.

Instead of advocating for one approach over another, we recommend employing collection strategies guided by thoughtful research designs that ensure consistency, replicability, and comparability beyond a single taxonomic group, field season, or archaeological site. The sampling strategy should be informed by the needs of all of the environmental archaeologists working on the materials, be understood by all of them, and be described clearly in reports and publications.

Laboratory Procedures

Analysis of molluscs and echinoderms relies on good sampling, correct identifications, and comparisons with modern analogues of living and dead assemblages to interpret environmental and cultural aspects of archaeological collections.

In some cases, laboratory procedures are very similar to those applied to sediments, soils, and other organic materials.

Preparation

Most mollusc and echinoderm remains require little or no preparation in the laboratory, unless they are recovered in "whole" soil samples. As a general rule, samples need only be washed and dried, though materials recovered from wet, frozen, or desiccated contexts may require special handling. It may be necessary to screen soil samples through nested screens. In some cases, a form of controlled flotation can be used. One such approach involves cleaning gently, pouring off into a nest of screens of various mesh diameters, adding chemicals to produce a froth, additional rinsing, and finally drying (Davies 2008:5–6). Other techniques may be used depending on the specific characteristics of the deposits and organic remains (e.g., Claassen 1998:89–90).

Sites rich in molluscs and echinoderms can produce thousands of fragments, most of which cannot be identified beyond phylum. A decision should be made whether the study requires sorting and identifying all of these fragments, can be limited to a predetermined list of diagnostic portions, such as the apex, the umbo, or the hemipyramid, or can be limited to a predetermined list of taxa most likely to have distinctive incremental structures (e.g., compare Davies 2008:6 with Giovas 2009). The choice of which taxa or portions to select during sorting is based on the research design, characteristics of the study assemblage, and anatomical aspects of the organisms themselves. It is desirable to facilitate compatibility with similar studies and to anticipate the need to replicate the current study when deciding which taxa or portions to select. Highly idiosyncratic and inconsistent choices are undesirable. If sorting is restricted to a specified list of taxa or portions, the sorting staff must be able to recognize those specimens in fragmentary materials. The resulting reports and publications should clearly specify whether sorting and identification were restricted or a thorough study of all specimens was undertaken.

Restricting the study to a predetermined list may be a practical way to manage limited resources, but it precludes some analyses (Giovas 2009). For example, it biases comparisons among taxa if all taxa are not studied, or if allowances are not made for anatomical differences among taxa. Ideally, some of the unstudied fraction will be kept for future study. The decision about how to handle the thousands of unstudied fragments should be guided by project objectives and policies of the curatorial facility. If the unsorted, unstudied materials will be discarded, at the very least this fraction should be weighed.

The number of specimens to examine is best defined by the research objectives. There are two aspects of sample size: the size needed to reliably reflect the relative abundance of significant taxa and the size required to detect rare taxa (Pearsall 2000:112). Much larger samples are needed if the objective is to ensure that as many rare taxa as possible are included in the study. In some cases, sample size is

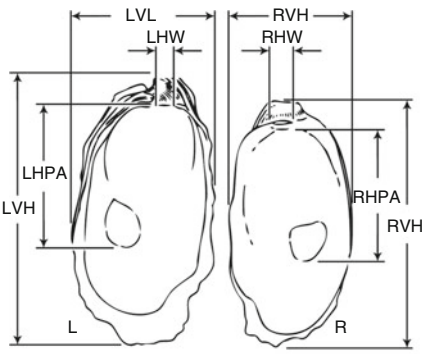
established by a specified standard count: the number of specimens or the volume of material that will be studied is determined in advance. Davies (2008:5), for example, recommends processing raw sediment samples for terrestrial snails until at least 150 shells per sample are recovered.

Identification

The excellent reference books and illustrated keys available for many molluscs and some echinoderms cannot replace reference collections. The pretty, perfect shells illustrated in these references generally bear little resemblance to archaeological fragments. Most publications focus on adults and illustrate features of living molluscs and echinoderms that seldom survive in the archaeological state, such as color and soft-tissue anatomy. The reference collection should more closely approximate the appearance of archaeological materials and include multiple specimens of different sizes in different stages of preservation. Some molluscs are very sensitive to environmental changes, and many coastal and terrestrial locations have changed markedly over time (e.g., Martin 2005). To capture individual and clinal variations, specimens should be from all of the habitats the species occupies throughout its modern range, including marginal ones, not just the habitat where the organism flourishes today. To capture environmental change, reference collections should include taxa from ecosystems that once might have been present near the site. It should include examples of organisms from more distant locations, animals that are exotic to the locale today, anticipating that some shells were important trade goods. The analyst should be prepared to recognize the important evidence of exchange networks, social relationships, and ritual behavior embedded in these materials.

Identifications usually are based on characteristics such as shell shape; sculpturing; the number, location, and appearance of teeth; size; and the number of body whorls. Identification and subsequent analysis rely on symmetry and other aspects of these animals. The anterior and posterior plates of chitons are distinctive and can be identified with a relatively high degree of precision. Typically the apex, aperture, opercula, and columella or umbilicus of gastropods are diagnostic, as are the hinge and umbo of bivalves. Some valves have diagnostic shapes or sculpturing. For echinoderms, identification may focus on components of the Aristotle's lantern. If identifications are based on selected portions of molluscs and echinoderms, a record should be kept of taxa observed in the collection but represented by other portions, and, consequently, omitted from the taxonomic list.

Measurements of length, width, or thickness of specific parts may facilitate identification (Fig. 11.13; Jerardino and Navarro 2008; Reitz and Wing 2008:383). Measurements should be thoroughly described, accompanied by an illustration showing the landmarks and terminology used, and be replicable. Preference should



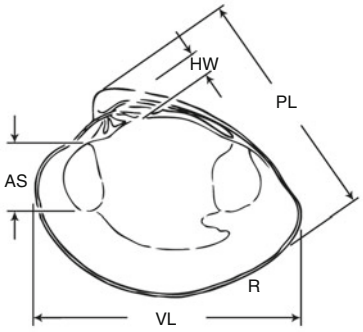
Crassostrea virginica

LEFT VALVE

LVH	=	left valve height.
LHPA	=	left valve hinge plate to posterior adductor muscle scar. This is along the greatest axis between the two landmarks.
LVL	=	left valve length.
LHW	=	left hinge width.

RIGHT VALVE

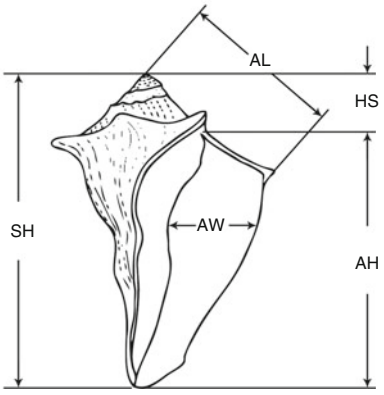
RVH	=	right valve height.
RHPA	=	right valve hinge plate to posterior adductor muscle scar. This is along the greatest axis between the two landmarks.
RVL	=	right valve length.
RHW	=	right hinge width.



Mercenaria spp.

RIGHT VALVE

PL	=	length of the posterior slope - from the umbo to the posterior margin along the greatest growth axis.
HW	=	hinge width.
VL	=	valve length.
AS	=	anterior adductor muscle scar. This is taken from the greatest growth axis.



Busycon carica

SH	=	shell height.
AL	=	apex to lip.
HS	=	height of spire.
AH	=	aperture height.
AW	=	aperture width.

Fig. 11.13 Some standard measurements for eastern oyster (*Crassostrea virginica*), quahog (*Mercenaria*), and knobbed whelk (*Busycon carica*). Used by courtesy of Irvy R. Quitmyer

be given to standardized measurements that conform to published guidelines (e.g., Claassen 1998:109–110). Measurements of chitons can be taken of the greatest width of each valve, or of just the anterior and posterior plates. With gastropods, measurements may be of the shell height, the distance between the apex and the

lip, aperture height, and aperture width. For bivalves, valve height, length, and hinge width are measured, as are dimensions of the muscle scar. For echinoderms, parts of Aristotle's lantern can be measured (Campbell 2008a). Many archaeological specimens are fragmented and other dimensions may be more practical, such as aperture length or umbo height. Restricting identifications to a predetermined list of diagnostic portions may preclude metrical studies if the portions studied do not include measurable dimensions.

Analytical Procedures

Analysis is based on primary data such as the taxonomic attribution of the animals in the study assemblage, the number of taxa present (richness), the anatomical portions represented, specimen count (NISP), specimen weight, measurements, and modifications. Secondary data such as ratios, minimum number of individual (MNI), dietary estimates, diversity, and equitability are derived from these primary observations. Analysis is enhanced by corroborative evidence from other organisms as well as sediments and soils.

Other than ubiquity, most analysis builds upon NISP and weight, from which ratios and other secondary data are derived. All of the chiton's plates can be counted. Often only gastropod apices and bivalve hinges are counted; a procedure that should be reported along with the data. Bivalves usually are bilaterally symmetrical, though some, such as oysters, may have one valve that is larger than the other one. In either case, it is possible to refine the description and count of most bivalves by noting the number of left and right valves. In the case of echinoderms, fragments of tests, spines, and the components of Aristotle's lantern can be described and counted. Specimen weight should be recorded for all of the material. These procedures may need to be altered if the study is restricted to a predetermined list of taxa or diagnostic portions.

Much analysis is based on estimates of MNI, an approach that is more developed and widespread in the study of molluscs and vertebrates than it is for other animals, though it can be applied to other animals (e.g., Osborne 1983; Chap. 10). MNI is an estimate of the smallest number of individuals necessary to account for all of the specimens of a particular taxon in the collection (Reitz and Wing 2008:205–210). Unlike NISP, which communicates the actual number of specimens observed in the study assemblage, MNI is solely an analytical product. This numerical estimate of individuals should not be confused with an actual number of individuals in living, death, and deposited assemblages. To estimate MNI, the analyst considers not only taxonomic attributions and the portions represented in each sample, but also spatial and temporal aspects of the archaeological context, symmetry, age, and size. It is for this reason that the portions in the study assemblage are described and why it is necessary to indicate whether the specimen is from the left or right side, or is unique in the organism (e.g., the anterior plate of a chiton, a columella).

The advantages and disadvantages of MNI for molluscs, and for vertebrates, are widely discussed in the literature and will not be repeated here (see Reitz and Wing 2008:205–210 for a review) except to mention the relationship between MNI and excavation strategies. Estimates of MNI rely upon definitions of analytical units that in turn rely on interpretations of archaeological contexts and relationships between excavation units and cultural behavior. MNI is influenced by the manner in which data from archaeological contexts are aggregated during analysis. The aggregation of separate archaeological samples into a single unit of analysis ("minimum distinction") offers a conservative estimate of MNI, whereas the "maximum distinction method," in which MNI is estimated for each archaeological sample, yields a much higher estimate of MNI (Grayson 1984:31). Thus, two important components of aggregation are field decisions about where to place excavation units and whether to use arbitrary or natural levels during excavation. The analyst should know how excavation units and levels relate to cultural activity at the site before estimating MNI and the basis for aggregation should always be described in reports and publications.

Analytical samples are defined by the research problem and the site's occupational time line, as well as the number and placement of excavation units. As the objective of environmental archaeology usually is to study former environments and cultures, cultural units are the preferred units of analysis rather than the units and levels that guide excavation. At some point, site stratigraphy, absolute and relative dates, material culture, and other information about the site obtained by excavation and subsequent analysis define behavioral units and those behavioral units should replace the unit names, feature numbers, and depth measurements that are critical management tools in the field. This requires coordination among the researchers working on materials from the site, but is essential for an anthropological analysis.

If invertebrate remains are interpreted as food debris, invariably the next question concerns their dietary role compared with other organisms. By and large, estimates of dietary contribution focus on meat weight and not on the broader dietary spectrum, which includes calories, fats, proteins, vitamins, and minerals from a much wider array of nutritional sources. Most of the methods used to estimate meat weight rely upon one of three types of data: MNI, the size of the animal, or specimen weight (Reitz and Wing 2008:233–242). Applications that use MNI to estimate dietary contribution multiply the known meat weight of a typical modern species by that species' MNI estimate. Because molluscs and echinoderms grow indeterminately, the choice of a typical body size is problematic. Original body size and meat weight can be estimated for animals that grow indeterminately by using allometric equations in which known values are either measurements reflecting the overall size of the animal, edible meat, or specimen weight (Reitz and Wing 2008:234–237). In the first case, measured dimensions of archaeological specimens are used to estimate the size or dietary contribution of individual animals using a formulae based on the relationship between that dimension and size or meat weight in modern taxa. Often, however, "individuals" are not the appropriate unit of measurement, especially when meat is exchanged through cultural networks or

transportation costs encourage people to leave less-valued portions at the procurement or processing location. When it is likely that only a portion of the animal was consumed, specimen weight can be used to estimate meat weight using a formula based on the relationship between specimen weight and meat weight in modern taxa. In each case, the quantity of meat for a given body size is obtained from live weight and meat weight data archived with the reference collection. Zoological collections may not have these data, one of the many reasons to develop reference collections tailored specifically to the needs of archaeological applications. Meat weight can be converted into broader nutritional values, but seldom is.

Measurements not only are used to estimate dietary contributions, but also the original body size of animals, their growth habits, and growth rates. Some changes in body dimensions are related to stresses such as predation, crowding and competition for food and shelter, or disease. Morphological variations in the shape and size of aquatic organisms reflect latitude, location in the water column, and ambient water conditions. Changes in population structure related to size may be a normal part of the species' maturation cycle, so that the age of the animal can be estimated from its body dimensions (e.g., Campbell 2008b). A change in a species' body size over time may indicate that human predation focused on a different age cohort or habitat, or used a different collection technology. Response to increased predation, or a decline in predation, or changes in other ecosystem processes influence body size and other aspects of growth and reproduction. Juveniles and adults often have distinct habits and occupy different habitats (e.g., Campbell 2008b). Proportions of young individuals to older ones may be linked to reproductive strategies. For example, high numbers of juveniles, characteristic of *r*-strategies, may indicate an unstable or transient environment, whereas low numbers of juveniles, suggesting *K*-strategies, could be evidence of a more stable environment (e.g., Davies 2008:62; Chap. 1).

Measurements can be correlated with growth increments to estimate the size of an animal at a specific age, providing evidence of growth rates. In the case of animals that live approximately 1 year, such as the impressed odostome (*Boonea impressa*), size may indicate when during the year the animal died (Russo 1991). The impressed odostome is an epibiont of eastern oysters (*Crassostrea virginica*). These small gastropods (less than 1 cm) begin life in late spring or early summer and grow throughout their brief lives. Most members of an age cohort would be at about the same stage in their annual growth cycle and have a similar size, at any specific time of year. They feed on oysters along the Atlantic and Gulf coasts of North America. The season of death of odostomes, indicated by their total length, may be evidence for the season of death for the oysters to which they were attached; bearing in mind that oysters in this region grow primarily in clumps that contain both living and dead animals.

The type and source of fragmentation, wear, and other modifications provide information about many aspects of human behavior and postdepositional events. Fragmentation levels, portions represented, fracture types, and similar modifications illuminate site formation processes, especially butchering and food preparation techniques (e.g., Campbell 2008b). Shells serve utilitarian and nonutilitarian uses as

scoops, lamps, fish hooks, gorges, trumpets, and emblems of status, for example. Wear patterns provide evidence for such usages and may be a key feature to distinguish among these functions. The animal itself may be used as bait, which may produce accumulations of shell along the water's edge as the resulting waste is discarded (Claassen 1998:10–11). A similar accumulation, with similar modifications, may be created if the meat of shellfish is extracted along the water's edge to reduce the amount of weight that must be transported elsewhere (e.g., Newsom and Wing 2004:71).

Evidence may be sought for a change in the resource base or in the use of resources by measuring richness, diversity, and equitability (Reitz and Wing 2008:245–247). This approach combines data on numbers of categories (taxa) and abundance within each category to describe the heterogeneity (diversity) of the assemblage. Diversity is the relative number of individuals for each taxon. Equitability measures the distribution of numbers across taxa; it is a proxy measure of degree of dependence on the specific resources and the effective variety of organisms used at the site based on the even, or uneven, use of individual taxa. General patterns of taxonomic richness, diversity, and equitability are not only characteristic of communities and ecosystems, but also are associated with social complexity, particularly stratification. Changes in these attributes may be evidence of a stressed ecosystem or economy.

Several different measures are used to assess diversity and equitability. Two of the most common are the Shannon-Weaver Index (Shannon and Weaver 1949:14) and the Sheldon Index (Sheldon 1969). These indices allow discussion of economies in terms of the variety of resources used by people at the site and the emphasis placed on each. Diversity increases as the number of taxa increases or equitability decreases. A sample with many taxa in which the number of individuals slowly declines from most abundant to least abundant is considered highly diverse. Diversity is increased by adding a new taxon to the list, but if another individual of a taxon that is already present is added, diversity decreases. Low diversity indicates either few taxa were used, or one of the taxa was used more heavily than other taxa in the sample (low equitability). A high equitability indicates an even distribution of taxa in the sample. The probability of adding rare taxa may increase as the sample size increases (Fig. 3.7).

Complex interactions of the same environmental factors that affect shape and size underlie habitat preferences. Some molluscs and echinoderms are indicator taxa or members of indicator groups or packages because they have narrow habitat preferences and their presence documents that a specific habitat was nearby or exploited. Others taxa have broadly similar preferences that overlap and form an ecological group. Such groups may indicate the presence of specific conditions such as caves, dry valleys, or moist ditches (e.g., Evans 1972). Changes in indicator species or ecological groups may indicate environmental changes (e.g., Davies 2008:62–63).

Most presentations of mollusc and echinoderm data are similar to pollen diagrams. The vertical axis on the left shows the depth below the modern soil surface or some other datum point (Fig. 11.14; Davies 2008:110). One of the vertical axes

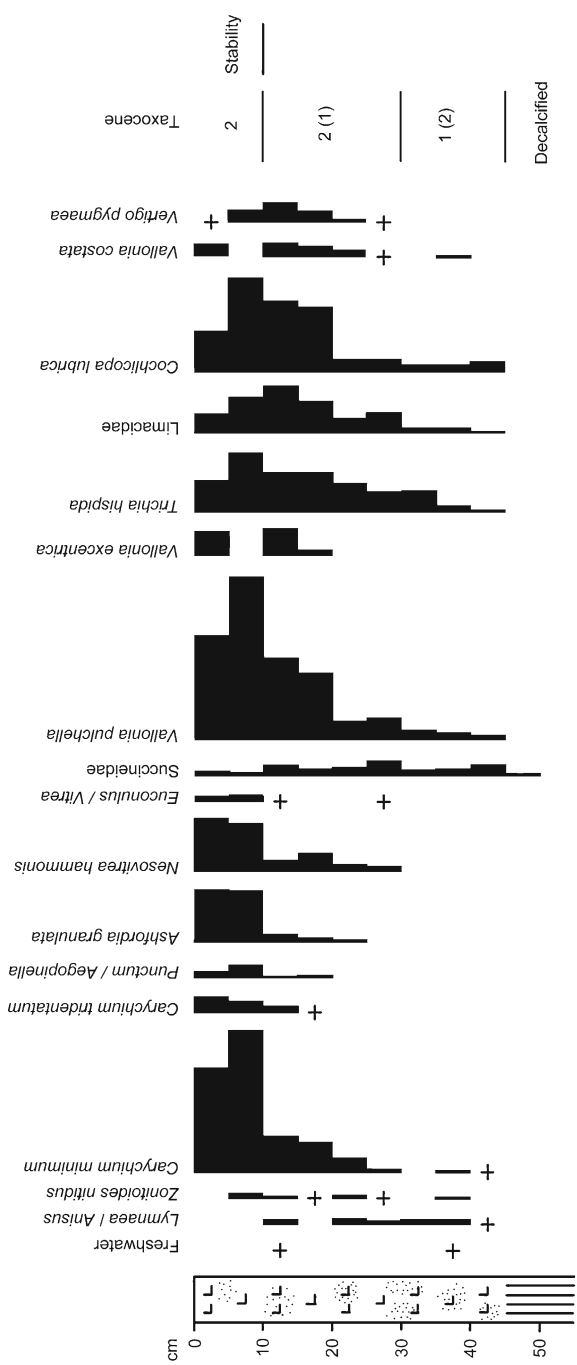


Fig. 11.14 Number of wet-ground mollusc specimens in an overbank alluvial sequence from Itchen Stoke Mill (Hampshire, UK) indicates a change in landscape from open, dry, pasture-like conditions with low-magnitude winter flooding (taxocene 1) to a structurally more diverse, open, wetter setting with higher magnitude winter flooding than taxocene 1, characteristic of a meadow or abandoned pasture-like conditions (taxocene 2). *Plus* indicates groups or taxa that are present, but rare. From Davies (2003; 2008:110); © 2003 by Taylor & Francis Books and used by courtesy of the author and Taylor & Francis Books UK

may include a schematized characterization of the stratigraphy. The lower horizontal axis summarizes data, and the upper horizontal axis lists individual taxa or taxa summarized into groups that represent habitat preferences, climatic preferences, or other variables important to the research. Data may be divided into ecological zones defined by the dominant taxa or by the overall assemblage. In Fig. 11.14, Davies (2008:102, 110) defines **taxocenes** to evaluate molluscs from the Itchen Stoke Mill site (Hampshire, UK). These are ecologically related groups of taxa known to have been associated in the past (Davies 2008:61–64, 102; Wilkinson and Stevens 2003:122). Figure 11.14 shows a transition from taxocene 1 to taxocene 2. Data may be NISP, as in Fig. 11.14, specimen weight, or MNI estimates, and be presented as either relative or absolute values. Measurements may be presented in the form of histograms that plot measurements against NISP to show temporal or spatial variations in the size of the organism. Tables are used to communicate more precise data, such as volume of sediment studied.

Applications

Size is a primary characteristic used to obtain taxonomic attributions and is a primary source of evidence for foraging strategies and responses to environmental degradation, domestication, climate change, seasonal resource use, overexploitation, and other factors. Size generally is estimated from measurements traditionally used by zoologists (e.g., Losey et al. 2004). Unfortunately, most of these standard measurements require complete specimens and cannot be applied to fragmented archaeological materials. Jerardino and Navarro (2008) address this problem in their study of limpets from coastal archaeological sites in South Africa. They note that limpets are present in small numbers at many sites, but that it is difficult, if not impossible, to obtain statistically reliable sample sizes using standard zoological measurements. They observe that fragmentation appears to affect larger limpet valves more than smaller ones, which could skew interpretations of population dynamics if only the more complete, smaller limpets were examined. The authors query whether morphometric "landmarks" that are both reliable predictors of body size and likely to survive site formation processes can be identified so that fragmentary archaeological valves can be used in population studies. Jerardino and Navarro (2008) develop landmarks for use in archaeological applications from modern reference specimens for seven limpet species, in most instances measuring specimens collected from each taxon's entire modern zoogeographical range. Their technique enables them to capture gradients in environmental parameters such as temperature, salinity, and turbidity that fall within the tolerance level of the animal. They identify several dimensions that typically survive intact even on fragmented valves (Fig. 11.15; Jerardino and Navarro 2008:1025). Their approach allows them to include measurements of two of the most common limpet species in shell deposits on the west coast of South Africa (Fig. 11.16; Jerardino and Navarro 2008:1027). Because they could include broken as well as whole valves, they have larger sample

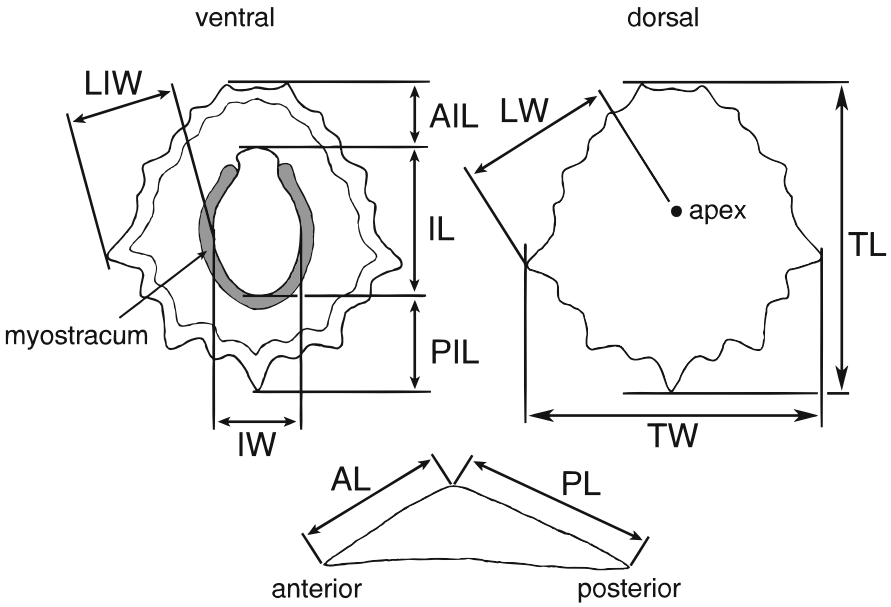


Fig. 11.15 Measurements obtained from limpet (*Cymbula*, *Scutellastra*) shells on both ventral and dorsal sides for the purpose of establishing morphometric equations. *TL* total length; *TW* total width; *AL* anterior length; *PL* posterior length; *LW* lateral width; *AIL* anterior inner length; *IL* inner length; *PIL* posterior inner length; *IW* inner width; *LIW* lateral inner width. Lateral width and lateral inner width were not measured on oval-shaped shells. From Jerardino and Navarro (2008:1025) and used by courtesy of the authors and Elsevier

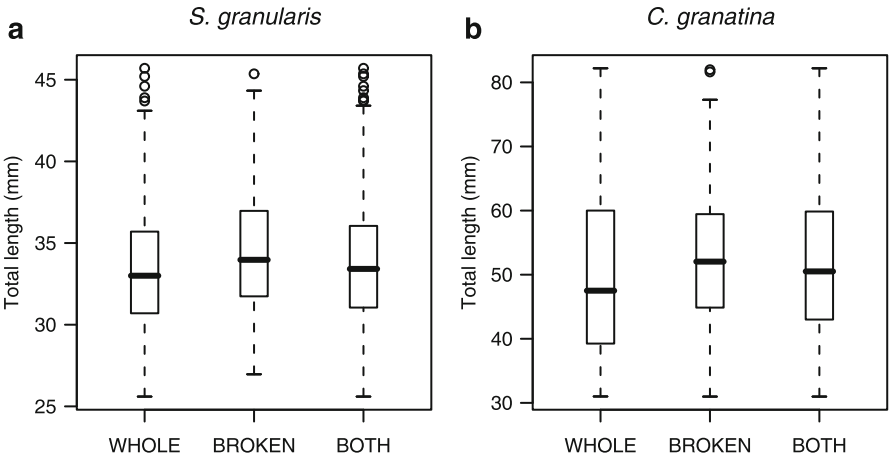


Fig. 11.16 Box-and-whisker plot of total shell length of whole and broken valves of two limpets: (**a**) *Scutellastra granularis*; and (**b**) *Cymbula granatina*, showing lower and upper quartiles (*box*), the median (*line across the box*), and the range (whiskers). Extreme values are shown as *circles*. From Jerardino and Navarro (2008:1027) and used by courtesy of the authors and Elsevier

sizes and can show that whole shells tend to be from smaller limpets and broken ones tend to be from larger ones, supporting a more reliable study of preservation biases and population-wide variations.

Some invertebrates can be used to track environmental changes because of their sensitivity to physical and chemical properties of their environments. Marriner et al. (2008) combine sediments, foraminifera, ostracods, and molluscs in their study of a seaport complex associated with the Phoenician city-state of Tyre (Lebanon) founded in the third millennium BC. To study the geomorphological evolution of the seaport, the research team drilled stratigraphic cores along the margins of the present-day harbor. The cores recovered organisms from several habitats (fresh water, brackish and marine lagoons, exposed coastline) and substrates (gravels, sands, silts, clays). Changes in these materials indicate that the seaport experienced siltation, **progradation** (seaward advance of a delta or coastline), tectonic subsidence, and other modifications through the Holocene. Marriner et al. (2008) suggest that an ancient northern harbor was maintained by Roman and Byzantine dredging, which removed part of the stratigraphic sequence. Some of the dredged material was used as fill within the city and in making ceramics. The seaport complex deteriorated to such an extent during the sixth to ninth centuries AD that it was exposed to the sea. Political instability could have been responsible for some of this deterioration, but natural catastrophes such as tectonic events and tsunamis also may have been responsible. Tyre was founded on an offshore island, but this island became joined to the mainland as a consequence of some of these processes. Much of the evidence for the evolution of the seaport is now under the Medieval and modern city centers. The researchers conclude that the seaport complex was more dynamic than previously thought and about twice its current size.

The causes, processes, and consequences of domestication are primary foci of environmental archaeology. Two of the chief characteristics of domestication are changes in body size and frequencies in key taxa. Reductions in body size and average age at harvest, combined with changes in relative abundance, are reported for molluscs at archaeological sites in many parts of the world, a pattern often interpreted as evidence for resource depletion or resource depression. This interpretation is based on assumptions that small individuals in archaeological deposits indicate younger animals were harvested, that young animals provide less meat, and that using such young animals results in a lower return for effort, all of which are thought to indicate exploitation of a resource experiencing stress. Whitaker (2008) considers whether the reduction in body size observed in archaeological specimens of the marine California mussel (*Mytilus californianus*) might be evidence of incipient aquaculture instead. The California mussel is sessile, grows quickly, lives in large, dense patches, and is ubiquitous in archaeological assemblages in the Pacific coast states of California (USA), Oregon (USA), and Washington (USA). Domestic dogs (*Canis familiaris*) were present and the productivity of wild grasses (Gramineae [Poaceae]) and oaks (*Quercus*) may have been encouraged, suggesting some familiarity with the needs of managed organisms and raising the possibility that other organisms were managed. Whitaker (2008) reports differences in the cumulative percentages of shell sizes observed when two different collection techniques are

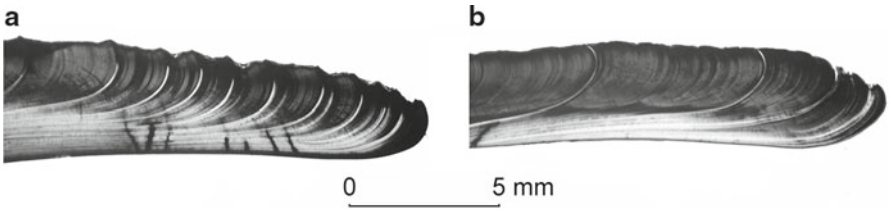


Fig. 11.17 Examples of (**a**) senile; and (**b**) mature growth-stage butter clam (*Saxidomus giganteus*) shells. From Cannon and Burchell (2009:1053) and used by courtesy the authors and Elsevier

used on modern populations of mussels. In the plucking technique, the largest individual mussels are collected and the bed left in a fallow period of a few months before another round of harvesting. Using the stripping technique, an entire section of the bed is harvested, collecting all body sizes, followed by a multiyear fallow period. Whitaker (2008) compares hypothetical stripping and plucking models derived from modern biological data with experimental tests of plucking and stripping and archaeological data from the Punta Gorda Rockshelter (California, USA; cal AD 1217–1420). He reports finding no decrease in mean shell size or relative occurrence. The author interprets this as evidence that people optimized long-term net productivity by stripping beds at 24-month intervals rather than maximizing short-term returns by plucking. He suggests this strategy could be considered incipient aquaculture, an alternative to resource depression as an explanation for reduced body sizes.

A similar interpretation is drawn by Cannon and Burchell (2009) from their study of growth-stage profiles of butter clams (*Saxidomus giganteus*) recovered from Pacific coastal sites in British Columbia (Canada). The authors construct growth profiles from the number, width, and spacing of final growth increments on the ventral margin (Fig. 11.17; Cannon and Burchell 2009:1053). They report that clams deposited at residential sites were older (senile) than the mature-stage clams recovered from short-term encampments (Fig. 11.18; Cannon and Burchell 2009:1055). They interpret this as evidence for different levels of harvest intensity. Less intensive harvests near residential sites suggest that foraging populations intentionally selected, managed, and conserved butter clams for at least 7,000 years. This may be evidence that individuals or kin groups owned resource locales (Cannon and Burchell 2009) or perhaps that an early mariculture tradition was practiced (Williams 2006).

Molluscs are widely regarded as ornaments, but distinguishing between invertebrates used as food and those used for other purposes can be a challenge. Wilkens (2005) examines molluscs recovered from Sumhuram (Oman), an important commercial center founded in the first century BC. The fortified city's fortunes declined after siltation closed the harbor, and it was abandoned by the fourth century AD. The mollusc remains include chitons, gastropods, bivalves, and cuttlefishes, most of which were used as food. One gastropod, the swollen olive (*Oliva bulbosa*), is both common in the collection and perforated in a pattern that suggests use as beads or net weights, however. *Oliva* specimens are perforated

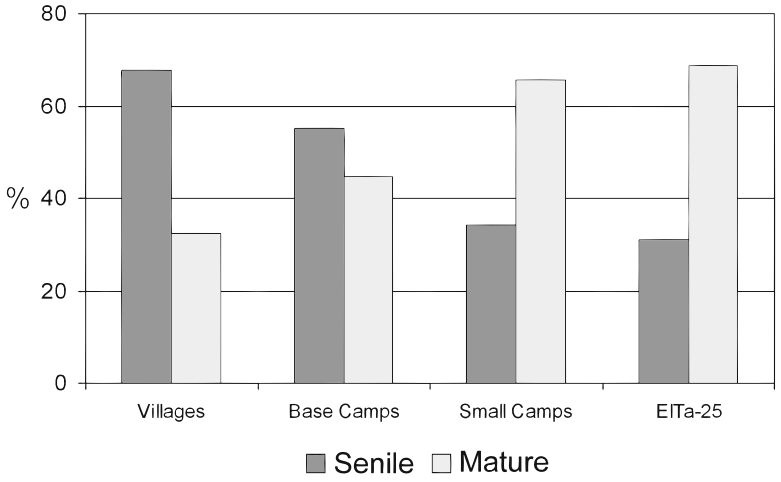


Fig. 11.18 Relative proportions of mature and senile clam shell sections by site type. EITa-25 is a small camp site that may have been occupied specifically to harvest and process clams. From Cannon and Burchell (2009:1055) and used by courtesy of the authors and Elsevier

at the apex and down the length of the shell. Both the apex and the siphonal canal show signs of wear, as though the shells were strung together. Other characteristics of *Oliva*, and of other molluscs, suggest that dead shells were collected from the beach.

Elsewhere, the distance between inland sites and the coast is so great that it is more likely marine molluscs were obtained through long-distance trade or other contacts with coastal communities and were used as ornaments rather than as food. Deshpande-Mukherjee (2005) draw such a conclusion for Chalcolithic farming sites (2000–700 BC) in the Deccan region (India). Although marine mollusc shells, bangles, beads, pendants, and debitage are uncommon or absent at most inland sites in the region, their use as charms, amulets, and luxury goods combined with the effort required to obtain these rare goods suggest they were highly valued.

Molluscs are used to produce dyes. Ruscillo (2005) examines the production steps required to make "Royal Purple" dye from the gastropod *Murex* [*Hexaplex*] *trunculus*. Purple, blue, and red dyes are produced from a variety of organisms, including other molluscs, dyer's madder (*Rubia tinctorum*), and lichens. In the Americas, purple is derived from a scale insect known as cochineal (*Dactylopius coccus*). Textiles dyed with *Murex* were highly valued symbols of status and traded widely throughout the Aegean region and the Near East from the Bronze Age until early Byzantine times. *Murex* dye eventually was replaced by less expensive dyes. The procedures used to produce dye from *Murex* were poorly understood until Ruscillo's experimental work. Kommos, Palaikastro, Knossos, and other sites on Crete (Greece) yield thousands of crushed *Murex* shells. Ruscillo (2005) tested several locations and methods for collecting living *M. trunculus*. She obtained enough snails to extract dye only with some difficulty. The snails had to be kept

alive until the hypobranchial gland was removed. Removing the gland requires making a hole in the body whorl of the snail, which produces a large pile of gastropod shells with characteristics similar to those in archaeological specimens. Her replication finds that wool is the best fabric for obtaining deep colors. Ruscillo (2005) reports that by modifying the production steps slightly, she also can produce the color known as "Biblical Blue," sacred in antiquity as well as today. Making dye from *Murex* yields what Ruscillo (2005:105) describes as "a terrible odour," which is transferred to the fabric. Ruscillo (2005) suggests that the wealthy, influential people whose garments were dyed with *Murex* might be eager to purchase perfumes. She found that the dye could be used for temporary tattooing; hands remained stained for as long as 6 weeks.

Summary

Molluscs and echinoderms contribute to research objectives intended to reconstruct former environments, trace ecosystem transformations, establish land-use histories, evaluate subsistence strategies, and consider other aspects of human–environmental interactions. The study of molluscs and echinoderms is particularly valuable when combined with sediments, soils, and other organisms for an overall picture of change and continuity in environments and cultures. Molluscs and echinoderms document the highly diverse and dynamic environments in which these organisms live and can be used to track environmental changes because of their sensitivity to physical and chemical properties of those environments. In some locations, marine mollusc beds may have been owned and managed to ensure long-term productivity, much as predicted for early stages in plant domestication. As the applications show, molluscs serve many other cultural roles. Some of these spatial and temporal characteristics, and the human role in forming them, are elaborated upon with reference to vertebrates in the next chapter.

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Chapter 12
Vertebrates

Vertebrate skeletal, dental, and other materials often are relatively well-preserved and visible in archaeological sites, adding substantially to what we learn from other archaeological evidence. They are important sources of information about change and continuity in environments, site functions, and cultures over time and through space.

As with other organisms, environmental information is derived from evidence for vertebrate growth habits and growth rates. Vertebrates with indeterminate growth respond episodically to favorable or unfavorable conditions, which may leave distinctive increments in skeletal and dental specimens. Episodic growth occurs in teeth of some vertebrates with determinate growth. As with episodic growth in other organisms, this may be associated with broad ecosystem processes, climate patterns, and other environmental factors. Some vertebrate materials (e.g., otoliths) contain calcium carbonate, which offers a palaeothermometer for assessing climate cycles and former temperature regimes. The age of the animal at death and the season of death may be estimated from these and other aspects of growth. In many cases, growth rates and the body size achieved by each age cohort are associated with rates of reproduction and predation. This knowledge can be converted into survivorship and mortality curves to analyze ecosystem processes, identify habitats exploited, interpret human predation and culling strategies, and infer technologies used to capture specific animals or groups of animals.

A significant body of research focuses on economic decisions and cultural institutions related to vertebrate use. Decisions about balancing terrestrial and aquatic resources, primary and secondary products, domestic and wild resources, preferred and less preferred menu items, dietary and nondietary products, or plant and animal resources, for example, are important aspects of human behavior. Cultural responses to seasonal habits of targeted animals and environmental change are particularly interesting. Skeletal specimens and skin materials provide insights into the sources and uses of raw materials, manufacturing processes, and the value of secondary products, such as wool, skins, blood, and dairy products. Vertebrate remains provide information about residential patterns, exchange systems, and cultural roles and

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norms linked to status, ethnicity, and belief systems. Some vertebrates are symbols of human attributes, such as bravery, cunning, and intelligence; meanings that may be communicated in rites of passage, feasting, and other ritual behaviors. Many aspects of vertebrate use affect human and environmental health.

The stimuli, processes, and consequences of animal domestication are particularly important aspects of economies, cultural innovations, social institutions, and residential patterns. Criteria involved in domestication may be milk or meat quality, draft ability, tolerance to disease and pests, docility, productivity, or a color pattern that bears a social message. If the sources and timing of early domestic animals can be defined, this may clarify trade and migration routes, or periods of colonization.

Both nonhuman and human remains are included in this chapter because of the frequency with which human remains are found in vertebrate collections; similarities in anatomy; common taphonomic, field, and laboratory considerations; and the contributions of both human and nonhuman materials to environmental and cultural interpretations. Some scholars question whether human remains fall within the scope of environmental archaeology (see Derevenski 2001). From a strictly biological perspective, human skeletal and dental systems can be studied in the same way as other vertebrate remains, though many aspects of human biology are best considered by researchers experienced in such studies. Biological anthropologists and environmental archaeologists have mutual research interests, however, and their cooperation greatly enhances research in both disciplines.

Nomenclature

Chordates (Chordata; Table 12.1; Campbell et al. 2008:734; Nelson et al. 2004) are animals with bilateral symmetry and a dorsal nerve cord. The nerve cord is associated with a **notochord** (a flexible rod composed of fluid-filled cells and stiff, fibrous tissue) during at least part of the animal's development (Brusca and Brusca 2003:854–857; Campbell et al. 2008:699). The notochord provides skeletal support in adult forms of some chordates, but most retain only a vestige of the notochord, such as the gelatinous discs between the vertebrae of mammals.

Chordates include Urochordata (tunicates or sea squirts), Cephalochordata (lancelets), and Craniata (vertebrates). Urochordata and Cephalochordata are invertebrate chordates; they have a nerve cord that is not protected by a vertebral column (Brusca and Brusca 2003:854–855). Tunicates are primarily sessile marine organisms classified as chordates because of characteristics expressed in the larval stage, most of which are lost in adults. Lancelets are fish-like chordates that have a notochord, but do not have a vertebral column or a cranial skeleton. Neither tunicates nor lancelets have exoskeletons or endoskeletons.

The most familiar chordates are vertebrates, animals with vertebral columns and complex endoskeletons (Brusca and Brusca 2003:855). One group of vertebrates (Agnatha) lacks hinged jaws and teeth (Thain and Hickman 2004:15–16). Their skeletons are composed of **cartilage** (a connective tissue of proteins and carbohydrates) and their preservation in archaeological sites is rare. Agnatha include

Table 12.1 Classification of some chordates[a]

Category	Examples
Subphylum Urochordata	Tunicates, sea squirts
Subphylum Cephalochordata	Lancelets
Subphylum Craniata (Vertebrata)	Vertebrates
Myxini	Hagfishes
Cephalaspidomorphi	Lampreys
Chondrichthyes	Cartilaginous fishes, sharks, rays
Actinopterygii	Ray-finned fishes
Actinistia	Lobe-finned fishes, coelacanths
Dipnoi	Lungfishes
Amphibia	
Urodela	Salamanders
Anura	Frogs, toads
Apoda	Caecilians
Reptilia	
Crocodilia	Alligators, crocodiles
Squamata	Lizards, snakes
Testudines	Turtles
Sphenodontia	Tuataras
Aves	Birds
Mammalia	
Monotremata	Platypuses, echidnas
Marsupialia	Kangaroos, opossums, koalas
Insectivora	Moles, shrews
Chiroptera	Bats
Primates	Lemurs, monkeys, apes, humans
Xenarthra	Sloths, anteaters, armadillos
Lagomorpha	Rabbits, hares, pikas
Rodentia	Squirrels, beavers, mice, porcupines
Cetacea	Whales, dolphins, porpoises
Carnivora	Dogs, cats, weasels, otters
Pinnipedia	Walrus, sea lions, seals
Proboscidea	Elephants
Sirenia	Sea cows, manatees, dugongs
Perissodactyla	Horses, zebras, tapirs
Artiodactyla	Cattle, pigs, deer, giraffes

[a]Following Campbell et al. (2008:734) and Nelson et al. (2004)

hagfishes (Myxinidae) and lampreys (Petromyzontidae). Hagfishes have a notochord that is not protected by vertebrae and lampreys protect their notochord with a cartilaginous sheath.

Most vertebrates have hinged jaws and cranial skeletons (Gnathostomata). The notochord in adult gnathostomes is substantially reduced and the spinal cord is protected by a jointed vertebral column. Gnathostomes include Pisces and Tetrapoda. Pisces are cartilaginous fishes (Chondrichthyes) and ray-finned (or bony) fishes (Actinopterygii, formerly Osteichthyes). Tetrapods have four limbs, though these may

Table 12.2 Characteristics of vertebrate classes[a]

Mammalia	Vertebrae complex and differentiated along the column; centrum usually with flat articulating surface; usually a differentiated tooth row with teeth that have roots that fit in alveoli; fused cranium in adult
Aves	Vertebrae complex with differentiation along the column; saddle-shaped vertebral centra; mouth sheathed with keratinized epidermal beak; skeleton modified for flight
Reptilia	Some differentiation along the column; vertebrae vary greatly though many have centra that are concave anterior, convex posterior; in turtles the trunk vertebrae are fused to the shell; turtles have a keratinized beak; many reptiles, such as most lizards and snakes, have teeth anchored to the edge of the jaw; rooted teeth anchored in sockets occur among the crocodilians
Amphibia	Vertebrae of frogs and toads are reduced in number; typically the anterior centrum is concave and the posterior centrum is convex; tail vertebrae are fused into a single rod, and the ilium is greatly elongated; centra of salamanders are biconcave
Chondrichthyes	Calcified centra biconcave and cylindrical
Actinopterygii	Vertebral centra generally biconcave; vertebrae complex and differentiated along the column in advanced fishes; vertebrae simple, cylindrical, and undifferentiated along the column of primitive fishes

[a]From Reitz and Wing (2008:40) and used with permission of Cambridge University Press

be reduced or lost in adults (e.g., snakes [Serpentes]). Amphibians (Amphibia), reptiles (Reptilia), birds (Aves), and mammals (Mammalia) are tetrapods. Some classifications place reptiles and birds together as Reptilomorpha or Sauropsida because of their evolutionary histories (e.g., Brusca and Brusca 2003:855). Each of these classes is divided into orders and families with distinctive morphological characteristics that facilitate identification and analysis of archaeological remains (Table 12.2; Davis 1987:54; Reitz and Wing 2008:40) and some of which are illustrated in Figs. 12.1–12.3. It is to these animals that "vertebrate" refers in this volume.

Vertebrate hard tissues contain different proportions of inorganic (bone mineral) and organic (mostly protein) materials, in addition to water (Table 12.3; Alexander 1994:37–39; Davis 1987:48; Lyman 1994:72; Waldron 2009:14; Weiner 2010:104). These proportions generally reflect stresses typically experienced by each part of these systems; for example, the difference between a weight-bearing leg and a tooth. This means that most skeletal and dental tissues, even of many so-called cartilaginous fishes, are at least partially **calcified** or **ossified** with bone mineral. This bone mineral is carbonate commonly referred to as hydroxyapatite, or sometimes as hydroxylapatite or dahllite (Pollard and Heron 2008:272–2763; Weiner 2010:84–85, 102–104). Weiner (2010:84) notes that the widespread use of these terms is incorrect because they refer to the noncarbonated mineral form, which is rare in archaeological sites. He argues that bone mineral should be more correctly referred to as carbonate hydroxylapatite, and occasionally as carbonate fluorapatite. Bone mineral consists of calcium, phosphorus, oxygen, and hydrogen, which confers rigidity, hardness, and compressive strength to vertebrate structures. The organic component is primarily a fibrous structural protein (**collagen**) that confers toughness, resiliency, and elasticity. Specimens with a high percentage of bone mineral are more likely to survive in the archaeological record than are those with little mineral.

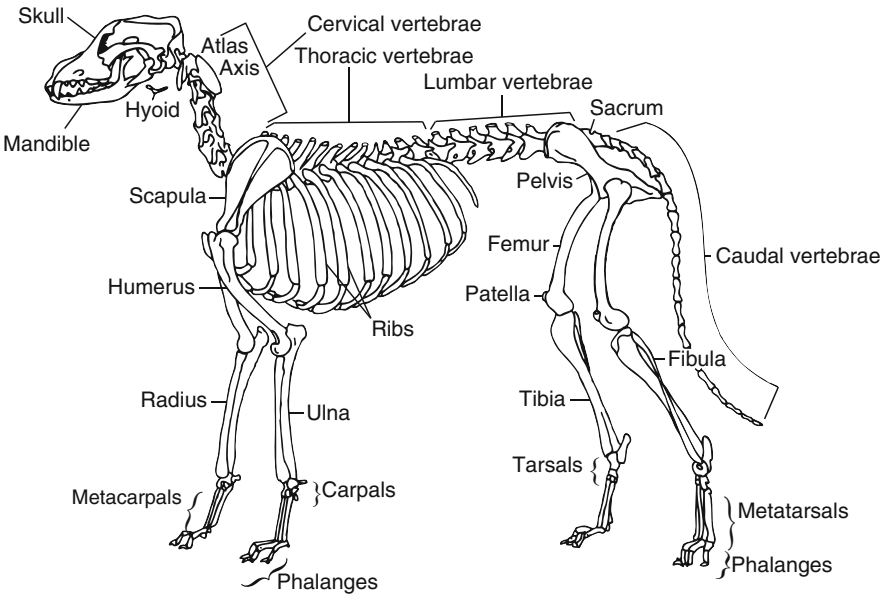

Fig. 12.1 Dog (*Canis familiaris*) skeleton with some elements labeled. Modified from Davis (1987:54); © 1987 by Yale University Press and used by courtesy of Simon J. M. Davis, Yale University Press, and Taylor & Francis Books UK. Drawn by Evelyn Davis

Some confusion may arise from the general use of the term "bone" to refer to different organizational levels of this living connective material, which range from whole skeletal elements, such as the tibia and the humerus, to the basic mineral constituents (Thain and Hickman 2004:92). The intent is usually clear from the context of each usage, but the diverse levels of meaning for the same term obscure the fact that skeletal and dental systems contain materials other than bone mineral and that these have different properties (Weiner 2010:102–110).

The primary constituents of vertebrate teeth are enamel, dentine, and cementum (Table 12.3). Teeth generally consist of an enamel exterior and a dentine interior (Fig. 12.4; Hillson 2005:146; Reitz and Wing 2008:47). **Enamel** is almost entirely inorganic and is one of the hardest biological materials known. Enamel protects the exposed surfaces of teeth, though it is found on the scales of some fishes. **Dentine** is softer than enamel because dentine has a higher percentage of collagen (Hillson 2005:8). Primary dentine lies beneath (is interior to) the enamel surface of teeth, surrounds pulp cavities and root canals, and forms as the tooth forms (Hillson 2005:184–189). Secondary dentine is continuously deposited in some animals. **Cementum** is a bone-like material with a bone mineral content similar to that of dentine. It forms on the exterior surfaces of roots and holds teeth in place (Wolff 1991:327–328).

Teeth are part of the digestive system. The diverse shapes, functions, number, and replacement sequences of teeth are useful for identifying them and estimating age at death for individuals (Fig. 12.5). Tooth shapes reflect feeding habits, prey

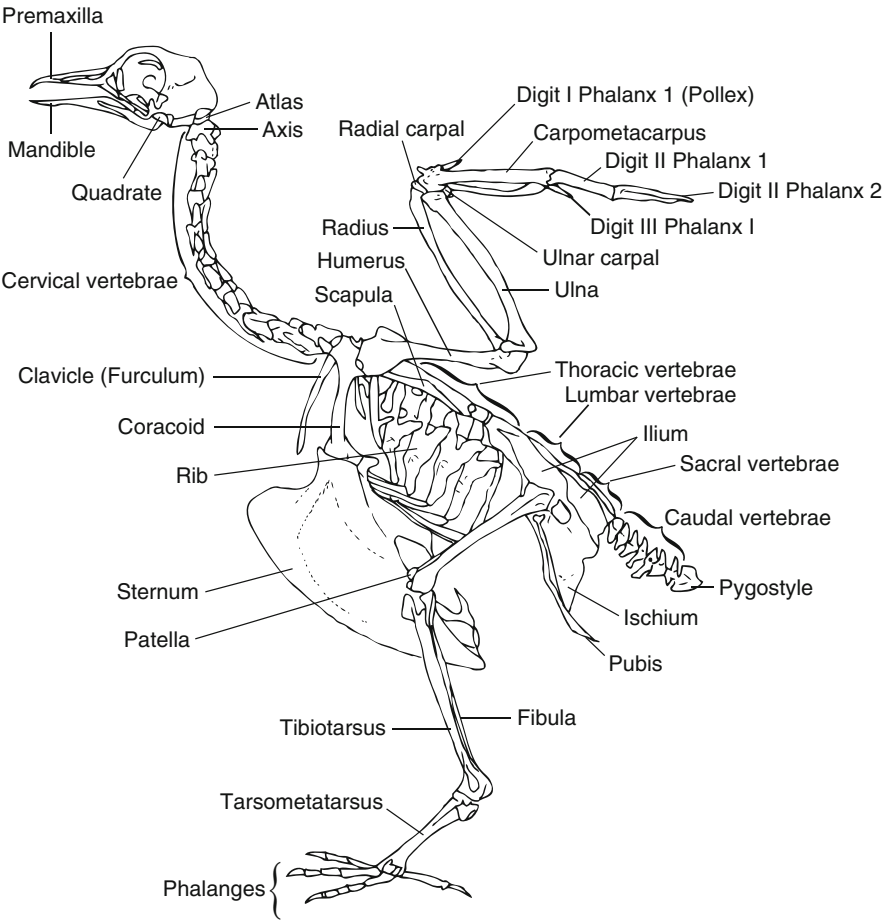

Fig. 12.2 Bird skeleton with some elements labeled. From Reitz and Wing (2008:364) and used by courtesy of Cambridge University Press

behavior, defense mechanisms, and reproductive displays. Carnivore teeth usually are sharp and pointed to capture, hold, and tear apart prey, for example. Herbivore teeth are commonly high-crowned and ridged to process plant material. Teeth with broad, crushing surfaces are found in vertebrates that eat molluscs. The multicusped molars of pigs (Suidae) and people are characteristic of omnivores. Some vertebrates, such as turtles and birds, have no teeth (**edentate**). Others have a few teeth that are replaced sequentially (e.g., elephants [Elephantidae]) or many teeth that are replaced as needed (e.g., sharks, fishes, snakes).

Many mammals have only two sets of teeth: juvenile and adult. Juvenile teeth are replaced as the individual matures, generally following a sequence that correlates with age. The sequence of replacement (**eruption sequence**), which teeth are replaced early and which are replaced later, and which teeth are present only in an adult form are generally the same for all mammals. The exact age at which specific

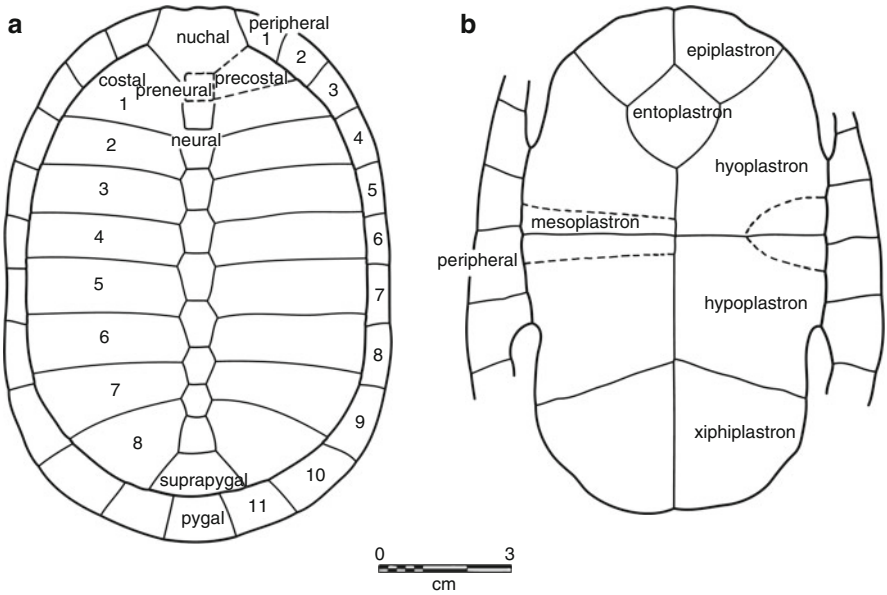

Fig. 12.3 Turtle (**a**) carapace and (**b**) plastron with some elements labeled. Illustration modified from Zangerl (1969:320)

Table 12.3 The relative percentage of organic and inorganic constituents of some vertebrate hard tissues[a]

Tissue	Organic percentage	Inorganic percentage
Tooth: enamel	0.5–4	96–99.5
Tooth: dentine	20–25	75–80
Tooth: cementum	35–40	65–70
Bone	35	65
Bone: young children	39	61
Bone: middle-aged people	34	66
Antler	41	59
Otolith	0	100

[a]Data from Alexander (1994:37–39), Davis (1987:48), and Lyman (1994:72)

juvenile teeth are replaced by adult teeth, however, reflects taxonomic affiliation, sex, health, and other factors associated with growth and development. There are, of course, many exceptions to this generalization.

Many sharks, rays, and ray-fined fishes are protected by dermal denticles or scales (Wheeler and Jones 1989:83–86, 116–120). **Placoid** (platelike) scales, in which each plate bears a small cusp, are common among sharks and related fishes. These very small scales may be referred to as **dermal denticles**. **Ganoid** scales are diamond-shaped and characteristic of gars (Lepisosteidae). **Cycloid** (thin, smooth discs) scales are roughly circular in shape and characteristic of many freshwater fishes, especially minnows (Cypriniformes), as well as codfishes and hakes (Gadiformes). **Ctenoid** scales bear small pointed projections (**ctenii**) along the

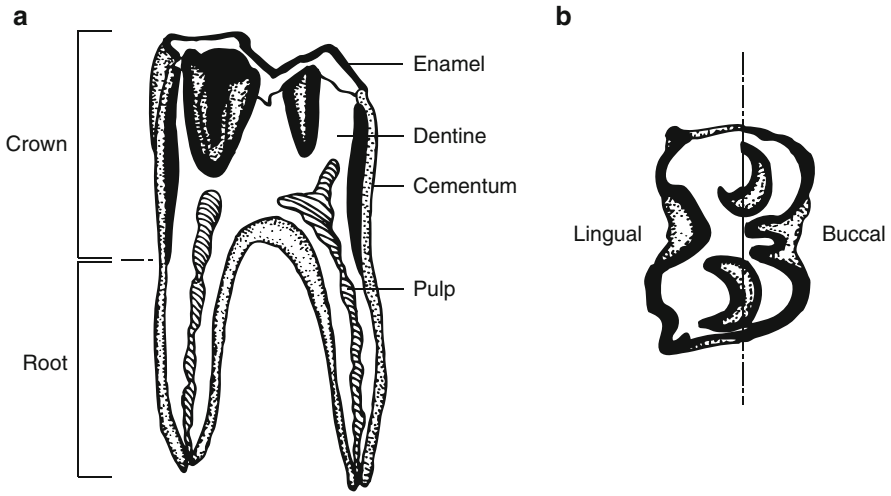

Fig. 12.4 Right lower first molar of a cow (*Bos taurus*): (**a**) cross-section; and (**b**) occlusal view indicting the position of the cross-section. The cross-section shows a view of the lingual half. Drawn by Virginia Carter Steadman. From Reitz and Wing (2008:47) and used by courtesy of Cambridge University Press

posterior margin and are common among perciform fishes (Perciformes) and flatfishes (Pleuronectiformes). Some scales form distinctive plates (e.g., boxfishes [Ostraciidae]) or spines (e.g., porcupinefishes [Diodontidae]). Most scales grow incrementally (Wheeler and Jones 1989:117–118).

Bone, cartilage, and keratin form the skeletal system. Bone contains higher percentages of collagen than teeth and lower percentages of bone mineral (Table 12.3). It is more flexible but not as durable as enamel or dentine, one reason why teeth are more likely to be found in archaeological deposits than are bones. Cartilage is almost entirely organic, containing relatively little bone mineral. Cartilaginous specimens that are partially calcified, such as shark and ray vertebrae, can be common in archaeological deposits. **Keratin** is a hard tissue composed of fibrous protein and is found in hair and hoofs, among other tissues.

Many mature skeletal elements consist of an interior area of **cancellous bone**, also known as **spongy** or **trabecular bone**, and an exterior surface of dense **compact** or **cortical bone** (Fig. 12.6; Steele and Bramblett 1988:11). Cancellous bone often is located at the ends of elements such as the humerus and femur, where it forms **trabeculae** (bars, plates, struts) that confer strength without adding much weight. The central (**medullary**) cavity and the network of cancellous bone containing marrow or fat are important in the production of red blood cells. Compact or cortical bone forms the outer surface of each element. Regions with thick compact bone are more durable than those with thin compact bone. The amount of cortical bone (**cortical area, CA**); the relative proportions of the medullary cavity or area (**MA**) to cortical and cancellous areas; and the overall shape of the element reflect biomechanical stresses experienced by the element in life (e.g., Larsen et al. 2001; Smith and Horwitz 1984).

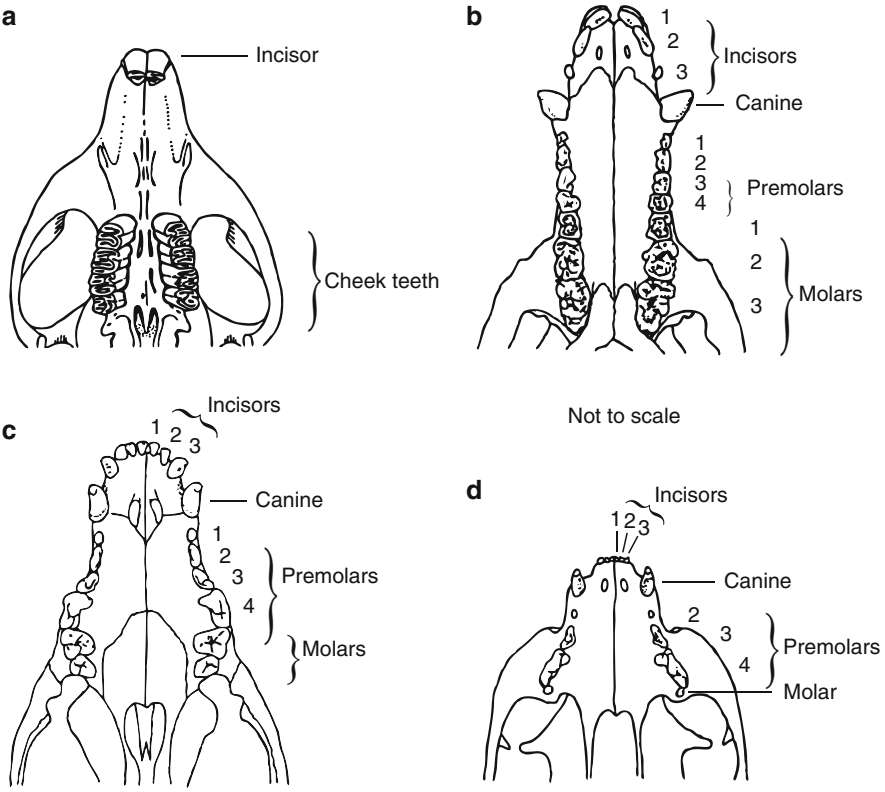

Fig. 12.5 Different mammalian dental characteristics in the upper dentition of (**a**) an herbivore (beaver [*Castor canadensis*]) with a long diastema, one incisor, and four cheek teeth, one of which is a premolar and three of which are molars; (**b**) an herbivore-omnivore (pig [*Sus domesticus*]) that is primarily an herbivore but will also eat animal tissue; (**c**) a carnivore (dog [*Canis familiaris*]); and (**d**) a specialized carnivore (cat [*Felis catus*]) with a reduced number of teeth and premolars specialized for shearing. Figures are not drawn to the same scale (**a**) drawn by Virginia Carter Steadman; (**b**–**d**) from Wolff (1991:367) and used by courtesy of Ronald G. Wolff

The spinal cord runs through a central neural canal in vertebrae, protected by a dorsal **neural arch** and a ventral **centrum** (Reitz and Wing 2008:362). Dorsal, ventral, and lateral processes extend from most vertebrae to provide attachments for the muscles and tendons of the back. The shape of the centrum, the location and shape of the processes, and the way vertebrae articulate with each other reflect patterns of movement typical of each animal.

Sharks, rays, bony fishes, amphibians, and reptiles grow indeterminately, though, as in other organisms, growth may slow as the individual ages or episodically during life in response to reproductive or other stresses. In animals with indeterminate growth, the size of the animal may correlate with age. Thus, small individuals of a fish species that typically grows very large can be interpreted as young animals. As with other aspects of development, growth rate is influenced by a number of factors, many of which are associated with clinal, nutritional, genetic, and individual variations. Rates of predation influence growth rates and the body size achieved by each age cohort.

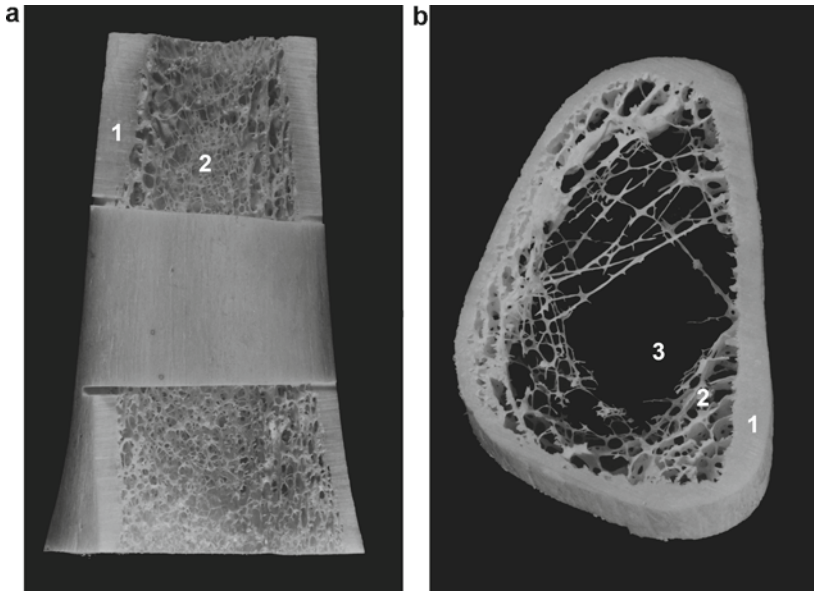

Fig. 12.6 Bone structure: (**a**) longitudinal section of a long bone, 1 cortex, 2 cancellous bone; and (**b**) cross-section of a long bone, 1 cortex, 2 cancellous bone, 3 medullary cavity. From Steele and Bramblett (1988:11) and used by courtesy of the authors and Texas A&M University Press

Birds and mammals experience determinate growth. Most, but not all, skeletal elements begin as a cartilage model that is replaced by bone mineral and other compounds as the animal matures (Weiner 2010:105–109). Replacement is experienced by many vertebrates to some extent, but it is particularly characteristic of birds and mammals. A typical example of this process is exemplified by a mammalian tibia (Fig. 12.7; Schmid 1972:153). The shaft of the tibia (singular: **diaphysis**; plural: diaphyses) grows in length and width as the cartilage model is replaced. At the same time, the ends of the element (singular: **epiphysis**; plural: epiphyses) enlarge and assume the adult shape. In many cases, a single diaphysis may have several epiphyses. When the element reaches adult size, the diaphysis and epiphyses fuse together and this type of growth ceases. The exact age at which epiphyseal fusion occurs depends on factors such as sex, nutrition, health, and environmental conditions, but the sequence of fusion (i.e., which aspect of which element fuses early and which fuses later) is similar among most mammals. The sequence may be similar among birds, though, as with mammals, growth rates are variable (Serjeantson 2009:38–40).

Age at death, estimated from growth rates, provides information about many aspects of the relationships between peoples and environments. Hunters, for example, may target, or avoid, a particular age group. Selective use of a specific age group is considered one of the attributes that distinguishes hunting, herding, and scavenging. Changes in maturation sequences may indicate responses by targeted animals to excessive (or reduced) predation rates or changes in other environmental features. In some cases, the maturation process is altered by animal husbandry. If husbandry methods provide improved nutrition and shelter from harm, animals may grow more

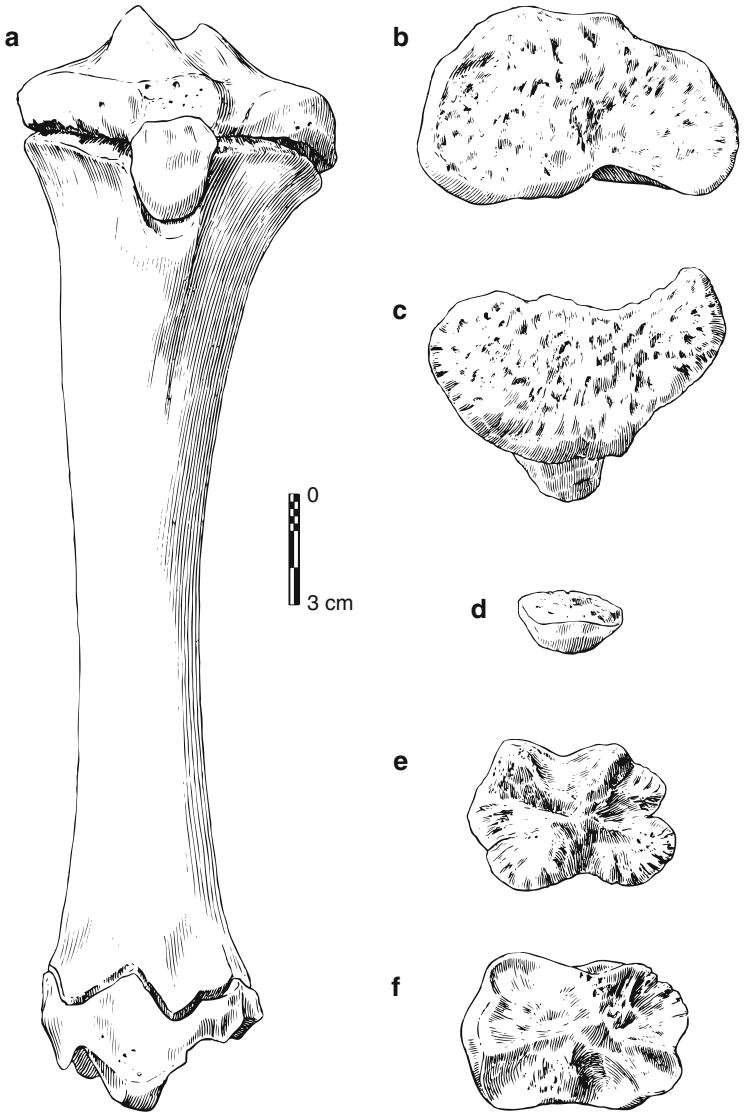

Fig. 12.7 The tibia of a young cow (*Bos taurus*) showing the diaphysis and the unfused epiphyses: (**a**) entire element; (**b**) ventral surface of the proximal epiphysis; (**c**) proximal surface of the diaphysis (the two rough surfaces of **b** and **c** fit together); (**d**) proximal anterior epiphysis; (**e**) distal surface of the diaphysis; and (**f**) proximal surface of the distal epiphysis. Reproduced from Schmid (1972:153)

rapidly and mature earlier. Castration of male animals (caponization in birds) alters stature and other aspects of the animal's growth, though the exact outcome depends on the age of the animal when it is castrated. Castration delays fusion and prolongs growth so that limbs become longer than they are in females and intact males. The resulting differences in size and shape are considered evidence of domestication.

Broadly speaking, elements grow throughout life in animals with indeterminate growth, but only in young individuals of animals with determinate growth. Bone, however, is a living material; it forms and is resorbed by a process known as **remodeling** (Waldron 2009:17–19). This allows even animals with determinate growth to respond to activity patterns and damage even as adults. Skeletal elements can respond to events that occur during adulthood, which distinguishes them from teeth because enamel and dentine do not remodel (Hillson 2005:185).

Some other skeletal elements provide evidence for age at death, season of death, and sex. Among these are the antlers and horns in ungulates (e.g., Artiodactyla, deer [Cervidae], cattle [Bovidae]). **Antlers** grow annually from **pedicels** (a pair of processes on the skull). Developing antlers are covered by vascularized skin (**velvet**), which transports minerals and proteins to the underlying skeletal element. When the antler reaches full size, the velvet dries and is rubbed off. The antler itself is shed when the mating season ends. In some cervids, only males grow antlers; in others, both males and females do. **Horn cores** are permanent, unbranched elements in males and often in females. These are covered by keratinized sheaths, are not shed, and grow throughout life. Buffaloes (*Bison*), gazelles (*Gazella*), ibexes (*Capra ibex*), and many other members of the bovid family have horns. Some domesticated bovids, such as sheep (*Ovis aries*) and some cattle (*Bos taurus*), may be **polled**; they have no horns though wild members of each genus do. Natural polling is one of the changes associated with domestication in some mammals, and artificial polling is a common husbandry practice. Pronghorn antelopes (*Antilocapra americana*) have permanent bone cores that are unusual because the keratinized sheaths are shed annually.

Some structures are associated with only one sex. A **baculum** (penis bone) is present in most male mammals, though subsequently lost in some groups, such as humans. Bony spurs develop on the tarsometatarsus of male gallinaceous birds (Galliformes) such as chickens (*Gallus gallus*), but are absent among most, though not all, females (hens). Among males (roosters), spurs increase in size with age (De Cupere et al. 2005). A calcified tissue found in the medullary cavity of birds is called **medullary bone** (Serjeantson 2009:49–50). This is a storage tissue for calcium and fat in female birds in egg-laying condition. Some animals have sexually dimorphic features associated with competition for mates, such as the enlarged canines of male pigs compared with female pigs. In some male turtles, the **plastron** (the ventral portion of the shell) is markedly concave to accommodate the female **carapace** (dorsal portion of the shell) during mating. Differences in the shape of pelvic elements are useful in distinguishing between males and females in some mammals, such as humans and sheep (e.g., González et al. 2007; Hatting 1995).

Many vertebrate tissues other than skeletal and dental specimens are studied by environmental archaeologists. These include otoliths, egg shells, keratinized structures, skin materials, and gastroliths. Most of these materials require advantageous site formation processes to preserve and careful field work to recover. When these materials do survive and are analyzed, they provide valuable perspectives on environments and cultures.

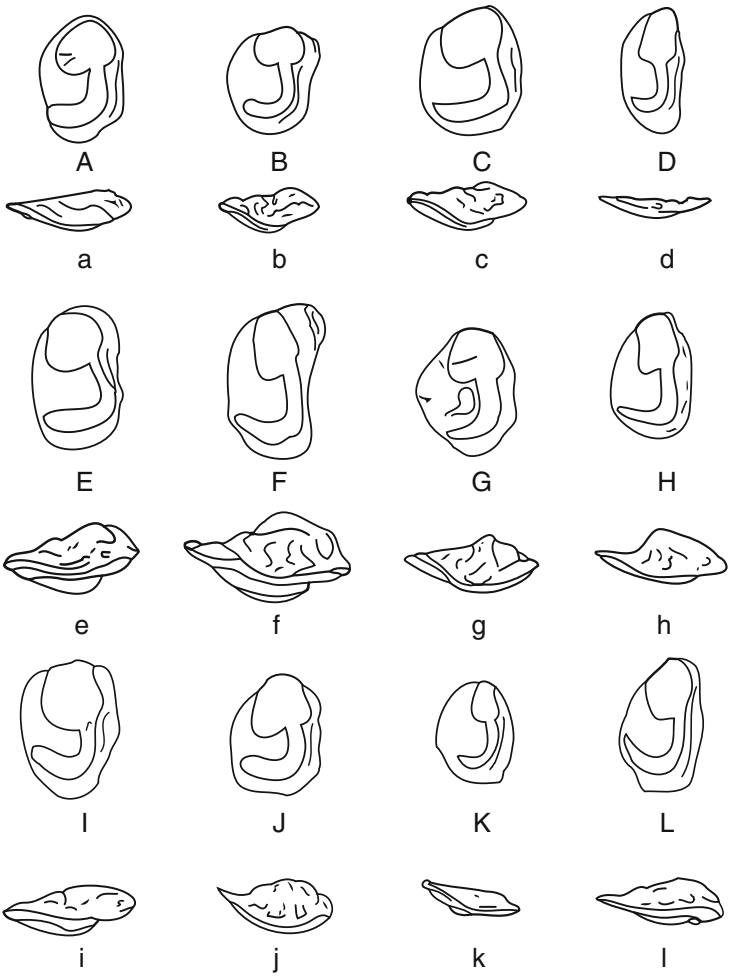

Fig. 12.8 Inner surface (*capital letters*) and lateral view (*lower case letters*) of sagittae following the *Sciaena* (Sciaenidae) pattern: (**A**, **a**) *Ctenosciaena gracilicirrhus*; (**B**, **b**) *Equetus lanceolatus*; (**C**, **c**) *Equetus punctatus*; (**D**, **d**) *Leiostomus xanthurus*; (**E**, **e**) *Pareques acuminatus*; (**F**, **f**) *Pareques umbrosus*; (**G**, **g**) *Sciaena trewavasae*; (**H**, **h**) *Sciaena bathytatos*; (**I**, **i**) *Umbrina coroides*; (**J**, **j**) *Umbrina milliae*; (**K**, **k**) *Pachyurus schomburgkii*; and (**L**, **l**) *Plagioscion surinamensis*. From Chao (1978:15). Used by courtesy of the U. S. National Oceanic and Atmospheric Administration (NOAA)

Otoliths

Otoliths (or **otoconia**) are paired calcium carbonate structures found in several vertebrate groups but are most distinctive in bony fishes (Fig. 12.8; Chao 1978:15; Weiner 2010:154–157; Wheeler and Jones 1989:114). Calcium carbonate, primarily in the form of aragonite, is derived from food and ambient water. Otoliths are

part of the system that controls balance and hearing. They form in three sac-like pockets associated with the semicircular canal, which is filled with fluid (**endolymph**). An otolith's shape conforms to the contours of the pocket (sacculus, utriculus, lagena) in which it forms. Otoliths occur in three pairs, named after their shapes: **sagitta** (arrow), **lapilla** (small stone), and **astericus** (small star). The sagitta, which forms in the sacculus, is usually the largest, though some fishes develop distinctive otoliths in all three pockets.

Otoliths increase in size throughout the life of the fish. This growth is achieved as layers of aragonite are laid down episodically over an organic matrix (**otolin**) in a concentric fashion outward from the central **core**. The overall size of an otolith provides evidence of the size of the fish when it died. As with other incremental growth structures (e.g., tree rings, mollusc increments), these layers generally correspond to daily, seasonal, and annual episodes in food availability, photoperiodicity, temperature, salinity, reproduction, and similar variables (Andrus 2011). In most cases, increments form major pairs that may be interpreted as annuli and the number of annuli is used to estimate the age of the fish when it died. Measurements from the otolith core to the edge of each annulus indicates the growth rate of the individual, the size of the fish at each year of life, and when death occurred during the final growth phase. These data can be interpreted in terms of fishing schedules, technologies, fishing locations, and predation rates.

Egg Shells

Egg shells are recovered from some archaeological sites and may be identifiable with high magnification and a good reference collection (Beacham and Durand 2007; Keepax 1981; Serjeantson 2009:170–176). In some cases, eggshell fragments may be assigned to species using studies of ancient DNA (Oskam et al. 2011). They may be more common than we know, but be underreported. They can be recovered from in a wide range of archaeological sites, especially where the eggs of large, flightless birds such as rheas (*Rhea* spp.) occur (e.g., Medina et al. 2011).

Many vertebrates lay eggs, including fishes, amphibians, reptiles, birds, the duck-billed platypus (*Ornithorhynchus anatinus*), and four species of echidna (also known as spiny anteaters [Tachyglossidae]). The external coat of a lizard egg is largely organic and unlikely to survive long, but some turtle egg shells are calcareous and could persist under conditions similar to those in which bird egg shells are preserved (Sidell 1993:10). Snake egg shells may survive, though they may not be recognized as such (van Wijngaarden-Bakker and Troostheide 2003). As a general rule, most egg shells recovered from archaeological sites are those of birds.

Bird egg shells are composed mainly of organic material and calcium carbonate in the form of calcite (Weiner 2010:79, 151–154). The inorganic portion of an egg shell consists of several layers that grade into one another. These are broadly termed the **mammillary** and **palisade layers** (Fig. 12.9; Beacham and Durand 2007:1613; Mikhailov 1997). The mammillary layer is internal to the palisade layer. Microcrystals

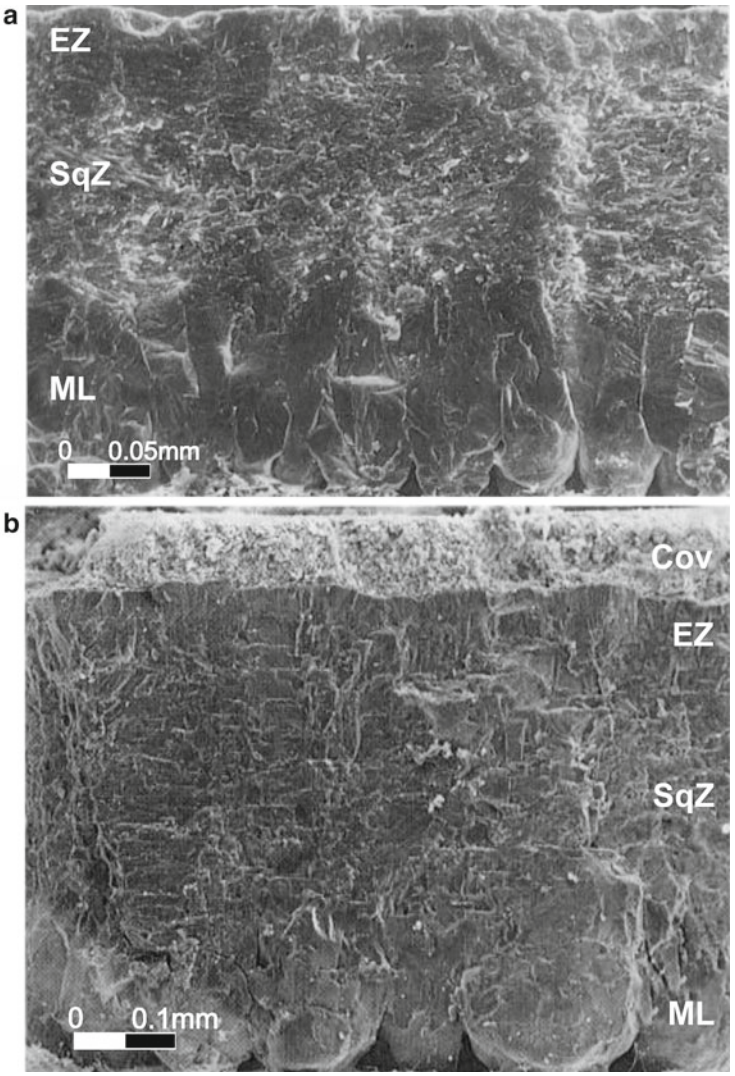

Fig. 12.9 Electron micrograph cross-section through eggshell of: (**a**) turkey (*Meleagris gallopavo*); and (**b**) greater flamingo (*Phoenicopterus ruber*) showing the mammillary layer (ML), the squamous zone (SqZ), the external zone (EZ), and the cover (Cov). The relative thickness of the layers differs among families. From Mikhailov (1997, plates 4f and 9a) and used by courtesy of Konstantin Mikhailov

grow in the mammillary layer until they meet and fuse, forming hexagonal **mammillae cones** and leaving spaces, or **pores** (Sidell 1993:6). The mammillae may grade into a continuous layer that has a spongy (**squamatic**) texture. The external inorganic layer is known as the palisade, squamatic, **prismatic**, or **columnar layer** or zone, depending on its structure. This inorganic layer consists of intergrown calcite crystals.

The outer portion of this layer defines the shape of the shell and is covered by an organic **cuticle**. The pores that penetrate shells to permit the transfer of water vapor and gases may have diagnostic shapes. Using Sidell's (1993:7) descriptive nomenclature, **fissures** are gaps between mammillae at the surface; **sutures** are junctions of fusion between mammillae; and **membrane facets** are sculpturing on the surface of mammillae.

Sidell (1993:9–10) recommends observing shell color, measuring shell thickness, counting the number of pores and cones per square millimeter, describing the internal surface, and calculating the ratio of the mammillary layer to the palisade layer (see Serjeantson 2009:171–176). These characteristics not only permit shell identification, but also enable the degree of shell resorption to be assessed (e.g., Beacham and Durand 2007). As the embryo develops, it draws upon the shell as a calcium source for its skeleton. The progression of resorption indicates the developmental stage of the egg from newly laid to hatched.

Egg shells derive their strength from their shape, an advantage that is lost once the shell is broken. Some egg shells are very thick (e.g., ostrich [*Struthio camelus*]) and fragments of these have a better chance of surviving. Like other calcium carbonate materials, egg shells fare poorly in acidic conditions, especially if the context is moist (Beacham and Durand 2007). They are, therefore, more likely to endure in alkaline, anoxic, and desiccated conditions.

Keratinized Structures

Keratin is a fibrous protein. Keratinized structures, such as nails, hoofs, feathers, horn, hair, and whale baleen, grow relatively quickly compared with other tissues and do not remodel. These have a short turnover rate and contain sequences of short-term events (e.g., White et al. 2009). Keratin survives best in extreme aridity and where it is shielded from biological agents and physical damage.

The presence of keratin and the structure of animal fibers distinguish them from plant fibers (Ryder 1984). **Primary hairs** form the animal's visible outer coat and consist of an external cuticle, a cylinder of small, spindle-shaped cells (**cortex**), and an internal **medulla** of large, columnar cells (Reed 1972:23–25). **Secondary hairs** (e.g., the wooly undercoat) are thinner than primary hairs, less numerous, and may lack the medullary region (Reed 1972:23; Ryder 1970). The pattern of primary and secondary **follicles** (sheaths of epidermal cells enclosing hair shafts, forming pits) and their relationships to muscle attachments, sweat glands, and sebaceous glands aid in the identification of skin materials (Reed 1972:25; Ryder 1970). Other characteristics that assist identification are color and distribution, cuticle thickness, the shape of medulla structures, overall hair shape, and fiber diameter (e.g., Appleyard and Wildman 1970; Ryder 1984). Some of these traits change as hair strands mature (Reed 1972:24).

Other structures are protected by or composed of keratin. The feathers that cover the body of a bird (**contour feathers**) consist of a central shaft (**rachis**) that terminates in a quill (**calamus**) at the base of the shaft (Fig. 12.10; Serjeantson 2009:189–192;

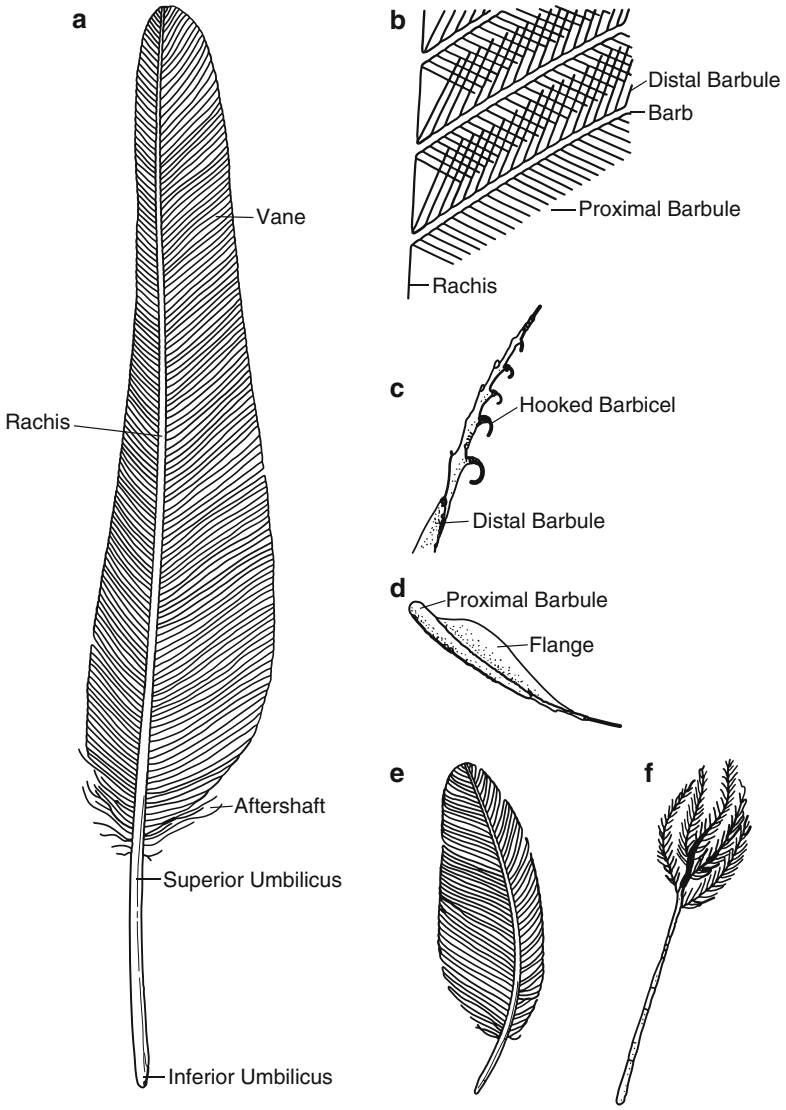

Fig. 12.10 Types of feathers: (**a**) quill; (**b**) detail of a vane; (**c**) detail of a distal barbule; (**d**) detail of proximal barbule; (**e**) contour feather; and (**f**) filoplume. From Shackley (1981:194)

Shackley 1981:194). Branches (**vanes**) extend outward from the rachis. The vane consists of stiff and soft barbs, some of which have hooks (**barbicels**) at their base. **Down** can be of several types, but many are hair-like underfeathers (**filoplumes**). Primary and secondary feathers of the wing and tail feathers each have slightly different structures. Keratin protects the external surface of tetrapod hoofs, nails, and claws. The underlying skeletal element is the **terminal phalanx** (the last element in a toe or finger; plural: phalanges). Some edentate animals, particularly birds and turtles, have

heavily keratinized beaks that function as teeth and may be serrated and sharp. Baleen whales (Mysticeti) are suspension feeders that use keratinized baleen plates to strain their food from plankton-rich waters. What is referred to in the vernacular as "turtle shell" is keratinized skin, and "horn" is a keratinized sheath that covers the bone horn core of bovids.

Skin Materials

Skin has several meanings. As an organ, skin consists of collagen fibers and covers most of the vertebrate body. It has an outer **epidermis**, a medial **mesodermis**, and an interior **endodermis**. Skins are pelts of small animals, such as calves and sheep, and **hides** are pelts of larger animals (Reed 1972:13). In addition, the term "skin" refers to materials **cured** by drying, with or without the addition of salts. When skin materials are **tanned** through the application of chemical reagents (tanning agents), **leather** is produced, normally from the mesodermis in many commercial applications (Morfit 1852; Procter 1914; Reed 1972:47). Tanning replaces some constituents of skin with minerals that prevent collagen from collapsing (Cronyn 2001:632). Most archaeological skin materials were cured or tanned (Reed 1972:174; Ryder 1970, 1984). They are found where decomposition is slowed by temperature, moisture, and oxygen levels unfavorable to bacteria and other decay organisms. Untanned skin is unusual, though not unknown (e.g., Pernter et al. 2007; Sandison 1970).

Curing and tanning are multistep processes that require periods of a few months to several years to complete (e.g., Morfit 1852:317; Reed 1972:47). Animal fats, plant products, and inorganic minerals are all used to produce preserved skin products (e.g., Reed 1972:90–91). Some treatments, such as **alum tawing** (mineral tanning with alum), do not produce true leather; in true leather, the treatment cannot be reversed (Reed 1972:64). Dung, brains, milk, butter, fish oil, marrow, neatsfoot oil, egg yolk, tallow, urine, and animal glue are among the many animal-based substances used to produce oil-tanned leather, such as chamois (Reed 1972:48, 55, 65–68, 90–91, 144). Most leathers are produced by vegetable tannage and the term "tanning" refers specifically to vegetable tannins. Some tanning agents decompose over time, but vegetable tannins react with collagen to reduce the water content of collagen fibers, a treatment that cannot be reversed and produces true leather (Reed 1972:73). Reactions to the stains used to produce microscope slides for study may distinguish among these treatments (Ryder 1984). The substances used to treat skin products could affect the color and additional minerals and dyes from plants, insects, and molluscs may be added to decorate the final product (e.g., Reed 1972:80, 87, 88, 91). Cured skins and leathers may retain hair (furs), or the hair may be removed.

The study of skin products provides insights into the animals used to produce them, the types of products made, manufacturing techniques, dyes, and paints. Skin products may be from many animals, such as sharks, reptiles, and birds, in addition to mammals such as dogs (*Canis familiaris*). The animals used may be identified from associated hairs, patterns on the skin surface produced by hair follicles (**grain pattern**), and structural details. In many cases, animal fibers and skin materials are combined with

plant fibers to produce garments, bags, and other products (e.g., Ryder 1984). The qualities, treatments, and uses of skin materials vary with the animal's age, sex, living environment, diet, and exposure to diseases and pests that produce irregularities in the skin (Morfit 1852; Reed 1972:36–44). Generally, the skin materials of younger animals are preferred over those of older animals, but this is not always the case.

Gastroliths

Some birds ingest stones (**gastroliths**) to aid in processing food in the digestive tract. These are termed "gizzard stones" in birds, which swallow small stones and store them in the gizzard where they are used for crushing food (e.g., Serjeantson 2009:32–33). These lithic gastroliths acquire a characteristic polish from chemicals and the grinding action of the gizzard. In archaeological deposits, an accumulation of polished pebbles might not be recognized as anything other than pebbles that appear water-worn. They provide clear evidence for the butchery of birds on site. Lithic gastroliths should not be confused with crustacean gastroliths, which are calcium carbonate deposits (Chap. 10).

Episodic or Periodic Growth in Vertebrates

Episodic growth is seen as increments in the skeletal and dental elements of vertebrates whose growth is indeterminate (Andrus 2011; Higham and Horn 2000; Wheeler and Jones 1989:89) and in the teeth of mammals (e.g., Hillson 2005:159–168, 245–253; Klevezal and Shishlina 2001; Stutz 2002). As with other organisms that grow episodically, pairs of increments are interpreted as evidence of fast growth during optimal conditions and slow growth during less optimal ones (e.g., Higham and Horn 2000; Hillson 2005:250; Hufthammer et al. 2010; Chaps. 8 and 11). Young animals experience multiple periods of rest and growth corresponding to general metabolic changes, and adults may fast during the mating season, when molting, or in response to other physiological, seasonal, or annual events. Some of these responses produce false annuli (Stutz 2002). Increments are used to estimate size and age at death as well as season of death (Andrus 2011). In vertebrates with indeterminate growth, scales, vertebral centra, spines, and other specimens can be informative, but the elements studied most frequently are otoliths (Andrus 2011).

Increments in dentine and cementum of mammalian teeth are studied to estimate age, season of death, and husbandry strategies (Fig. 12.11; Hillson 2005:245–253; Rendu 2010:1800). Cementum forms throughout life, whereas dentine forms only as the tooth's root develops. Increments in dentine, therefore, represent early life events, whereas increments in cementum reflect occurrences throughout life. The full range of environmental and physiological factors that influence increment formation in dentine and cementum is unknown. One possibility is that increments reflect changes in the strain associated with chewing foods of different toughness and the nutritional quality of those foods (Lieberman et al. 1990).

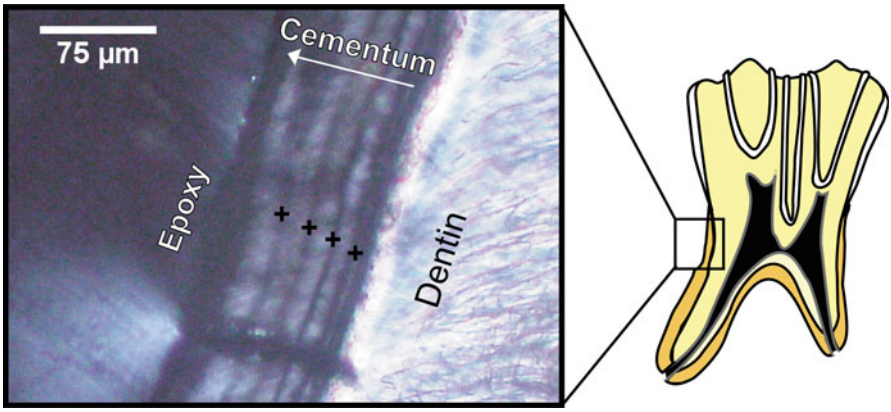

Fig. 12.11 Dental thin section exhibiting dark and light deposits indicative of slow growth (winter) and fast (summer) growth, respectively, seen under polarized light microscopy. The slow-growth deposits are highlighted by "+." From Rendu (2010:1800) and used by courtesy of the author and Elsevier

Activity Patterns and Pathologies

Stress is an extrinsic variable, or combination of variables, to which the organism reacts in some way. In many cases, the stress is a customary activity pattern (**biomechanical**) and the response of the skeletal system is not, strictly speaking, pathological. Trauma and disease, on the other hand, interrupt the normal remodeling process and produce anomalies, which, if they interfere with normal activities, may be pathological. Some stresses leave no osteological evidence, especially if the individual dies before skeletal elements (and dentition in young animals) have an opportunity to respond. Normal and pathological responses are mediated by genetic, environmental, and behavioral components as well as individual and clinal variation.

Structural adaptations occur in skeletal systems so that they can sustain routine biomechanical stresses (Larsen 1997:197–203). People and their domestic animals repeatedly perform activities that place mechanical stress on skeletal elements, including compression, bending, torsion, and sheer. Some of these are of sufficient duration and frequency to affect the shape of skeletal elements, such as kneeling, bearing loads, or pulling plows. Interpretations of activity patterns are based on **Wolff's Law**: remodeling occurs in the direction of functional demand (Larsen 1997:195; Larsen et al. 2001; Smith and Horwitz 1984). Thus, repeated mechanical stress may change the ratio of compact bone to the size of the medullary cavity, alter the thickness and shape of joints, cause vertebral wedging and pitting, and produce asymmetry, among other modifications. Although changes in the shapes of bones may not be pathological, repeated stress may result in other changes that are pathological.

Factors that adversely impact growth and development in skeletal and dental materials include population size and density, nutrition, joint diseases, infectious or metabolic diseases, and tumors. These may produce pits, grooves, lines, and other

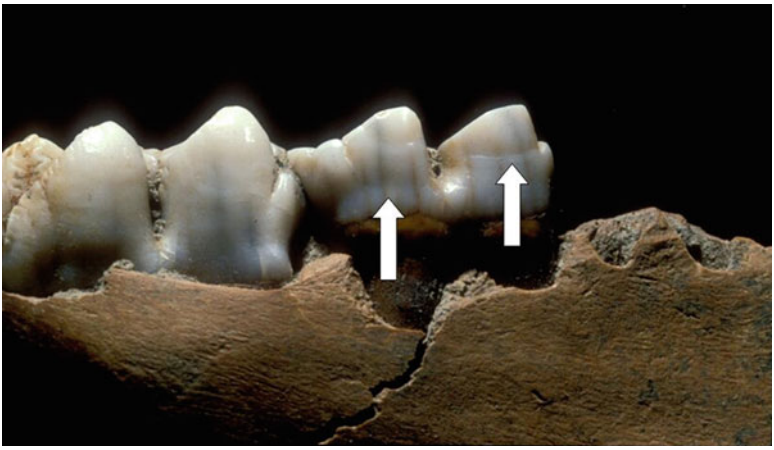

Fig. 12.12 Linear enamel hypoplasia on the lingual surface of domestic pig (*Sus domesticus*) molars. *Arrows* indicate hypoplasias. Used by courtesy of Keith Dobney

abnormalities in skeletal and dental tissues (Fig. 12.12; Dobney and Ervynck 2000:598; Larsen 1997:40–47; Siegel 1976). One response to extreme stress prior to adulthood is to stop growing. If the individual survives and growth resumes, this may produce **enamel hypoplasias** in teeth (Hillson 2005:169–171; White and Folkens 2005:334–335; 354; Wilkins et al. 2007) and **growth arrest lines** (e.g., Harris lines) in skeletal elements (Baker and Brothwell 1980:45). Both of these are transverse lines of increased density that form perpendicular to the main axis of growth. Evidence for arrested growth occurs only if the element otherwise is still actively growing. Although evidence of arrested growth experienced early in life may survive into adulthood, adults do not produce these lines.

Traumas such as fractures, dislocations, scalping, or wounds produce pathologies, if the individual survives (Larsen 1997:119–151; Siegel 1976; Waldron 2009:138–141). Domestic animals are subject to pathologies associated with restraints, stabling, castration, and polling that result in anomalous shapes beyond those associated with biomechanical stresses (e.g., Baker and Brothwell 1980:73, 97). If the trauma damages a skeletal element, the body attempts to repair the damage and achieve a functional recovery. Even though functionality is achieved, the repair itself may be irregular or abnormal. Of course, there is no recovery from fatal traumas such as slaughter, beheading, hanging, and strangulation, which may be indicated by alterations in the underlying skeletal element (e.g., crushed vertebrae), cut marks, and restraints left with the victim (e.g., Larsen 1997:145–146).

Some skeletal pathologies are the result of infections and disease (Hillson 2005; Larsen 1997; Waldron 2009; Zimmerman 2001). These may be specific to people or afflict a wide range of vertebrates (Baker and Brothwell 1980; Davies et al. 2005). Diseases include osteoarthritis and rheumatoid arthritis. Infectious diseases that may leave skeletal evidence include osteomyelitis, tuberculosis, leprosy, venereal syphilis, poliomyelitis, smallpox, fungal infections, and parasitic diseases, as well

as nonspecific infections such as sinusitis and periostitis. Metabolic diseases include osteoporosis, rickets, osteomalacia, scurvy, diabetes, anemia, and thyroid disease. Some, such as rickets and scurvy, have nutritional components.

In addition to hypoplasias, teeth have other pathologies. Some are genetic (e.g., supernumerary teeth); others are behavioral (e.g., abscesses, caries, calculus deposits, periodontal disease). When adult teeth are lost, the lower (**mandible**) or upper (**maxilla**) jaw become misshapen (Larsen 1997:79). Other dental pathologies include abnormal wear and grooves, crowded teeth, and malocclusion. Bits and other restraints modify the teeth of domestic animals (Reitz and Wing 2008:312; Siegel 1976). Teeth were intentionally removed from dogs in the West Indies, perhaps to accommodate a restraint (Wing 1991). The habit of using our own teeth to work hides and fibers, skin birds, or open bottles alters teeth (Larsen 1997:258–262; Serjeantson 2009:205).

Most anomalies indicate that chronic or acute stress was experienced, but do not identify the source (e.g., Waldron 2009:21–22). Often there is no direct association between sources of stress and specific skeletal or dental responses. Some diseases of the past are uncommon today and their osteological signatures may not be recognized. Pathologies associated with specific stresses may be characteristic of specimens that do not have high survival potential. For example, if vertebral spines are missing, osteological evidence for diseases that cause characteristic lesions on those spines will be absent. Finally, like so much in environmental archaeology, multiple causes can produce similar effects.

Some apparent pathologies are not pathologies at all or would not have been considered such by the people affected. These include artificial deformation and the results of medical practices (Larsen 1997:152–154; Waldron 2009:158–162). Cranial deformation is produced by altering normal development during early childhood (Perez 2007). This may be accomplished intentionally by strapping boards to an infant's skull to flatten it, or unintentionally by using a cradle board. Teeth may be deliberately mutilated to achieve attractive shapes or by the addition of stone or gold inlays (Hillson 1996:251–252). **Trephination** is a medical procedure in which a hole, often a very large hole, is drilled into the patient's skull. If the person lives, the body begins to repair the hole. Some people survived several trephinations, bearing scars in various stages of recovery (Larsen 1997:153).

Site Formation Processes

Vertebrate remains have different survival potentials depending upon the relative proportions of bone mineral and collagen present and characteristics of the depositional environment. As a general rule, they survive best in neutral and alkaline contexts; their lowest survival potential is in acidic contexts (Stiner et al. 2001). Recrystallization occurs between pH 7.6 and 8.1 (Berna et al. 2004). Like all organic materials, vertebrate remains are more abundant in stable contexts where they experience minimal mechanical, bacterial, and fungal activity. Elements protected by enamel (e.g., teeth)

are more likely to endure than are those consisting primarily of bone mineral. Bone mineral and collagen are subject to chemical and biological decay depending on the burial environment and the specific element under consideration. Skeletal elements with high percentages of cartilage, either from adult or incompletely ossified juvenile skeletons, are less likely to persist than are those with higher percentages of bone mineral. Keratin survives only under special circumstances.

Many activities produce modifications associated with butchering, fragmentation, and manufacture. All influence the types of skeletal and dental remains in the death, deposited, archaeological, and sample assemblages. Once the animal is killed, the carcass steadily disintegrates into smaller and smaller units because of transportation decisions, processing, exchange systems, symbolic and ritual uses, and manufacturing needs, until the surviving bits may be discarded (e.g., Bovy 2002; Munro and Grosman 2010). These site formation processes begin when people decide which parts of the carcass are worth transporting from where the animal was acquired to where it will be used. Some of these decisions reflect whether the animal was wild or domestic, and which part(s) of the carcass (e.g., meat, sinew, wool, skin, blood, oil, viscera) are valued and why. Exchange systems further distribute the carcass. Additional scattering occurs when skeletal parts are used in tools, ceremonies, or other activities. If small animals, such as anchovies (Engraulidae) and small rodents, are eaten, their remains may enter the archaeological record only in fecal matter, or not at all. It may also be the case that some resources, such as eggs, are consumed at locations other than the primary residential locations, perhaps ones specifically intended for use by either small, dispersed groups, or by large, extradomestic groups assembled for community events (e.g., Medina et al. 2011). None of these practices were uniform for all animals, sites, social groups, or time periods in the past.

People facilitate or discourage preservation through choices about where and how to dispose of organic debris. Burning removes some of the organic component; this reduces the appeal of the adhering tissue to scavengers and detritivores, but increases the fragility of the specimen. Rapid burial decreases exposure to weathering, scavenging, and trampling, but skeletal and dental materials continue to be altered after burial. By discarding vertebrate remains with molluscs, the length of time vertebrate remains survive may increase. Tossing refuse into a location in which microbial and fungal activities are slowed (e.g., into the nearest body of water) enhances preservation if the deposit is an alkaline, stable, anoxic one.

Other activities introduce vertebrate remains to the archaeological record unintentionally. The built environment offers ideal habitat to symbiotic organisms. Samples from cave sites, rock shelters, pits, and structures often contain remains of animals seeking food, shelter, or nesting sites. Such animals are important site formation agents and may indicate aspects of nearby and more distant habitats as well as the deposit's function. Although some of these animals are recovered from contexts that suggest they did not have a cultural role, frequently their remains are mixed with those of animals that did have cultural value. Interpretations that a particular animal in an assemblage was not used, or was used for a specific purpose, should not be based on our own cultural perspectives.

Field Considerations

Care should be used in recovering vertebrate remains and preparing them for transfer to other laboratories. Modifications to skeletal and dental elements are important primary data and field staff should avoid adding modifications through unskilled use of field tools and handling.

Two primary field considerations pertain to sample size and sample context. Researchers who study sediments, soils, botanical remains, and small animals such as arthropods and land snails tend to argue for small samples from multiple contexts. As reviewed in Chap. 11, those who study large molluscs and vertebrates tend to advocate the use of large samples, which typically are taken from a limited number of contexts because of time and financial constraints. The vertebrate literature is dominated by examples demonstrating the relationship between large sample sizes and rich taxonomic lists. Soil scientists, botanists, and others, however, routinely demonstrate the merits of studying samples from multiple contexts (e.g., Stiner et al. 2001). This oversimplifies the debate, but it is one reason why it is difficult for environmental archaeologists to share samples and recommend a uniform recovery method for all organismal remains.

Compared with analyses of some other materials, vertebrate studies draw upon a richer quantitative toolkit and this is one reason for the different sample size and context preferences. Quantification requires that all materials used to address a research question have an equal and random (in the statistical sense) opportunity to be recovered using a consistent recovery technique, that the studied samples be adequate in size, and that samples be approximately equal in size. An empirical method to measure adequacy is to add replicate subsamples until the study assemblage describes the taxonomic composition and character of the deposit (Reitz and Wing 2008:113–114). Vertebrate studies based on large samples consistently demonstrate the quantitative and interpretive biases introduced by small samples (Fig. 3.7). Although aware of the biases associated with interpreting an entire archaeological site from one or two column samples, researchers studying vertebrates typically opt for the more complete compilation of primary data afforded by large samples sizes, even though this means that the study assemblage does not represent all temporal, spatial, and functional aspects of the site.

Although biases introduced by field decisions appear to be infinite, many are related to the placement of excavation units and the size of the screen or sieve used in the field. Because many vertebrate studies use a limited number of large samples instead of many small ones, it is critical that the study assemblage be selected carefully. Animal remains from parts of the site with different functions (e.g., slaughter houses, temples, hearths, middens, markets) will be quite distinct. This is, of course, an argument for taking samples from multiple contexts. If multiple activity areas are not sampled, then the study assemblage needs to be appropriate to the specific research objective. If the research focus is on domestic behavior during a specific time period, it is inappropriate to study rubble used to construct temple walls, for example.

Field biases are compounded by inappropriate screening methods. With few exceptions, vertebrate remains should be recovered by passing excavated material through a screen with a mesh dimension that is adequate to capture the full range of animals present at the site. It is important to use a consistent screen size in the field. This may mean that the recovery process for a specific sample is initiated in the field with a relatively large screen size and that screening of the smaller fraction will continue in the laboratory. Sorting the fine-screen fraction should not be attempted under normal field conditions.

Although all environmental archaeologists working with organic remains are resigned to working with fragments, research is enhanced by the occasional intact specimen. In some cases, identification is difficult if the material is fragmentary; invariably the part that is broken off is exactly the portion needed to confirm an identification. Damage caused by excavation and transportation is particularly frustrating because it may be difficult to distinguish between excavation damage and modifications associated with site formation processes (e.g., butchering marks, carnivore tooth marks, use-wear, pathologies). Modifications offer critical primary data and field staff should avoid adding to them through careless use of trowels, shovels, pick-axes, and machinery. This is particularly important for molluscs and vertebrates because the interpretation of modifications contain significant information about technologies and processing decisions. The caution applies to all types of organic materials, however.

Laboratory Procedures

Many of the laboratory procedures are similar to those practiced by other environmental archaeologists. As with other materials, the first step is to record all of the contextual information provided by the field staff onto laboratory forms. Archaeological field notes and laboratory records, including maps, stratigraphic profiles, summaries of soil and sediment analyses, and preliminary, functional interpretations of contexts assist in preparing lab records and in correcting errors. These records will be updated as the work progresses. Some of the identification and analysis procedures may involve sectioning bones, teeth, and otoliths, procedures that are beyond the scope of this volume.

Processing

Most vertebrate remains require little or no processing in the laboratory prior to study, though this may not be the case for materials from damp, desiccated, or frozen contexts. Some items may need to be cleaned or stabilized, and additional screening may be required. Subsampling may be necessary, following procedures similar to those used for other materials (Chap. 5). This may not be very effective

Table 12.4 Primary data and other attributes recorded during a study[a]

Taxonomic identification of the specimen
Element represented by the specimen
Side (e.g., left, right, axial, unknown, or some other description)
Portion (e.g., proximal, distal, anterior, lateral, medial, shaft, unknown, or some other description)
Sex (description of morphological evidence for sex such as dental attributes, presence of sexually diagnostic features such as antlers or the shape of a turtle plastron, or other characteristics)
Age (e.g., fused or unfused long bone, degree of wear on teeth, stage of tooth eruption, or other characteristics)
Count (number of specimens referred to the taxon, often abbreviated as NISP)
Weight (weight of specimens referred to the taxon)
Minimum number of individuals (MNI)
Modification (description of the modification(s) including: state of preservation; gnawed by a human, rodent, carnivore, or artiodactyl; evidence for passing through a digestive system; butchering marks such as cut, hacked or chopped, sawed; evidence that the specimen was burned, worked, trampled, weathered, or pathological; description of where the mark is located and evidence that the mark made by a metal or stone implement; other characteristics)
Measurements (definition of the dimension measured, or source of the description; actual measurement of the defined dimension)
Other data as required by the research design (e.g., incremental growth patterns in dental cementum, or mollusc valves; stable isotopes; trace elements; DNA and molecular evidence; etc.)
Explanatory notes

[a]Modified from Reitz and Wing (2008:388)

because vertebrate remains range in size and shape from large, irregularly shaped elements (e.g., antlers, horn cores) to otoliths and dermal denticles, a variety not easily accommodated in a riffle box. It may be more productive to subsample using a table of random numbers to select a study assemblage from among the available archaeological samples.

Identification

As with other environmental materials, each archaeological specimen should be identified using appropriate reference specimens and drawing upon skills developed through experience and knowledge that encourages accuracy and caution. This is a multifaceted procedure that involves recording primary data: the element represented by the specimen, the taxon to which the specimen is attributed, and descriptions of other observable characteristics (Table 12.4; Reitz and Wing 2008:388). These characteristics include symmetry (left, right, axial), portion (proximal, distal), degree of fusion, whether teeth are deciduous or permanent, tooth wear, evidence for sex, and any modifications. Measurements recorded at this time should, whenever possible, follow published guidelines designed to facilitate comparability and

communication among researchers (e.g., Driesch 1976), or else be well-described (e.g., Losey et al. 2008). As primary data are collected, specimens referred to each taxon are counted (NISP) and weighed.

Analytical Procedures

Vertebrate analysis draws upon a large number of quantitative procedures (e.g., Lyman 2008; Reitz and Wing 2008; Serjeantson 2009; Wheeler and Jones 1989). The choice of which approach to use should be guided by the research question and the quality of the study assemblage. In some cases, the study assemblage is too small, too damaged, or otherwise obviously biased in some other way, limiting the analytical procedures that are appropriate. Familiarity with intrinsic attributes of the materials, as well as with the primary data from which secondary data are derived, influences the procedures followed. No analytical method meets every need; all have strengths and weaknesses. Methods are continually evaluated and researchers should seek independent verification of interpretations from studies of other proxy materials. Some of the analytical procedures applied to vertebrate remains are used for other organisms and are reviewed in earlier chapters (e.g., presence, ubiquity, NISP, Minimum number of individuals (MNI), richness, diversity, equitability, dietary estimates). Others commonly applied to vertebrates are reviewed here.

The primary difference between invertebrate and vertebrate analysis is that vertebrates have a wide range of skeletal and dental elements that can be measured and assessed for symmetry, age, sex, skeletal frequency, and modifications. To estimate MNI for vertebrates, for example, it is necessary to consider not only the archaeological context, taxonomic attribution, portion represented, and symmetry, as with invertebrates, but also evidence for age at death, sex, size, and conformation. If, for example, the sample contains a proximal left tibia that is fused and a proximal right tibia that is unfused, it is likely that two individuals are represented and not one, as would be estimated if symmetry were the only evidence to be considered. Furthermore, one of these individuals died at a younger age than the other. MNI can also be estimated for other animal products, such as eggs (e.g., Medina et al. 2011).

Interpretations of skeletal frequencies combine concepts of postmortem disturbance and human choice (e.g., Bovy 2002). This is made possible by the wide range of skeletal and dental elements that may be present in the study assemblage. This analysis relies on counting the number of specimens in the study assemblage and correlating this with skeletal portions to determine which parts of the skeleton are abundant or rare compared with complete skeletons of that taxon, to skeletons of that taxon from other archaeological contexts, or to skeletons of other taxa. Specimens may be evaluated in terms of the **minimum number of animal units** (MAU) or the **minimum number of elements** (MNE) represented (Reitz and Wing 2008:226–230). MAU and MNE are derived from vertebrate materials in several different ways, leaving the interpretation of data reported as MAU or MNE in doubt unless the procedure used is clearly described in the report or publication.

Skeletal portions are usually defined by the skeletal elements, anatomical regions, or butchering units represented in the collection. Most approaches quantify animal remains in terms of the frequency of specimens from various parts of the skeleton, a ratio between the number of specimens observed and the number of specimens in an unmodified skeleton, or their proposed utility. Frequencies may distinguish between animals killed some distance from a village and those killed nearby, assuming that heavy, less useful parts of a skeleton would not be carried very far, whereas valued portions would be transported over considerable distances. Not only might frequencies separate distant from local kills, they may distinguish between domestic animals and wild ones if domestic animals were slaughtered locally and wild ones killed further away. Skeletons of vertebrates dying of natural causes and buried immediately might be relatively complete because they were subject to little postmortem disturbance between death and burial. Carcasses that experienced a great deal of postmortem disturbance are expected to be less skeletally complete, typically missing portions that are particularly sensitive to decomposition and other site formation processes. The skeletons of commensal animals and ceremonial burials, for example, should be more complete than those of animals used for food or tools. This is a helpful way to distinguish food animals from draft animals; the latter might be more skeletally complete, and older at death, compared with food animals, which might be represented by only a few body parts from younger animals. Unusual density and quantities, as well as the specific skeletal portions present, are used as evidence for exchange networks, status, ethnicity, and ritual in archaeological settings.

Utility might guide decisions made by a consumer about which animals to use, which portions of a carcass to ignore, and which to transport or purchase. High status, or wealth, might be associated with higher-quality meat cuts than would be afforded by less affluent or less prestigious households. The definition of utility varies considerably because a carcass has a number of nutritional merits (fat, protein, vitamins, minerals) as well as nonnutritional values. They are important sources of raw materials (e.g., hides, sinew, tallow, glue, oil) used in many products. Animals, or parts of animals, are valued as symbols of authority, lucky charms, evidence of social identity, or badges of honor.

Modifications, fragmentation levels, and fracture types provide additional information on diagenesis, processing techniques, manufacturing applications, and other environmental and cultural phenomena when combined with skeletal frequencies (e.g., Munro and Grosman 2010; Serjeantson 2009:131). Modifications can be considered in terms of their location on the specimen, as well as the orientation and direction of cuts or blows. Butchery marks may indicate whether the animal was skinned, the ethnic identity of the butcher, the social standing of the consumers, whether butchery was for household consumption or for trade, and whether the butcher was producing units of meat to conform to market standards or was a farmer intent on maximizing the amount of food and other products obtained from the carcass. Characteristics associated with direct and indirect exposure to heat provide evidence of cooking techniques, waste disposal, burnt offerings, or other uses of fire (e.g., Koon et al. 2010). Burning may be circumstantial evidence of human use of a resource (e.g., Medina et al. 2011). Modifications may indicate a trophy was hung for display (e.g., Bartosiewicz 1995:55) or that a carnivore canine was worn as part

of a necklace. Some uses are unexpected, such as that of cattle metapodia and astragali as building materials in Medieval European cities (Armitage 1989a, b). Many modifications are produced by routine activity patterns, husbandry methods, and diseases (e.g., Davies et al. 2005). Fragmentation is related to site formation processes such as weathering, butchering techniques, food processing, and manufacturing methods. The presence or absence of marks attributable to human behavior may distinguish between culturally valued animals and commensal ones.

Estimates of body size and conformation, usually derived from measurements, support a number of interpretations about individual, spatial, and temporal variations. A change in dimensions might suggest that an animal population responded to environmental or ecological changes that affected predation, competition, and food quality. Body size reflects human choices about which taxon, age cohort(s), or sex to target; techniques to use in capturing the animal; and habitats to exploit (e.g., Losey et al. 2008). Changes in body size and conformation through time provide evidence for domestication and for overharvesting. Reductions in body dimensions may be evidence of poor nutrition or of intense exploitation impacting the growth habits and life histories of surviving individuals in the population. In some cases, the average size of individuals in a population declines because of high levels of juvenile recruitment, especially in areas of high productivity. Body size is used to estimate the dietary contribution of the animal.

The methods used to estimate age at death and age classes are different for animals with determinate and indeterminate growth. Epiphyseal fusion, tooth eruption sequences, and tooth wear are used for vertebrates with determinate growth. For those with indeterminate growth, age at death and age class are estimated from body size and growth increments (e.g., Losey et al. 2008). If several members of a species are represented, it may be possible to construct mortality or survivorship curves. Shifts in age classes over time, particularly those accompanied by changes in body size or conformation, may indicate changes in the demographic profile associated with environmental change, predation, competition, capture technologies, capture location, or domestication.

Changes in sex ratios may signal environmental shifts, predation decisions, or domestication. The sex of an individual is interpreted from morphological characteristics and measurements, often combined with estimates of age at death. The morphological characteristics examined are those that occur in only one sex, or that distinguish among males, females, and castrated males. They include body size or conformation, antlers, spurs, medullary bone, and the shapes of horn cores and pelvic girdles. Sexually diagnostic features are mediated by individual, clinal, and temporal variations, and breeds in domestic animals.

Animal Domestication

Indirect evidence for domestication includes devices used to restrain or control animals. These may be corrals, bits, wheeled vehicles, and plows. Illustrations of animals being milked, sheared, bled, or ridden suggest domestication as these activities

are unlikely with wild animals. Pathologies associated with crowding, stabling, hobbling, and harnessing usually are interpreted as evidence of domestication (e.g., Outram et al. 2009). In some cases, long, close association has resulted in exchanges of diseases between domestic animals and people, a connection demonstrated by evidence of parasitic microorganisms and skeletal modifications characteristic of specific diseases. As with plants, the concept of "stages," though useful for structuring discussions such as this, does not do justice to the diversity of stimuli and responses involving people and other animals.

Many of the historical and genetic factors that apply to archaeological evidence for plant domestication also pertain to animal domestication. Animal domestication initially may have involved capturing and controlling wild individuals and raising tame ones (Meadow 1989; Vigne et al. 2005; Zeder 2001). The domestic taxon might originally have been a commensal one that became habituated to people; it might have been a favored prey animal with game management leading to herd management; or the taxon may have been intentionally managed toward domestication. These steps led to populations of animals that are relatively tractable and reproduce in captivity. During the early stages of domestication, controlling breeding and isolating the domestic gene pool from the wild one may not have been achieved, sustained, or intended (e.g., Clutton-Brock 1989). Reproductive isolation is necessary for traits to emerge that are found only in domestic forms, however.

A key signature of domestication is the appearance of a species outside the preferred habitat of the wild progenitor; hypotheses about the range of the wild progenitor are central to zoogeographical interpretations (e.g., Beacham and Durand 2007). The presence of a turkey (*Meleagris gallopavo*) in Europe, for example, is solid evidence that this was a domesticated bird, but it is more difficult to determine this within North America itself because the species is relatively widespread, but was domesticated in only a portion of its known range (e.g., Speller et al. 2010). More often, remains of potential early domestic forms are found just beyond the present-day range of the hypothesized wild progenitor. In these cases, it is argued that the domestic form expanded outside of the wild progenitor's range via human trade and migration routes, though wild animals also might have been traded. As with plants, using biogeography as evidence of domestication is complex because of changes in Holocene ecosystems; often wild progenitors' former ranges cannot be defined with certainty. More importantly, some wild progenitors are now extinct so their habitat preferences and behaviors are unknown or unclear. Examples of extinct wild progenitors are aurochs (*Bos primigenius*) and horses (*Equus ferus*). On the other hand, when remains of guinea pigs (*Cavia porcellus*) are found in the Caribbean archipelago, these probably were from domestic animals. The wild progenitor (*Cavia aperea*) is restricted to the South American Andes and there is no palaeontological record of indigenous wild guinea pigs on Caribbean islands. It is very unlikely that guinea pigs lived in the archipelago without human intervention, an interpretation supported by osteological evidence for domestication.

Most domestic animals have characteristics that distinguish them from wild ones. Many domestic animals live in herds or flocks and tolerate close association with people, who exercise control over their reproduction, health, nutrition, and behavior.

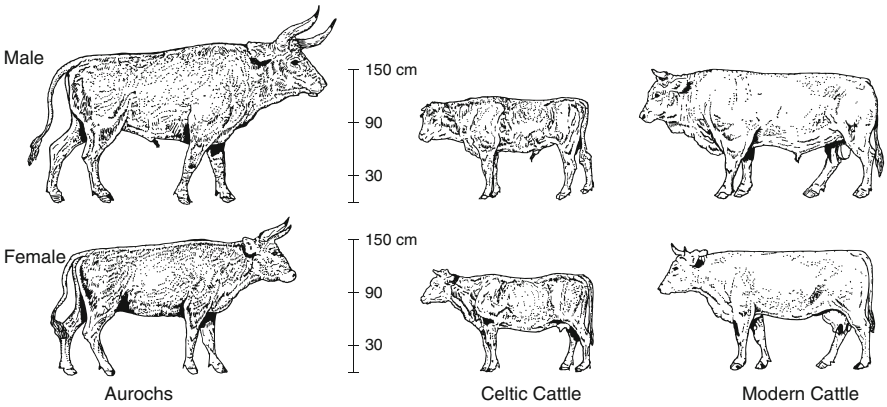

Fig. 12.13 Artist's reconstruction of the aurochs or wild ox (*Bos primigenius*), Celtic, and modern domestic cattle (*B. taurus*). From Davis (1987:135; originally produced by the late Joachim Boessneck); © 1987 by Yale University Press. Drawn by Evelyn Davis. Used by courtesy of Simon J. M. Davis, Yale University Press, and Taylor & Francis Books, UK

They may retain juvenile physical and behavioral traits, such as floppy ears, light-colored or multicolored hairs or feathers, and submissiveness. Other characteristics of domestic animals include curly instead of straight hair and a reduction in sexual dimorphism. The characteristics associated today with some domestic animals (e.g., sheep with wool, cattle with dairy and blood products) developed in the domestic state and were probably not the original stimuli for domesticating the species (e.g., Ryder 1970).

Many of these traits, so obvious in modern domestic animals, are rarely found in archaeological materials, though there are notable archaeological cases where attributes of plumage or hair survive (e.g., Sandweiss and Wing 1997). Archaeological studies more typically draw upon zoogeography as well as size and conformation, demographic profiles, relative frequencies of specific taxa, skeletal completeness, congenital abnormalities or diseases, variability within the remains indicative of breeds; behavior; and archaeogenetics. DNA analysis may provide some evidence for coat color variation associated with domestication (e.g., Ludwig et al. 2009). As with plants, biochemistry of stable isotopes may identify early stages of domestication before these are evident in skeletal and dental materials (e.g., Barton et al. 2009).

For evidence of domestication to be found in skeletal and dental remains, the wild genotype must change sufficiently to be expressed in the phenotype of the organism. This may take a long or short period of time. The primary osteological evidence is a change in body size and conformation (e.g., Outram et al. 2009). Most domestic animals are smaller than their wild progenitors (e.g., Fig. 12.13; Davis 1987:135), though some small animals, such as guinea pigs and chickens, increase in size, and others, such as dogs, become highly variable. The change in body size may be the result of genetic bottlenecks associated with domestication, selection, and breed formation; clinal variation; environmental change; or purposeful, selective culling of young individuals. All of these phenomena might result in diminished

or increased body size. Often juvenile characteristics such as a shortened facial area or a rounded cranial vault are retained in adults. Teeth are lost or become small, crowded, or overlapping. A naturally polled state may emerge in bovids, and spurs of male chickens may be altered. Such evidence is augmented by genetic studies that provide insights into ancestry and taxonomic affiliations (Renfrew 2000; Zeder et al. 2006).

Demographic profiles, reproductive behavior, and diets provide additional evidence for domestication. An idealized measurement curve with three peaks, representing a demographic structure that includes females, castrated males, and intact males, is often interpreted as evidence for domestication. Such a demographic profile might indicate a management decision to maintain reproductive female stock, retain a few castrates for their labor, and slaughter most young males. Demographic profiles that rely on measurements are confounded by clinal variations, responses to environmental change, sexual dimorphism, and differences in size at a specific age. Thus morphometric evidence for size, skeletal and dental evidence for age, and clinal variation must be considered together whenever possible. The presence of bird egg shells in all stages of development may indicate that birds reproduced in captivity, behavior that would be expected of tame or domestic birds but not of wild ones (Beacham and Durand 2007). Turkeys in Colorado (USA) are interpreted as domestic based on isotopic evidence for their diet. These turkeys were fed food scraps and maize (*Zea mays*) instead of available wild foods (Rawlings and Driver 2010). In other parts of the American Southwest, archaeogenetic evidence supports this interpretation (e.g., Speller et al. 2010).

As with plants, a number of other observations may suggest domestication. Among these are a change in the faunal spectrum from a relatively broad use of many different animals, to a different suite of animals, or to only a few species (e.g., Davies et al. 2005; Davis 1987:126–127; Zeder 2001). When the ubiquity of a specific taxon or group of taxa increases in regional faunal assemblages over time, this may be additional evidence of domestication. Economic and behavioral changes in human residential patterns, divisions of labor, and scheduling of other activities likely accompanied animal domestication. New social conventions would be required to establish expectations about how to control livestock and other animals, who is responsible for their management and the damage they cause, and who owns and inherits animals and pasturage. Animal domestication may be associated with new rituals intended to protect herds and enhance their productivity.

Human Biology as a Special Case

Arrangements should be made in advance with the project director regarding the handling of human remains because many ethical and legal issues are involved. Even small, unassociated finds may be covered by international treaties, national laws, permit restrictions, local protocols, and cultural patrimony agreements (Larsen 1997:341–342; Roskams 2001:199–200; White and Folkens 2005:21–30, 352–353).

This issue is most closely identified with the Native American Graves Protection and Repatriation Act (NAGPRA) passed in 1970 in the United States, but similar restrictions exist in several countries (e.g., Lawler 2010). Even where the treatment of human remains is not codified, local sensitivities may dictate how archaeologists proceed. If the vertebrate laboratory finds that some of the animal remains sent for study are human, the project director should be informed to ensure compliance with applicable requirements.

Vertebrate specialists need to be familiar with human remains because it is common for these to be unrecognized in the field if they are not in an obvious burial context (e.g., grave, funerary urn, cache). It is particularly difficult to recognize fetal or infant remains in the field because these small specimens are very different from adult materials (Scheuer and Black 2004). Unassociated adult teeth, fingers, and toes are not uncommon and can be overlooked in the field.

Some of the names for elements are different in human and nonhuman osteology, so if a preliminary identification is made in a vertebrate laboratory, appropriate terminology should be sought from the human osteologist responsible for their study or a reference manual (e.g., Cox and Mays 2000; Hillson 2005; Katzenberg and Saunders 2000; Roskams 2001:199–208; White and Folkens 2005). Reference manuals cannot substitute for experience with human remains, however.

Many aspects of environmental archaeology are improved if human remains can be studied along with other archaeological materials. Outram et al. (2005), for example, demonstrate the importance of studying peri-mortem, depositional, and postdepositional histories of both human and nonhuman remains before human remains are repatriated. Biochemistry and archaeogenetics can resolve many questions about human origins and behaviors, making it desirable for patrimony agreements to permit archival sampling whenever possible.

Applications

Two of the questions raised about human–environmental interactions are: what was the rate of human use of a resource in the past and what were the consequences of that use on the species in question? Answers to these questions are urgent for whales (Cetacea), seals and walruses (Pinnipedia), and sirens (Sirenia), whose numbers decline despite efforts to identify and maintain sustainable populations. McNiven and Bedingfield (2008) use the archaeological record to estimate former harvest rates of dugongs (*Dugong dugon*). Dugongs are herbivorous marine mammals weighing up to 400 kg associated with seagrass beds in the tropical Indo-Pacific from Madagascar (Africa) to Vanuatu (Polynesia). Dugongs in Torres Strait (Australia and Papua New Guinea) have declined from an estimated 72,000 individuals to 5,000 since the 1960s. Dugongs were important food and totemic animals among Torres Strait islanders and on the adjacent Australia and Papua New Guinea mainlands for at least 4,000 years, roles that continue today. Resource managers are charged with establishing levels of harvest that will sustain both dugongs and their cultural roles.

Table 12.5 Dugong (*Dugong dugon*) MNIs and densities for excavation pit at Dabangai Bone Mound, Torres Strait[a]

Deposit zone	Excavation unit	Depth (cm)	Volume (m^3)	Dugong MNI	Dugong density
Upper	1–19	0–66	0.285	110	386
Lower	20–23	66–86	0.066	5	76
Total	1–23	0–86	0.351	115	328

[a]Dugong density is MNI divided by m^3. Modified from McNiven and Bedingfield (2008:512). Used with permission of the authors and Elsevier

McNiven and Bedingfield (2008) examined dugong remains from Dabangai Bone Mound to obtain long-term data that could be used to establish benchmark hunting rates. The mound is part of a village-ceremonial complex on Mabuyag Island (Torres Strait), the home of the Goemulgal. Rituals took place at the mound to attract dugongs to the area. As part of these ceremonies, dugong remains, especially skulls, were deposited in the mound. Mound construction began ca. AD 1600 and ritual additions ceased by 1898. A single 70 cm×70 cm excavation pit, excavated to a maximum depth of 94 cm below the surface, contained 368 kg of deposit consisting primarily of dugong remains (Table 12.5; McNiven and Bedingfield 2008:512). Extrapolating from this single unit, the mound may have contained the remains of 9,971–10,954 dugong individuals, suggesting a pre-European harvest rate of 80–100 dugongs annually at Mabuyag Island alone. This harvest rate is much higher than the 100 dugongs per annum permitted for all of Torres Strait today. Based on the archaeological evidence, McNiven and Bedingfield (2008) argue that recent hunting rates are not the only explanations for the present decline in dugongs.

Many interpretations rely on correlations among colonization, deforestation, and related processes. Island ecosystems are particularly vulnerable to perturbations associated with human colonization (e.g., Morales et al. 2009). Easter Island (Rapa Nui, Chile), with its monumental statuary and isolation, has long attracted attention because of the possibility that human colonizers caused an ecological collapse leading to a cultural one. Hunt (2007) proposes that the first Polynesian colonists arrived around AD 1200, with deforestation and soil erosion beginning shortly thereafter (Horrocks and Wozniak 2008 suggest an earlier date: ca. AD 900). According to Hunt (2007), the island was covered by a mesophytic forest dominated by a giant palm (*Jubaea*), which is now extinct. Colonists introduced chickens and Pacific rats (*Rattus exulans*) to the island, though it is not known if the rats were brought intentionally or unintentionally. Pacific rats are omnivores with a preference for plants. Encountering minimal competition and predation on Rapa Nui, the rat population increased rapidly. Hunt (2007) argues that the rat population could have exceeded 3.1 million. The introduction of rats on other islands was accompanied by a decrease in the reproductive potential of trees because rats consumed the seeds. The trees of Rapa Nui had few defenses against these new predators. Palm endocarps from early colonial and noncultural contexts show evidence of gnawing by rats and archaeological deposits contain large quantities of rats. The number of rats eventually declines, which Hunt (2007) interprets as evidence that rats could not sustain large populations in the face of advancing deforestation. People and Holocene climate

Table 12.6 Measurements of the cat (*Felis*) from tomb 12 in the Elite Cemetery HK6 at Hierakonpolis compared to modern Egyptian specimens of two species of wild cat, in mm[a]

	HK6	*Felis silvestris libyca*	*Felis chaus nilotica*
Alveolar length, upper canine-first molar	37.3	26.3 (26.1–31.7) $n=12$	39.6 (34.9–41.9) $n=14$
Greatest length, upper fourth premolar	15.8	10.9 (9.9–11.9) $n=9$	14.9 (13.5–16.5) $n=18$

[a]Modern data include the mean, range, and number of individuals published by Osborn and Helmy (1980:437) and used by Linseele et al. (2008:2672). Modified from Linseele et al. (2008:2672) and Osborn and Helmy (1980:437)

change were additional causes of deforestation (e.g., Mieth and Bork 2010), but introduced organisms played a role in a complex web of interrelated environmental phenomena. Similar multicausal outcomes likely occurred on other islands that had few or no terrestrial herbivores and carnivores. Research such as this requires that well-dated depositional sequences be combined with good contextual control, sedimentary analysis, and biological studies because changes can occur within a very short time period.

Egypt is considered the probable center of domestication of today's domestic cats (*Felis catus*) and the wild cat (*Felis silvestris*) is interpreted as a likely wild progenitor (Bartosiewicz 1995; Clutton-Brock 1999; Linseele et al. 2007). *F. silvestris* is widespread in Africa, parts of southwest Asia, and Europe, leading some researchers to hypothesize that tamed or domesticated cats originated in other parts of its range (e.g., Driscoll et al. 2007; Vigne et al. 2004). A small cat with what seems to be a collar is depicted in an Egyptian tomb painting dated to 2500–2350 BC; though domestic status may not have been achieved until ca. 2040–1782 BC. Cats are common in Egyptian art after ca. 1976–1793 BC. The opportunity to examine the genotype and phenotype of the numerous cat mummies excavated from tombs in the early twentieth century AD is lost because many of these were used for fertilizer instead of being studied (Clutton-Brock 1999:138). Linseele et al. (2007) report on an incomplete cat skeleton buried around 3700 BC in a tomb at Hierakonpolis (Upper Egypt). The tomb contains the remains of several wild and domestic animals. Some of these animals were buried intact and others were buried as partial skeletons. The cat was a small, young (ca. 6–8 months old) male. Healed fractures of the humerus and femur indicate he lived in captivity for at least 4–6 weeks before he died (sacrificed?). Initial measurements and zoogeographical evidence suggest the Hierakonpolis cat could be attributed to *F. silvestris*. This is an early date for a tamed cat, preceding by several centuries illustrations of cats and numerous cat burials. Linseele et al. (2007) interpret the Hierakonpolis cat as evidence of an early stage when many species were kept in captivity, some of which subsequently were domesticated.

A key characteristic of the scientific method is reanalysis of earlier interpretations as part of a self-correcting process upon which scientists rely. Linseele et al. (2008) revise their 2007 attribution of the Hierakonpolis cat using additional materials from the tomb and published sources (Table 12.6; Linseele et al. 2008:2672; Osborn and Helmy 1980:437). In particular, they reevaluate their interpretation that the small,

young cat was *F. silvestris* and could be evidence of an early stage of cat domestication. In their 2007 publication, the authors consider, and reject, the possibility that the cat was one of the other small wild felids in the region. The 2007 attribution was based on relatively few reference measurements because many museum reference collections contain only skulls, whereas the Hierakonpolis materials available for the study published in 2007 were all postcranial specimens. The difficulties posed by the limited series of comparative measurements available to study the cat were compounded by the fact that the animal had not achieved adult size. Further work with animal remains from the tomb found measurable cranial elements, which made additional comparative measurements available for evaluating the archaeological materials. The expanded study indicates that the remains of the Hierakonpolis cat are those of the jungle cat (*Felis chaus*), another species of wild cat in the region. Linseele et al. (2008) conclude that the Hierakonpolis cat is not evidence for an early stage of domestication, but one of many wild animals kept in captivity.

Summary

Analyses of vertebrate and other animal remains contribute to our understanding of the evolution of landscapes and cultures, the distribution of organisms in landscapes, and the impact of people and environments on each other. The quality of those contributions depends first of all on the quality of the samples available for study. As with other biological remains, attention must be paid to all facets of deposition, excavation, identification, and interpretation to obtain reliable information. Only in this way can data from a specific context or site enlarge upon temporal, spatial, behavioral, and theoretical perspectives. Most of the research reviewed in Chaps. 6–12 relies upon accurate taxonomic attributions, which often are difficult to achieve. The archaeological record contains information for which taxonomic identity may not be needed or that cannot be associated with a specific taxon. These data, and techniques to obtain and evaluate them, are addressed in the next chapter.

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Chapter 13
Stable Isotopes, Elements, and Biomolecules

The most dramatic advances in environmental archaeology during the past few decades are in archaeological applications using stable isotopes, chemical elements, organic molecules and compounds (e.g., enzymes, blood residues), and genetic material. These methods merge biological, chemical, and physical attributes to forge interdisciplinary perspectives on environments and cultures (e.g., Leng 2006; Pollard and Heron 2008; Reed 2005; Zeder et al. 2006). Although they are applied to a wide range of phenomena, the focus here is on applications related to biological materials and the human sphere of influence. Many of these analyses verify or elaborate interpretations developed from studies of other archaeological materials or suggest new directions for additional research.

Much of environmental archaeology is guided by questions such as: What organisms were present at this site? What aspects of human–environmental relationships are learned from these organisms? What did these relationships mean for organisms, populations, communities, ecosystems, and people? Except in a few cases, the approaches reviewed in this chapter often are not intended to provide the taxonomic identifications needed to answer these questions. Instead, they draw upon connections fundamental to organic remains, such as those among chemistry, climate, sediments, geochemistry, and trophic levels. Most do not yield direct evidence of specific diets, stresses, residential patterns, or other environmental, ecological, and cultural phenomena. Instead, they elaborate upon systemic relationships that unify multiple classes of materials. Subjecting modern plants and animals to isotopic, chemical, and genetic analyses establishes baselines that can be used to verify, interpret, and expand upon the results and interpretations derived from taxonomic studies and provides insights into diet, health, status, mobility, environments, and ecosystems not available from single sources of data.

Biological, chemical, and physical attributes and relationships among isotopes, elements, organic molecules, and genetics are much more complex than this summary implies. They are subject to many individual, geographical, temporal, taphonomic, cultural, and analytical variables (e.g., Andrus 2011; Evershed et al. 2003; Grupe et al. 2009; Hallmann et al. 2009; Pollard and Wilson 2001). The most

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successful applications are those that use modern reference specimens and standards as controls and draw upon multiple perspectives and proxies to corroborate and refine results. Many of these methods use human skeletal and dental remains as sources of primary data. When human remains are unavailable for study, proxy organisms may be used. Two of the most common proxies are dogs (*Canis familiaris*) and pigs (*Sus domesticus*), animals that have shared environments, histories, diseases, and diets with people for millennia (e.g., Barton et al. 2009; Morey 2006; Shaw et al. 2009; White et al. 2001).

Stable Isotopes

Isotopes are different varieties of a chemical element that have the same number of protons but different numbers of neutrons in their nuclei (singular: nucleus). The number of protons gives the element its **atomic number**. For example, oxygen has eight protons so its atomic number is 8. Oxygen has eight electrons because the number of protons is balanced by the number of electrons. The **atomic mass**, however, is the number of protons plus the number of neutrons. There are several isotopes of oxygen, for example, each of which has a different number of neutrons. Atomic mass is the designation by which the isotope commonly is known (^{16}O, ^{17}O, ^{18}O), though the full notation includes the atomic number as a subscript (i.e., $_{8}{}^{16}O$).

Isotopes may be either unstable or stable. **Unstable isotopes** spontaneously decay into other elements. In the most familiar isotopic application, the unstable isotope of carbon (^{14}C) decays into nitrogen at a predictable rate after an organism dies, a relationship fundamental to radiometric dating (Renfrew and Bahn 2008:142). **Stable isotopes** are not radioactive; they do not spontaneously decay or change. Archaeological applications of stable isotopes rely on this characteristic (e.g., Hoefs 2009). Stable isotopes, nonetheless, are subject to many biogenic and diagenetic processes.

Analyses of stable isotopes from organic remains, tools, and other archaeological materials offer qualitative perspectives into life histories, habitats, and niches of the resources consumed. Stable isotopes are used primarily, though not exclusively, to assess the provenance of people and resources (e.g., migration, trade, the biogeography of domestication), roles of specific groups of plants in diets, proportions of plants and animals in diets, uses of diverse trophic levels, roles of nonnative domesticated plants, and climatic regimes (Schwarcz et al. 2010). In some cases, they may distinguish between closely related domestic and wild animals (e.g., Noe-Nygaard et al. 2005). Barrett et al. (2011) use stable isotopes of carbon and nitrogen to distinguish between cod (*Gadus morhua*) taken from local waters near 12 archaeological sites in England and Belgium and those that were part of a long-distance trade in preserved fish transported from Norway, Iceland, or Scotland. They conclude that initially cod were from local waters, but subsequently were obtained from more distant waters as part of the globalization of the world's fisheries. The stable isotopes most frequently examined are those of oxygen, carbon, and nitrogen, though

barium, lead, strontium, and sulfur also are studied (e.g., Hedges et al. 2006; Linderholm and Kjellström 2011; Nehlich and Richards 2009; Rasmussen et al. 2008; see Table 1.1 for a list of elements and symbols). Ratios of hydrogen isotopes ($^{2}H/^{1}H$; $\delta^{2}H$, reported as δD because ^{2}H is commonly referred to as deuterium) are indicators of trophic levels or geographical origins (Pollard and Heron 2008:352–353; Reynard and Hedges 2008).

Dietary Applications

One major use of stable isotopes targets food webs and diets. Due to the different sources of essential nutrients and changeable environments, diets combine nutrients derived from many sources, resulting in a complexity that is difficult to capture through the identification of specific organisms from archaeological remains (e.g., Bocherens et al. 2006). Human remains may provide evidence of health status that can be linked to nutrition, but rarely indicate the actual foods and beverages consumed. Stomach contents and palaeofeces provide direct evidence of consumption, but only for those substances ingested just prior to death (stomach contents) or at one moment in time (palaeofeces). Taxonomic lists of plants and animals provide few insights into the ways these ingredients were combined into drugs, beverages, and foods, or who used them and why. Even in those very rare cases when the remains of plants, animals, human skeletons, stomach contents, and palaeofeces are available from the same temporal, spatial, and functional contexts, the results may be incomplete or incompatible due to site formation processes and differences in data collection (e.g., Grupe 2001; Pollard and Wilson 2001). Similar challenges are encountered in studies focused on environments and ecosystems.

Dietary variations derive from relationships such as the proportions of meat to plant foods consumed, the sources of those foods, and the position of these resources in the food chain. These relationships are studied by measuring carbon and nitrogen isotope ratios in organic remains. Different isotopes of carbon and nitrogen are preferentially taken up or retained at different rates by plants and animals along the food chain. Consequently, the relative proportions of isotopes in organisms that are producers and those that are consumers differ in a systematic, predictable manner. This change through trophic levels involves depletion or enrichment of isotopes and is measured as a ratio of the heavier or rarer isotope to the lighter or more abundant one with reference to a standard (Gaines et al. 2009:289; Leng 2006:297; Pollard and Heron 2008:420–423).

In the most common archaeological applications, ratios of ^{13}C to ^{12}C or of ^{15}N to ^{14}N in organic materials are compared with these ratios in standards. The standard for carbon originally was carbon dioxide (CO_2) in a marine fossil (*Belemnitella*) obtained from the Cretaceous Pee Dee formation of South Carolina (USA), which was free of ^{14}C. This source, known as **Pee Dee Belemnite** (PDB), is depleted and was replaced by a new standard known as **Vienna PDB** (VPDB; Gaines et al. 2009:289). The standard for nitrogen is atmospheric nitrogen (**Ambient Inhalable**

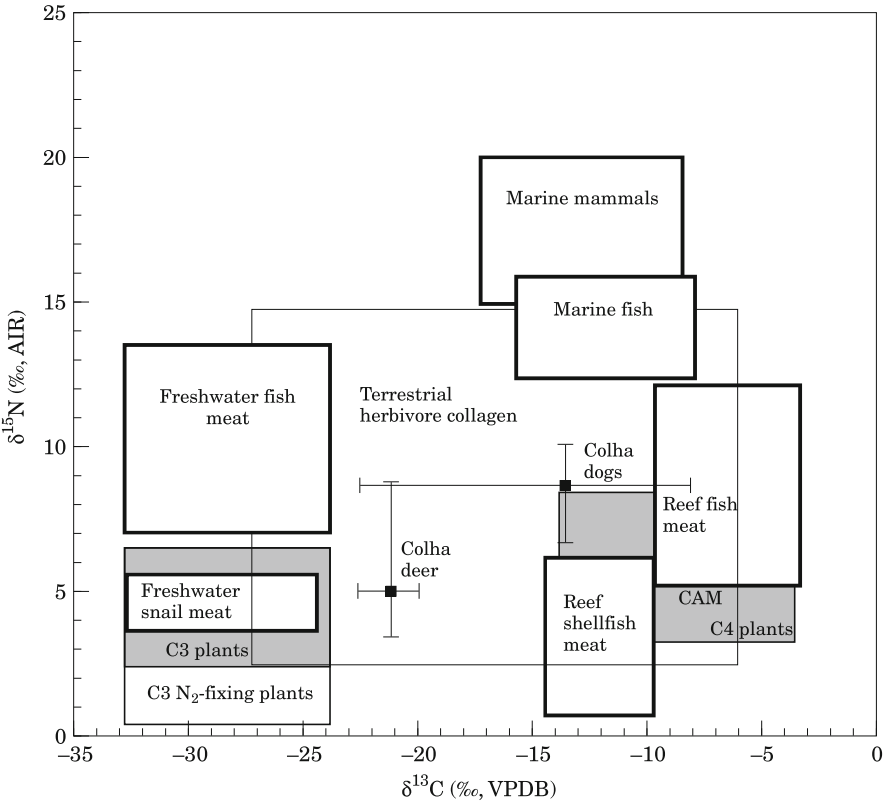

Fig. 13.1 Theoretical model of major Maya food resources showing the $\delta^{13}C$ and $\delta^{15}N$ ranges for most plants (*large box*), C_3 and C_4 plants (*shaded boxes*), dogs (*Canis familiaris*), and white-tailed deer (*Odocoileus virginianus*) from Colha (Belize) within the model. The $\delta^{13}C$ values are not adjusted for a diet-collagen offset (~5‰) and the $\delta^{15}N$ values are not adjusted for trophic level (~3‰). From White et al. (2001:95) and used by courtesy of the authors and Elsevier

Reservoir [AIR]). Deviations from these standards are expressed using the delta notation (**delta [δ]**). This is a relative measure of differences in the ratio of stable isotopes in a material compared with the standard (Leng 2006:291). Differences are measured in parts per thousand (**per mil, per mille, ‰**). The measure of difference is expressed as a positive or negative departure from the standard. $\delta^{13}C$ values are negative compared with the standard and $\delta^{15}N$ typically is more positive than the standard.

Ratios of $^{13}C/^{12}C$ and of $^{15}N/^{14}N$ change as they pass through the food chain from their sources in producers (e.g., autotrophs, plants) to consumers (e.g., heterotrophs, animals; Fig. 13.1; Grupe et al. 2009; White et al. 2001:95). Bone collagen $\delta^{13}C$ values reflect the isotopic characteristics of the primary production source. Bone collagen is replaced slowly during the life of the organism; thus isotope ratios in collagen reflect consumption over many years (Barton et al. 2009). Although related

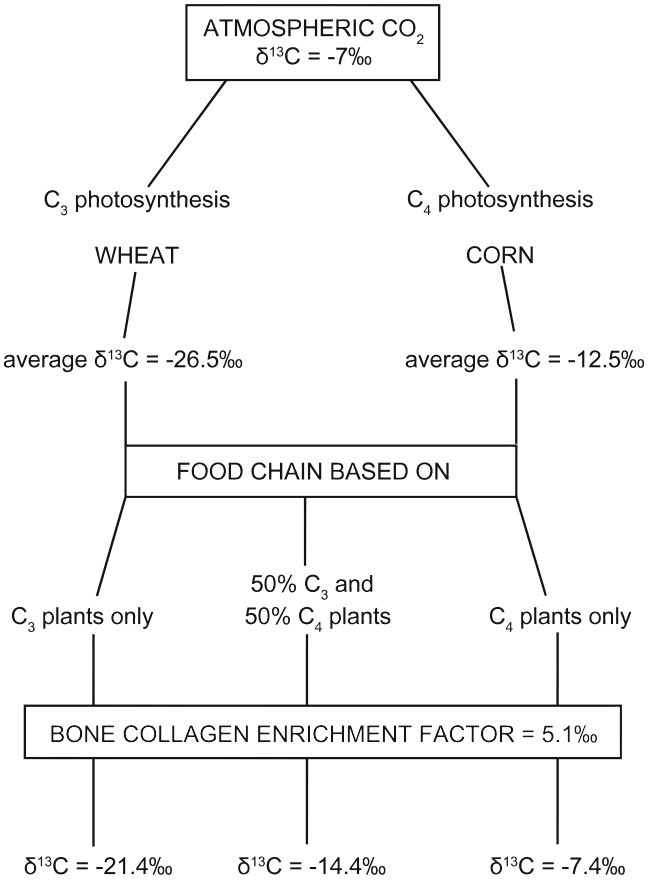

Fig. 13.2 Photosynthetic plant fractionation of carbon isotopes and its effects on ^{13}C in human bone collagen in three different vegetarian diets. One of the diets is based entirely on C_3 plants, one combines C_3 and C_4 plants, and the third consists entirely of C_4 plants. Data from van der Merwe (1982:602). Average values are shown. From Herz and Garrison (1998:283) and used by courtesy of the authors and Oxford University Press

primarily to diet, ratios also reflect local environments and broader climatic regimes. For example, marine fishes and mammals have higher (less negative) $\delta^{13}C$ values than do terrestrial herbivores, but freshwater fishes have lower (more negative) $\delta^{13}C$ values than either terrestrial or marine animals. Stable isotopes of carbon and nitrogen are often used together; a spatial or temporal change in both $\delta^{13}C$ and $\delta^{15}N$ values is strong evidence for dietary differences. Nitrogen isotope ratios ($\delta^{15}N$ values) reflect the trophic levels of foods consumed.

As carbon passes through the food chain from autotrophs to consumers, the abundance ratio of the isotopes ^{13}C to ^{12}C is systematically changed by biogeochemical and physical processes (**fractionation**; Fig. 13.2; Herz and Garrison

1998:283; van der Merwe 1982:602). This makes it possible to distinguish three broad groups of autotrophs defined by the **photosynthetic pathway** used by members of each group to convert CO_2 into three-carbon (C_3) or four-carbon (C_4) molecules. These are known as C_3 (Calvin-Benson), C_4 (Hatch-Slack), and CAM (crassulacean acid metabolism) pathways. The photosynthetic cycle strongly fractionates carbon isotopes when plants metabolize atmospheric CO_2. In most locations, ^{12}C is much more common than ^{13}C (99% ^{12}C and 1% ^{13}C). During photosynthesis, the heavier ^{13}C is discriminated against in favor of the lighter ^{12}C (Ambrose 1993; Larsen 1997:271). Plants with different photosynthetic pathways have different ratios of ^{13}C to ^{12}C, as do herbivores that consume them, and carnivores feeding on those herbivores. A significant C_4 component may be produced from consuming C_4 plants or animals that eat C_4 plants. C_3 and C_4 pathways are associated with specific combinations of atmospheric CO_2 and daytime temperatures during the growing season (Edwards et al. 2010).

The interpretation of stable isotopes from coastal settings is more complex because dissolved CO_2 is less abundant in seawater. Although marine plants are primarily C_3 plants, they tend to have $\delta^{13}C$ values similar to those of C_4 terrestrial plants, which is reflected in the less negative $\delta^{13}C$ values of reef fishes compared with freshwater fishes in Fig. 13.1.

The **C_3 pathway** is the most common pathway, found in 97% of vascular plant taxa (Edwards et al. 2010). C_3 plants convert CO_2 less efficiently than do C_4 plants. Consequently, they have less ^{13}C in their tissues and lower $\delta^{13}C$ (i.e., more negative) values than do C_4 plants. C_3 plants often grow at high latitudes, at high elevations, and in areas with high winter rainfall or a cool growing season (Ambrose 1993). Most broad-leaved and temperate zone terrestrial trees, shrubs, grasses, and forbs are C_3 plants. These include oats (*Avena sativa*), barley (*Hordeum vulgare*), rice (*Oryza sativa*), and wheat (*Triticum aestivum*). Algae, phytoplankton, root crops, and legumes use the C_3 pathway and honey has a C_3 signature. Consumers of C_3 plants have $\delta^{13}C$ values within the range of C_3 plants (Fig. 13.1).

The **C_4 pathway** is associated with warm, low altitude, low latitude grasslands. Plants using this pathway are more efficient at using CO_2, take up more ^{13}C than do C_3 plants, and have characteristically higher $\delta^{13}C$ values (Fig. 13.2). C_4 plants generally grow in sunny, dry habitats with high temperatures and strong sunlight during the growing season (Ambrose 1993). The C_4 pathway is particularly associated with grasses (Gramineae [Poaceae]), though 40% of C_4 taxa are not grasses (Edwards et al. 2010). C_4 plants include: amaranths (*Amaranthus*), chenopods (*Chenopodium*), common millet (*Panicum miliaceum*), some sugarcanes (*Saccharum*), sorghum (*Sorghum bicolor*), and maize (*Zea mays*), as well as tropical pasture grasses and salt-marsh grasses (Ambrose 1993). People eating mostly tropical grains and animals grazing on C_4 plants have $\delta^{13}C$ values similar to those of C_4 plants. In northern latitudes, elevated $\delta^{13}C$ values associated with C_4 plants would be unexpected. If high $\delta^{13}C$ values are found in animal remains in northern locations, this may indicate consumption of introduced (i.e., domesticated) C_4 plants (e.g., Barton et al. 2009). The primary domesticates in many regions, such as north China, Mesoamerica, and sub-Saharan Africa, are C_4 plants (Cunniff et al. 2010).

CAM plants fix CO_2 by either pathway depending upon environmental variables such as salinity, day length, night temperature, and water. Consequently, their isotope ratios are intermediate and may overlap with local C_3 or C_4 plants (Larsen 1997:272). In hot, arid regions, CAM plants may have $\delta^{13}C$ values similar to C_4 plants. CAM plants include cacti (Cactaceae), spurges (Euphorbiaceae), agaves (Agavaceae), bromeliads (Bromeliaceae, e.g., pineapple [*Ananas comosus*]), and orchids (Orchidaceae, e.g., vanilla [*Vanilla*]).

In archaeological applications, carbon isotopes are most commonly studied in both the organic (collagen) and inorganic (variously referred to as hydroxyapatite, hydroxylapatite, carbonate, bioapatite, or apatite; Chap. 12) constituents of human skeletal and dental remains. Researchers disagree about which carbon isotopes are best studied in which tissues (Ambrose 1993; Garvie-Lok et al. 2004; Grupe et al. 2009; Lee-Thorp and Sponheimer 2003). Generalizing broadly, collagen is composed of amino acids and should more closely reflect ^{13}C in dietary protein sources, whereas the carbonate in hydroxyapatite reflects dietary inputs from carbohydrates, fats, and proteins (Grupe et al. 2009). Mixed diets combining terrestrial and aquatic foods that vary seasonally and over time will diminish the correlation between $\delta^{13}C$ in collagen and carbonate, especially given the complexity of aquatic ecosystems (e.g., Katzenberg et al. 2009). Postmortem changes in collagen are measured using the ratio of elemental carbon and nitrogen (C:N) as a screening method (Nehlich et al. 2009).

Similar $\delta^{13}C$ values are produced by distinct combinations of C_3 plants, C_4 plants, and marine foods. Marine fishes and mammals have $\delta^{13}C$ values that are relatively more positive than those of terrestrial animals feeding on C_3 plants and slightly more negative than those of terrestrial animals feeding on C_4 plants (e.g., Fig. 13.1; van der Merwe et al. 1993). In other words, marine animals have $\delta^{13}C$ values that fall between those for C_3 and C_4 terrestrial plants. Differences in carbon isotope ratios are associated with water depth; shallow waters have more positive values than do deeper waters (Grupe et al. 2009). Combining carbon and nitrogen isotopic studies with identifications of organic remains may clarify instances in which terrestrial and marine signatures overlap.

Nitrogen is studied in a variety of organic materials, but archaeological applications focus on bone collagen and other proteinaceous materials such as keratin and muscles (when these survive). Nitrogen isotopes are used primarily to assess trophic levels, often in combination with carbon isotopes (e.g., Fig. 13.1). The ^{15}N isotope is concentrated or enriched as nitrogen is transferred from plants to herbivores and then to carnivores; thus $\delta^{15}N$ values are more positive in a consumer than in the standard (AIR) or in the food source. Nitrogen-fixing legumes, such as peas (*Pisum*), peanuts (*Arachis*), and beans (*Phaseolus*), obtain nitrogen from both the atmosphere and soil, whereas nonlegumes obtain it only from soil. Thus, nitrogen-fixing terrestrial plants may have $\delta^{15}N$ values very similar to AIR. Because soil nitrate and ammonia have higher ^{15}N levels than AIR, nonlegumes have higher $\delta^{15}N$ values than do legumes.

Most marine $\delta^{15}N$ values are higher than terrestrial ones. Freshwater and marine food chains are longer than terrestrial ones and contain more trophic levels, many

of which are occupied by carnivores. Because marine plants have higher concentrations of ^{15}N than do terrestrial plants, marine mammals have higher $\delta^{15}N$ values than do terrestrial mammals (Fig. 13.1; Ambrose 1993; Larsen et al. 1992). Blue-green algae, however, have $\delta^{15}N$ values similar to AIR.

It is for these reasons that nitrogen isotopes provide information about trophic levels and distinguish between terrestrial and marine food chains. Bone collagen $\delta^{15}N$ is enriched by 3–5‰ with each trophic level. Animals feeding at high trophic levels have higher $\delta^{15}N$ values than do those feeding at lower trophic levels; terrestrial herbivores have lower $\delta^{15}N$ values than do omnivores and carnivores in the same ecosystem. $\delta^{15}N$ values have a negative correlation with rainfall in terrestrial locations; they are higher in deserts than in areas with high rainfall (e.g., Schwarcz et al. 1999). Nursing children have slightly higher $\delta^{15}N$ values than their mothers; $\delta^{15}N$ declines after weaning when children begin eating adult diets that often are richer in plant foods. Temperature, humidity, soil conditions, diagenesis, physiology, pathologies, breast feeding, herding practices, and irrigation all influence $\delta^{15}N$ values (Larsen 1997:282–284; White et al. 2009). Experimental work shows that manuring as a crop management practice raises $\delta^{15}N$ values in grains and chaff and may produce ratios in human remains that suggest largely animal-based or mixed plant/animal diets even when the diet actually consisted primarily of plants (e.g., Bogaard et al. 2007; Jones et al. 2010).

Studies confined to either collagen or bone mineral, or to specific skeletal or dental remains, are constrained by the amount of organic and inorganic constituents in the specific specimen being studied, the survival potential of that specimen, and the probability that the specimen contains a record of only part of the life cycle. Vertebrate hard tissues have different percentages of organic and inorganic constituents (Table 12.3). Enamel does not remodel and is resistant to diagenesis, though not impervious (Lee-Thorp and Sponheimer 2003). If the study uses tooth enamel, the organic component will be low, though the inorganic component will be high. The isotopic record will be that of isotopes incorporated into the enamel when the tooth formed early in life. Although in some cases teeth may grow throughout the animal's life (e.g., rodent incisors), this is not typical of many teeth, particularly of mammals. The other component of teeth, dentine, has a relatively high amount of bone mineral and does not remodel, so it is another record of early-life events. Dentine, however, can be brittle in archaeological specimens and may not survive in usable form (Hillson 2005:184–185, 189). Bones remodel and reflect sources of foods and liquids, seasonality, and mobility during the last 10–30 years of life in long-lived organisms such as people (Nehlich et al. 2009; White et al. 2009). Skeletal remains containing low amounts of bone mineral, such as those of young individuals, may have poor survival potential. Thus, skeletal elements are a better source of information about diets during adulthood than for the early years of life, but may not survive as well as teeth.

The advantage of studying isotopes in keratin is that materials such as nails and hair grow very quickly, do not remodel, and record dietary variations on shorter time scales than do enamel, dentine, and skeletal remains (Schwarcz and White

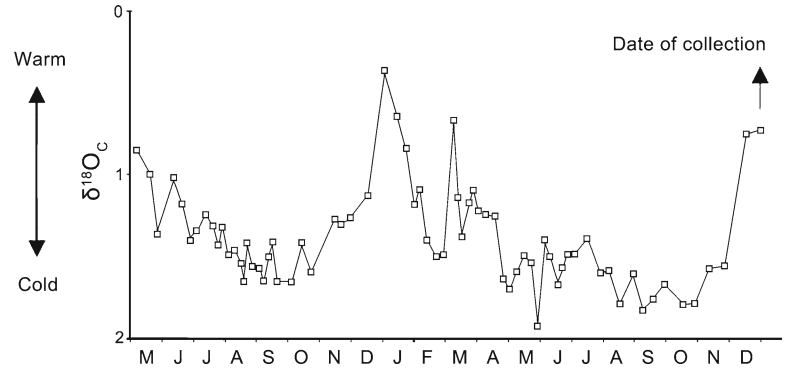

Fig. 13.3 Stable oxygen isotopic ratios ($\delta^{18}O$ in ‰ vs. VPDB) measured along the growth axis of a surf clam (*Mesodesma donacium*) shell (N5-1) from level N5 of the archaeological site Quebrada de los Burros (Peru). Shell $\delta^{18}O$ variations reflect changes in the sea surface temperature. A monthly time scale was reconstructed from the shell growth lines. The end of the profile provides the collection date for this individual. A comparison of the date of collection determined by isotopic profiles and sclerochronology was performed on 12 archaeological shells. From Carré et al. (2009:1175) and used by courtesy of the authors and Elsevier

2004; White et al. 2009). Studies of living humans find no significant differences in carbon isotope ratios of major proteins in keratin. Nail keratin has higher $\delta^{15}N$ values compared with hair keratin in the same individual and bone collagen has both higher $\delta^{15}N$ values and higher $\delta^{13}C$ values relative to hair keratin (O'Connell et al. 2001).

Environmental Conditions

Although stable carbon and nitrogen isotopes are used to study environmental conditions (e.g., Alam et al. 2009; Iriarte et al. 2010), the isotopes most frequently associated with environmental conditions are those of oxygen (^{18}O, ^{16}O). This is measured as a ratio of the rare, heavier isotope to the more abundant, lighter one ($^{18}O/^{16}O$). Oxygen fractionation in carbonates is sensitive to environmental conditions, many of which are related to temperature and salinity (Andrus 2011).

The standard for oxygen may either be **Standard Mean Ocean Water** (SMOW) or **Vienna Standard Mean Ocean Water** (VSMOW). The $\delta^{18}O$ value in carbonate materials reflects the ratio present in the surrounding water when the carbonate precipitated. Broadly speaking, higher ratios correspond to cooler waters and lower ratios to warmer ones (e.g., Fig. 13.3; Carré et al. 2009:1175). As temperature rises, the ambient amount of ^{18}O in water declines relative to ^{16}O and the $\delta^{18}O$ value is lower or more negative. The $\delta^{18}O$ values in aquatic organisms mirror those in their

environments. Marine environments are enriched with ^{18}O and freshwater systems are depleted (Grupe et al. 2009). In the case of marine mammals, drinking water is derived from food and freshwater films that accumulate in the ocean (Grupe et al. 2009). $\delta^{18}O$ values of terrestrial mammals reflect the isotope ratio of drinking water, food, and atmospheric oxygen. The relationships between oxygen isotopes and carbonates in organisms are more complex than this summary implies (e.g., Grupe et al. 2009; Hallmann et al. 2009).

Oxygen isotopes are most frequently studied in calcium carbonate structures of aquatic organisms (Andrus 2011). Calcium carbonate precipitates in isotopic equilibrium with surrounding water in diatoms, foraminifera, corals, ostracods, molluscs, and fishes (e.g., Quitmyer et al. 1997). Experimental studies of $\delta^{18}O$ values in these organisms show that increments related to episodic growth generally correspond to water temperature, but salinity, rates of evaporation, rainfall, other freshwater inputs, latitude, altitude, and proximity to marine environments also are involved (e.g., Andrus and Crowe 2000; Andrus et al. 2002; Mannino et al. 2003). Coastal settings are analytical challenges because of the tidal mixing with the open ocean and influx of fresh waters from coastal rivers (e.g., Culleton et al. 2009). The temperatures prevailing during an animal's last growth episode may be derived from the final increment (e.g., Andrus 2011; Culleton et al. 2009). Periodic formation of increments is not necessarily seasonal, thus isotopic analysis should be combined with visual inspection of the increments (Andrus and Crowe 2000; Andrus et al. 2002). Aquatic temperature regimes should not be equated with atmospheric temperature because of the time lag between aquatic and atmospheric temperatures.

Oxygen isotopes are present in the bone mineral of nonaquatic organisms, providing both environmental and cultural information. Oxygen isotopes bound to the phosphate in hydroxyapatite are more likely to be well preserved than are those bound to the carbon (Weiner 2010:87). Phosphate oxygen is considered equivalent to carbonate oxygen and is related to drinking water and water in plants (Hedges et al. 2006). Oxygen isotopes reflect periodic (e.g., seasonal) temperature and moisture regimes, latitude, altitude, distance from the nearest coast, and sources of drinking water (Turner et al. 2009). In most mammals, tooth enamel grows rapidly during fetal development and early life as the first set of teeth forms and is replaced by adult dentition. Variations in $\delta^{18}O$ values in tooth enamel may reflect maternal water sources prior to weaning and other sources of water consumed as teeth develop, all of which reflect water sources used before adulthood. Variation among individuals and between individuals and local water sources, for example, indicate substantial variations in sources of drinking water during tooth development within the Machu Picchu (Peru) human population, suggesting that people who died at the site spent at least part of their early lives in several other locations (Fig. 13.4; Turner et al. 2009:324). Oxygen isotopes in increments in the enamel of herd animals provide insights into the use of specific animals in the annual cycle and seasons of birth and mortality in animals, permitting tests of models relying on evidence of annual cycles in herd management strategies, herd mortality profiles, and human residential mobility (Fig. 13.5; Balasse et al. 2003:208; Schwarcz et al. 2010:350).

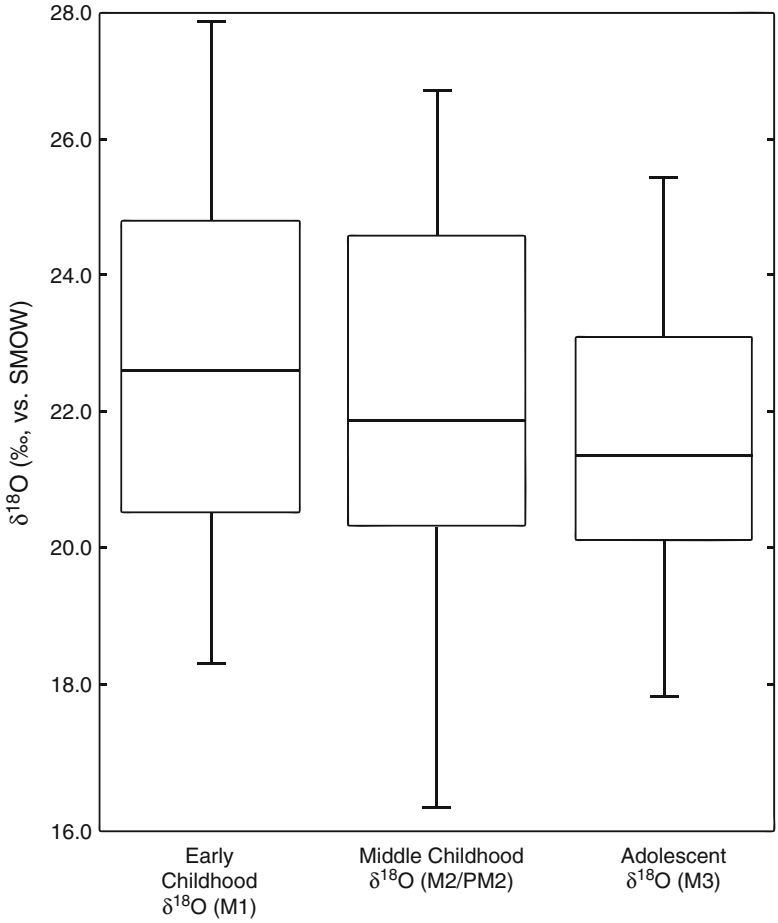

Fig. 13.4 Machu Picchu (Peru) enamel $\delta^{18}O$ in human teeth classified by developmental stage (early childhood, middle childhood, adolescence). Developmental stage is based on the general age of individuals when tooth enamel forms in second premolars and in first, second, and third molars. Plots show the mean (*horizontal bar*), second standard deviation (*box*), and range (*vertical bar*) for each stage. From Turner et al. (2009:324) and used by courtesy of the authors and Elsevier

Reference collections should be collected with archaeological applications in mind. This may require collecting or capturing species under controlled conditions at regular intervals throughout at least one annual cycle in the region of the archaeological study. Changes in annual temperature regimes and in longer climatic patterns may be incorporated into the reference specimens by collecting organisms from locations at the extreme margins of their present geographical range to observe differences in growth patterns and isotope ratios under different environmental conditions.

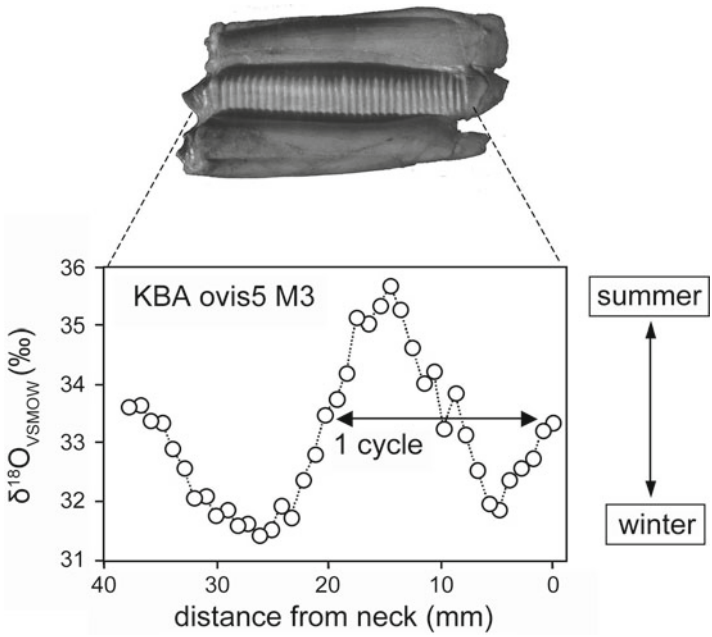

Fig. 13.5 Sequential sampling of enamel along the tooth, and intra-tooth variation in oxygen isotopic ratios ($\delta^{18}O$) of enamel bioapatite in a sheep (*Ovis aries*) third molar (M3) from Kasteelberg (South Africa). One and a half cycles are represented in the tooth, indicating the age of the animal at death and the season of death. KBA refers to Kasteelberg A, ca. 1860–1430 BP, an occupation of Late Stone Age pastoralists. From Balasse et al. (2003:208; see also Schwarcz et al. 2010:350) and used by courtesy of the authors, Elsevier, and Springer Science + Business Media

Elemental Analysis

Elemental concentrations in organic and inorganic materials show broad variations that may correlate with the trophic levels of organisms and their natal environments. **Major elements** are carbon, hydrogen, iron, nitrogen, calcium, phosphorous, oxygen, potassium, sulfur, chlorine, sodium, and magnesium (Table 1.1; Larsen 1997:290). These are needed for structural maintenance, generally in relatively large quantities. **Trace elements**, such as zinc, manganese, lead, mercury, and cadmium, are needed in small amounts and often work in tandem with enzymes in metabolic processes. Some major elements may be toxic depending on the overall health of the organism and the amount ingested. Some trace elements are toxic at very low levels.

Strontium is an alkaline earth metal present in trace amounts in the geological substrate. Background strontium levels usually are derived from local bedrock, soils, and groundwater. The relative abundance of ^{87}Sr and ^{86}Sr ($^{87}Sr/^{86}Sr$) reflects geological age, mineral composition, and weathering patterns of the parent material as well as the proximity of a marine environment. Older rocks have higher $^{87}Sr/^{86}Sr$

ratios than do younger ones. Sea water strontium isotope ratios are generally much higher than ratios in the terrestrial bedrock and terrestrial plants and animals on the adjacent coast.

Elemental concentrations of strontium, ratios of strontium to minerals such as calcium (Sr/Ca) and barium (Sr/Ba), and isotope ratios of ^{87}Sr to ^{86}Sr in enamel, dentine, and bone reflect the trophic level of the organism (Nehlich et al. 2009; Price et al. 2002; Slovak et al. 2009; the δ notation is not often used for Sr isotope ratios [Pollard and Heron 2008:370]). Isotopes of strontium pass through the food chain without fractionation; but the amount of strontium decreases up the food chain because animals preferentially retain calcium while excreting strontium. Plants absorb strontium from soil and water, along with calcium, in proportions roughly equal to its presence in the environment. Strontium concentrations differ in terms of the kind of plant and the part of the plant consumed or studied. Animals acquire strontium through foods and liquids. Animals cannot excrete all the strontium they ingest and what remains is deposited in enamel and dentine, during early development, and in bone throughout life. Woody vegetation accumulates higher strontium concentrations than do grasses; therefore, **browsers** (e.g., animals eating leaves, shoots, etc. of shrubs or trees) have higher concentrations of strontium than do **grazers** (e.g., animals eating grasses, etc.). Carnivores have lower ratios of strontium to calcium than do herbivores; omnivores have intermediate ratios.

As with other elements, strontium is subject to complex biogenic and diagenetic processes. Strontium isotopes in enamel represent ratios of ^{87}Sr to ^{86}Sr in local geological formations experienced by young individuals while tooth enamel forms, which can be over a period of several months or years (e.g., Montgomery et al. 2010). Strontium in skeletal remains is more likely to reflect the geochemistry of the region in which the individual lived later in life (Slovak et al. 2009). Thus, there is a distinction between strontium archived in enamel during tooth formation and that ingested subsequently if the individual changed residential area after enamel and dentine were formed. Although enamel is resistant to diagenesis, dentine and bone are sensitive to such processes (Price et al. 2002); bone may absorb strontium from the soil in which it is buried (Schwarcz et al. 2010).

Strontium provides data about the relative proportions of plants and animals in the diet and of marine and terrestrial organisms consumed, but it is most frequently used to assess residential patterns and migrations (e.g., Chenery et al. 2010; Larsen 1997:288–289; Nehlich et al. 2009; Price et al. 2002; Shaw et al. 2009; Slovak et al. 2009; Turner et al. 2009). If people relied heavily on marine foods, as they might do in coastal settings, strontium ratios will reflect the marine strontium level instead of the terrestrial one. Likewise, if people relied on imported foods, their strontium ratios reflect those external food sources. Dufour et al. (2007), for example, analyze both oxygen and strontium isotopes in the tooth enamel of carp (Cyprinidae: *Carassius, Cyprinus, Pseudophoxinus, Tinca*) to assess the origin of fishes traded to Sagalassos (Turkey). From the geochemical signatures in these teeth, the authors conclude that fishes were from lakes rather than rivers, though they are unable to specify which lakes because the carp $^{87}Sr/^{86}Sr$ ratios do not match those found in local lakes (Fig. 13.6; Dufour et al. 2007:1234).

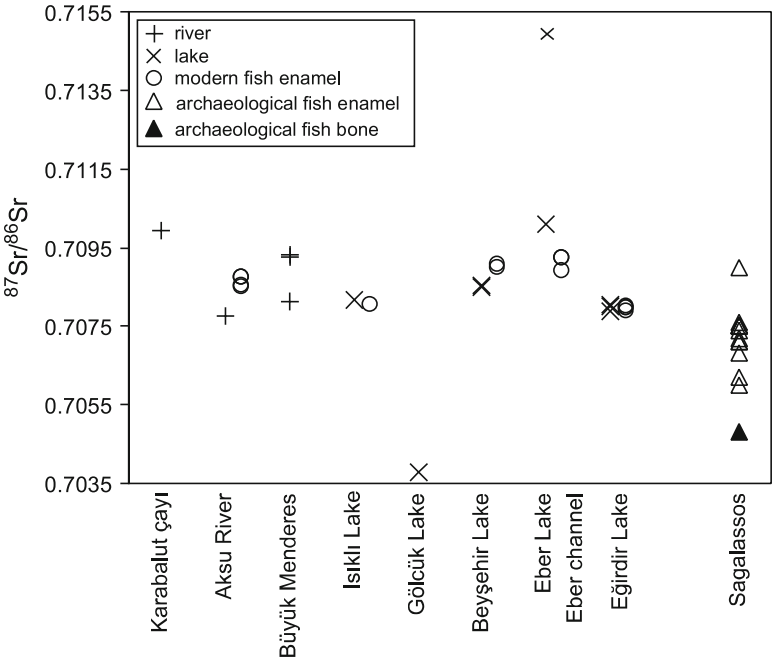

Fig. 13.6 $^{87}Sr/^{86}Sr$ ratios of water environments and tooth enamel of modern fish (*Cyprinus carpio* and other fish species) from several locations in Anatolia (Turkey) compared with strontium ratios in tooth enamel and bone of archaeological carp from Sagalassos (Turkey). From Dufour et al. (2007:1234) and used by courtesy of the authors and Elsevier

Many strontium applications focus on residential patterns, such as distinguishing between where an individual lived while young and where the individual lived and died as an adult. Differences between the strontium ratios in human remains compared with those at the burial site is evidence that the person spent some time elsewhere. Tooth enamel with strontium ratios dissimilar to those in the bedrock at the archaeological site from which the teeth were recovered probably indicates that the individual lived elsewhere as a juvenile or subadult. Differences in the strontium ratios in the enamel and bone mineral of the same individual suggest that the individual lived in different places as a juvenile and as an adult. Such studies offer insights into mobility, population diffusion, residence, colonization, and forced relocations (e.g., kidnapping, slavery). A similar approach can be taken for domestic animals.

Barium, lead, sulfur, copper, iron, and zinc provide information about health, diet, climate, diagenesis, and other environmental and cultural phenomena (e.g., Hjulström and Isaksson 2009). Although barium is very similar to strontium, it does fractionate. Consequently, barium values are lower in herbivores than in plants, lower in carnivores than in herbivores, and lower in marine environments than in terrestrial ones (Arnay-de-la-Rosa et al. 2011; Larsen 1997:294–295). Lead does

not appear to have a trophic level effect; but lead concentrations and lead isotopes ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, abbreviated as $^{20n}/^{204}Pb$) can suggest trade routes and the amount of lead absorbed, ingested, or inhaled from soil, dust, and food. Lead-glazed ceramics and pewter are significant sources of lead and lead also is used in body paints, shot, and net weights (e.g., Larsen 1997:298–300). Variations in lead values in tooth enamel represent local geological formations experienced during childhood and those in bone represent life-long exposures (Larsen 1997:298–299; Turner et al. 2009). Both lead and copper are atmospheric pollutants (Hong et al. 1994, 1996). Sulfur may contribute to dietary studies by elaborating upon freshwater fish consumption (Privat et al. 2007). Iron deficiencies are associated with significant human illnesses and zinc may discriminate between different levels of farming intensity (Larsen 1997:297–298).

Biomolecules and Compounds

Biological molecules and compounds include amino acids, lipids, waxes, sterols, resins, tars, pitches, polyphenols, and tannins (e.g., Hjulström et al. 2006; Pearsall 2000:183–186; Pollard 2001). They are particularly valuable evidence that an artifact was used to obtain or process a specific organic material or suite of materials (e.g., Copley et al. 2005; Koirala and Rosentreter 2009; Oudemans et al. 2007). Organic molecules in residues adhering to an artifact may indicate the object was used to harvest plants, skin animals, or process a variety of substances (e.g., Morton and Schwarcz 2004; Outram et al. 2009). They indicate which compounds were used as curing and tanning agents and dyestuffs, for hafting implements, and in similar applications (e.g., Vanden Berghe et al. 2009). Sterol biomarkers also may enable a distinction to be made between fecal and nonfecal deposits (e.g., Shillito et al. 2011). A number of site formation processes influence these molecules and compounds (e.g., Evershed et al. 2001; Gernaey et al. 2001; Grupe 2001).

Carbohydrates, lipids, and proteins are **organic molecules** containing carbon; most contain hydrogen and oxygen and some contain nitrogen (Campbell et al. 2008:90). They generally are distinguished from the fourth group of organic molecules, nucleic acids, because they contain information that is not exclusively genetic, whereas nucleic acids are closely associated with deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) (Renfrew 2000). As with most such divisions, distinguishing between nucleic acids and other organic molecules is useful as an organizational tool, but not one that is sustained in practice.

Carbohydrates contain carbon, oxygen, and hydrogen (Krogh 2009:44). Starch grains are complex carbohydrates and sugars are simple carbohydrates, reflecting their molecular structure. The cellulose in the cell walls of plants is a rigid (polymerized) carbohydrate. Chitin is a carbohydrate. Plants store carbohydrates as starch and animals store glucose as **glycogen** (the animal form of starch).

Lipids mix poorly with water, but are soluble in organic solvents (Evershed et al. 2001; Heron et al. 2010; Krogh 2009:47). They consist of carbon, hydrogen, and

oxygen, just as carbohydrates do, but contain relatively more hydrogen than do carbohydrates. Lipids include fats, phospholipids, and steroids. The cuticle of plants is a lipid in the form of wax. The term **fatty acid** generally refers to fats and fatty oils of plants and animals (Hjulström and Isaksson 2009; Koirala and Rosentreter 2009). **Saturated** and **unsaturated fat** distinguish between structures of hydrocarbon chains in fatty acids. Steroids include cholesterol and the vertebrate sex hormones, testosterone and estrogen. Lipids are relatively stable compared with carbohydrates, a close relationship exists between fatty acid ratios and food sources (Koirala and Rosentreter 2009).

Lipids are subject to many diagenetic processes, such as length of time and intensity of use prior to discard, oxidation, and exposure (Evershed et al. 2003). Different lipids oxidize at different rates; therefore, Koirala and Rosentreter (2009) recommend comparing ratios of lipids that oxidize at the same rate when studying residues that might contain lipids. Lipids are found on tools, in soils, sediments, plant, and animal remains, and as amorphous deposits of substances such as resins, tars, pitches, and bitumens (Evershed et al. 2001; Heron et al. 2010; Hjulström et al. 2006). They are also found in palaeofeces (e.g., Shillito et al. 2011). Plant epicuticular waxes, beeswax, and dairy products are rich in lipids (e.g., Spangenberg et al. 2006). The lipid outer coating of some plants may be durable and can provide evidence for leafy plant foods (i.e., vegetables) difficult to obtain through studies of other botanical materials (Jones and Colledge 2001). Lipids serve many purposes beyond nutritional ones, including as fuels, lubricants, cosmetics, glues, sealants, drugs, and skin products.

Amino acids form polypeptide chains that fold to become **proteins**, which, therefore, contain carbon, hydrogen, oxygen, and nitrogen, and rarely, sulfur (Krogh 2009:53–58). Studies of blood residues focus on proteins, particularly on enzymes. **Enzymes** are proteins that are biological catalysts essential to many chemical reactions and other functions but are not consumed by them (Campbell et al. 2008:152). **Isozymes** (**isoenzymes, allozymes**) are different forms of an enzyme that have phylogenetic significance and indirectly reflect DNA sequences and genetic variations (Marr et al. 2007; Sanjur et al. 2005; Thain and Hickman 2004:23, 386). **Electrophoresis** is a method used to separate isozyme variants. Some molecules are composed of both proteins and lipids (**lipoproteins**) or carbohydrates and proteins (glycoproteins). Collagen is a glycoprotein, for example. Proteins are recovered from many of the same archaeological contexts as lipids.

Prior exposure of organisms to infections and parasites is assessed by examining reactions of protein residues to **antisera** (singular: antiserum) containing antibodies with affinities to specific substances (Thain and Hickman 2004:35–36, 38, 40). **Antibodies** are glycoproteins that bind selectively to substances that are foreign to the host. Antibodies that are recognized by the host because of a prior exposure stimulate the host to produce antigens. In archaeological applications, concentrations of antigens may verify the former presence of a disease. This is the approach taken by Bianucci et al. (2009) in their tests for plague bacillus (*Yersinia pestis*) in the skeletons of four Benedictine nuns and two priests buried at Poitiers and La Chaize-le-Vicomte (France), and elsewhere, between AD 1587 and 1632.

These burials were thought to be plague victims because they were buried with lime, a treatment often associated with the disease. All six tested positive for plague antigens and nonplague burials and soil samples were negative. Mitchell et al. (2008) use a monoclonal enzyme-linked immunosorbent assay (**ELISA**) technique to detect in two thirteenth-century CE latrines in Acre (Israel) the presence of enteric parasites that cause dysentery. The test was positive for *Entamoeba histolytica* and *Giardia duodenalis*, but negative for *Cryptosporidium parvum*. Using standard microscopic techniques, they found ova from parasitic intestinal helminths.

Archaeogenetics

The fourth group of organic molecules are **nucleic acids**, which store and transmit hereditary information. The study of genetic material is the basis of cladistics and parsimonious explanations of evolutionary changes. Archaeogenetic studies extend these concepts and methods to archaeological materials (e.g., Renfrew and Boyle 2000; Zeder et al. 2006). These studies facilitate the identification of specific organisms; their sex and kinship affiliations; organic materials such as drugs, textiles, and eggs shells; populations; as well as pathogens or the disease itself if it has a genetic component (Brown 2001; Leles et al. 2010; Travis 2010; Waters et al. 2011). In this section, the focus is on human genetics. The genetics of other organisms and viruses diverge considerably from this basic description, though their study greatly enlarges our understanding of the past (e.g., Preus et al. 2011).

One of the two types of nucleic acids is DNA and the other is RNA. DNA molecules contain the genetic material that individuals inherit from their parents (Campbell et al. 2008:86). These specify biological characteristics of organisms, such as how to build and maintain living tissues, instructions mediated by enzymes and other biochemicals (Sykes and Renfrew 2000). These instructions are communicated through combinations of four organic chemicals: adenine, cytosine, guanine, and thymine. These chemicals form pairs of **nucleotide bases** (base pairs, bp) that, along with sugars and phosphates, constitute DNA. Nucleotide chains can be of immense length or very short. RNA molecules are active in the synthesis of proteins, but they are more fragile than DNA and less frequently studied.

The total genetic material of an organism, the sum of its DNA, is referred to as its **genome**. The genome is organized into **chromosomes** (gene-carrying structures) that are contributed by both parents and located within the cell nucleus. A **gene** (a specific nucleotide sequence) codes for proteins that implement specific tasks, mediated by RNA. Two copies of a DNA sequence that differ at one or more nucleotide sites are considered different versions (**alleles**) of a gene. In some terminologies, a **haplotype** is a group of alleles at different **loci** (places on a homologous chromosome; singular: locus) that are transmitted, usually, as a unit. Many different alleles of a gene may exist within a population (Campbell et al. 2008:265–267; Krogh 2009:198). In a simple example, where two alleles differ, one of these will be the **dominant allele** that is expressed in the phenotype of the organism and the other

will be a **recessive**, unexpressed, allele. Processes such as human and natural selection, founder effects, genetic drift, and bottlenecks, all of which are associated with population migrations and domestication, reduce the amount of variation among alleles at a particular genetic locus. Thus, the genetic diversity of a domestic organism is reduced compared with its wild ancestor, but, nonetheless, will be similar to that of the wild progenitor (e.g., Speller et al. 2010; Xia et al. 2009).

DNA sequencing refers to the sequence of nucleotide bases in a length of DNA amplified by **polymerase chain reaction** (PCR) to produce multiple copies (Olsen and Schaal 2006; Krogh 2009:276–277; Thain and Hickman 2004:215). This amplification enables initially small quantities of **nucleotide sequences** (sequences of organic chemicals, sugars, and phosphates) to be studied. Differences in DNA sequences occur as substitutions (one base is substituted for another), insertions (bases are added), or deletions (bases are deleted). Genealogical relationships are inherent in DNA sequences and haplotype genealogies provide historical information about the genetics of a population. Nucleotide sequences persist even in archaeological materials that were burned or otherwise modified (Pearsall 2000:186–187).

Some applications consider repetitive pairs of nucleotide sequences that may be relatively long (**minisatellites**, 10–20 base pairs) or short (**microsatellites**, 1–4 bases long; Thain and Hickman 2004:636). Simple sequence DNA contains many copies of short or **simple tandem repeats** (STRs; 2–5 nucleotides repeated [or **simple sequence repeats**, SSRs]) and analysis looks for the number of reiterated units of noncoding DNA sequences at several locations in the genome (Campbell et al. 2008:436; Emshwiller 2006; Olsen and Schaal 2006). A single base-pair site where variation is found in at least 1% of the population is called a **single nucleotide polymorphism** (SNP; Campbell et al. 2008:417; Thain and Hickman 2004:636). The terminology for these studies is in a state of flux; for example, the term "haplotype" may refer to STRs or to SNPs. The term **"haplogroup"** may be used to refer SNPs. **Polymorphism** refers to the degree of variability among individuals. Genealogical relationships are not easily inferred from microsatellite alleles, limiting their usefulness in reconstructing phylogenetic studies concerned with recovering the history of speciation (Olsen and Schaal 2006). Microsatellites are widely used to develop genetic maps and in kinship studies, however.

Nuclear DNA (nDNA, nuDNA) contains genetic material from both parents, whose chromosomes are recombined to produce an offspring's genome. The nuclear genome is unique to each individual, but broadly similar within a species. A cell that is not sperm or an ovum is referred to as a **somatic cell** (Campbell et al. 2008:250; Krogh 2009:159, 178, 185). Somatic cells have homologous pairs of chromosomes (**diploid**, two sets of chromosomes, $2n$), in addition to two **sex chromosomes**. Nonsex chromosomes are known as **autosomes**. Sex chromosomes are designated X and Y. Females have a homologous pair of X chromosomes, but males have an X and a Y chromosome. Y chromosomes are inherited only through the paternal line. Although Y chromosomes do not undergo recombination, differences among them are associated with remodeling and the loss of genes, among other sources of variation. In contrast to somatic cells, **gametes** (reproductive or germ cells; i.e., eggs and sperm) are **haploid cells** ($1n$), containing a single set of chromosomes instead of a pair.

Although the diploid and haploid conditions are considered standard, many other combinations exist, especially among plants (Jones and Luchsinger 1986:88–89; 177–178; Schlumbaum and Jacomet 1998). Some organisms are polyploids; they have more than two sets of chromosomes. **Triploid organisms** have three sets of chromosomes (3*n*) and tetraploid organisms have four sets of chromosomes (4*n*; Campbell et al. 2008:297). A tetraploid plant can fertilize itself (self-pollinate), but cannot interbreed with a diploid plant, which isolates a tetraploid from the parent population quickly. Autopolyploids are individuals whose multiple chromosome sets derive from a single species, whereas allopolyploids, the more common form, are individuals whose chromosomes are from more than two species (Campbell et al. 2008:495–496). It is possible for polyploid hybrids to produce fertile offspring, though they cannot interbreed with either species of the parental generation. Polyploidy is particularly common in angiosperms and has played an important role in the evolution of domestic plants, many of which are polyploids (Emshwiller 2006; Thain and Hickman 2004:566). It is very rare in animals, having been reported in some insects, fishes, amphibians, reptiles, and a single mammal (e.g., Gallardo et al. 1999).

Some DNA resides outside of nuclei, in mitochondria (Campbell et al. 2008:301–302; Thain and Hickman 2004:461–463). **Mitochondrial DNA** (mtDNA) is inherited primarily through the maternal line in contrast to nDNA, derived from both parents, and the Y chromosome, inherited only from the father. The mitochondrial genome is relatively short and mtDNA does not undergo recombination, but it occurs in many copies in each cell. Mutations do occur and mtDNA evolves relatively rapidly. Many archaeogenetic studies focus on the mitochondrial genome because it is abundant, not subject to recombination, generally not subject to paternal inheritance, and can distinguish between closely related taxa or among populations within a species.

The assumption has been that Y chromosomes experienced very slow or little change over time. Recent work with human and chimpanzee (*Pan*) male sex chromosomes, however, demonstrate that portions of the Y chromosome can experience rapid evolution, including gene loss, gene gain, rearrangement, and relocation. Variations in the Y chromosome between chimpanzees and humans stand in sharp contrast with the similarities in the mtDNA of these two primates (Hughes et al. 2010).

Extracting and sequencing **archaeological DNA** (aDNA) holds much promise, but presents difficulties (e.g., King et al. 2009; Rollo et al. 2007). The DNA from microorganisms, scavengers, and people who handle specimens during and after excavation all add to the specimen's aDNA. Results of aDNA studies, however, can be verified through subsequent studies or be used to expand upon knowledge derived using other methods. For example, aDNA from extinct Pleistocene European cave bears (*Ursus spelaeus*) enables researchers to construct a bear family tree (Noonan et al. 2005). When the cave bear aDNA is compared with that of modern bears, functional differences and similarities among extinct and modern bears emerge. Studies of genetic diversity and phylogenetic relationships of people and their domesticated plants and animals suggest that the origins, sequence, timing, and processes of domestication are more varied than originally thought (e.g., Bramanti et al. 2009; Cai et al. 2009;

Doebley et al. 2006; Harter et al. 2004; Lentz et al. 2008; Pionnier-Capitan et al. 2011; Sanjur et al. 2002; Zeder 2008).

PCR-sequence analysis is applied to organic residues and tissues to examine the identities and histories of organisms through their genotypes rather than their phenotypes. DNA may reveal ancestral lineages and origins as well as characteristics favored at specific locations or in domestic organisms. Most of these studies focus on nDNA or mtDNA, though other genetic characteristics may be examined, such as those in **ribosomes** (cell organelles containing rRNA).

DNA generally degrades rapidly after death, but sometimes it survives for a long time (Adler et al. 2011; Pruvost and Geigl 2004; Yang et al. 2005). This offers opportunities to define the evolutionary and migratory histories of people, the organisms associated with them, and trade routes (e.g., Arndt et al. 2003; Bonnichsen et al. 2001; Bramanti et al. 2009; Haak et al. 2010; Matisoo-Smith and Robins 2004; White and Folkens 2005:346–348). Evidence from aDNA about the ancestry of domestic plants and animals provides insights into the processes and histories of farming at local, regional, and global scales (e.g., Cai et al. 2009; Decker-Walters et al. 2001; Edwards et al. 2004; Erickson et al. 2005; Harter et al. 2004; Larson et al. 2005, 2007; Pollmann et al. 2005; Savolainen et al. 2002; Zeder 2008). Archaeogenetic studies may distinguish among taxa that are difficult to separate using anatomy or morphology (Barnes and Young 2000; Newman et al. 2002; Schlumbaum and Jacomet 1998; Yang et al. 2004). Archaeogenetics can be used to determine the function of a tool (Shanks et al. 2001); identify pathogens (Aufderheide et al. 2004; Bathurst and Barta 2004; Bianucci et al. 2009; von Hunnius et al. 2007); suggest manufacturing processes (e.g., Campana et al. 2010; Padden et al. 2000; Pangallo et al. 2010); document the ancestry of enslaved peoples (e.g., Lee et al. 2009); and indicate vessel functions (e.g., Foley et al. 2012). Archaeogenetics provides evidence from Pliocene, Pleistocene, and Holocene contexts that can be used to trace evolutionary trajectories of critical taxa; this is information that can guide efforts to manage modern organisms extirpated from former ranges and ones that currently are threatened or endangered (e.g., Arndt et al. 2003). Reference collections and archived archaeological specimens are critical resources in such studies. Due to the variations and conflicting results, and the variety of responses of biological tissues to genetic and environmental inputs, confirmation of genetic results by traditional anatomical and morphological attributions is recommended whenever possible.

Genetic relationships are presented graphically in several ways (Campbell et al. 2008:552–545; Woolley et al. 2008). A **rooted phylogenetic tree** has a unique **branch point** (node) corresponding to the most recent common ancestor shared by two evolutionary lineages. **Sister taxa** are two groups of organisms that share a branch point and are closely related. An **unrooted tree** suggests no common ancestor, usually because the relationship is unresolved but is recognizable when more than two descendant groups emerge from a branch point. The length of the lines sometimes indicates the relative amount of genetic change or time, but often lines simply show patterns of descent. **Neighbor-joining trees** represent the degree of relatedness by the length of the branches of the dendrogram (Fig. 13.7; Germonpré et al. 2009:482).

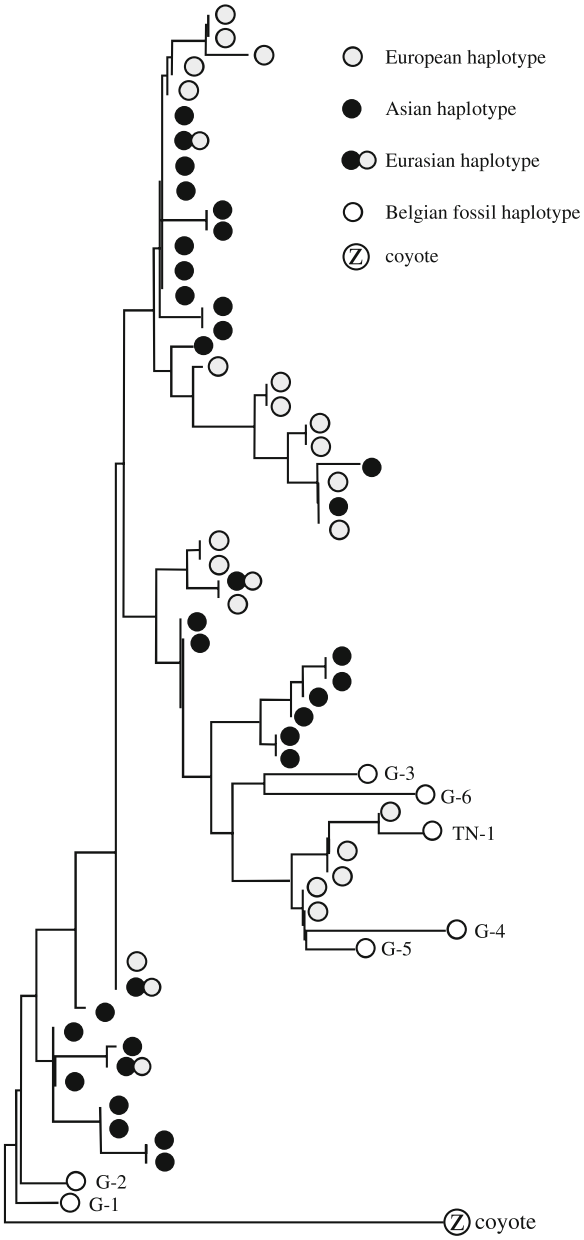

Fig. 13.7 Neighbor-joining tree of ancient Belgian large canids and recent wolves based on 57 base pairs (bp) of the mitochondrial control region. Ancient Belgian haplotypes from the archaeological site of Goyet Cave (Belgium) are labeled G-1 through G-6 and that from Trou des Nutons Cave (Belgium) is labeled TN-1. Bootstrap values are low for all nodes due to the short sequence length. AMS age of Goyet Cave specimen 5, ca. 13700 BP; Goyet Cave specimen 6, ca. 24800 BP; Trou des Nutons specimen 1, ca. 21800 BP. Morphological analysis suggests that the Goyet Cave canids are early domestic forms not yet genetically identifiable as early dogs. The morphology of the Trou des Nutons specimen indicates that it is from a fossil wolf. From Germonpré et al. (2009:482) and used by courtesy of the authors and Elsevier

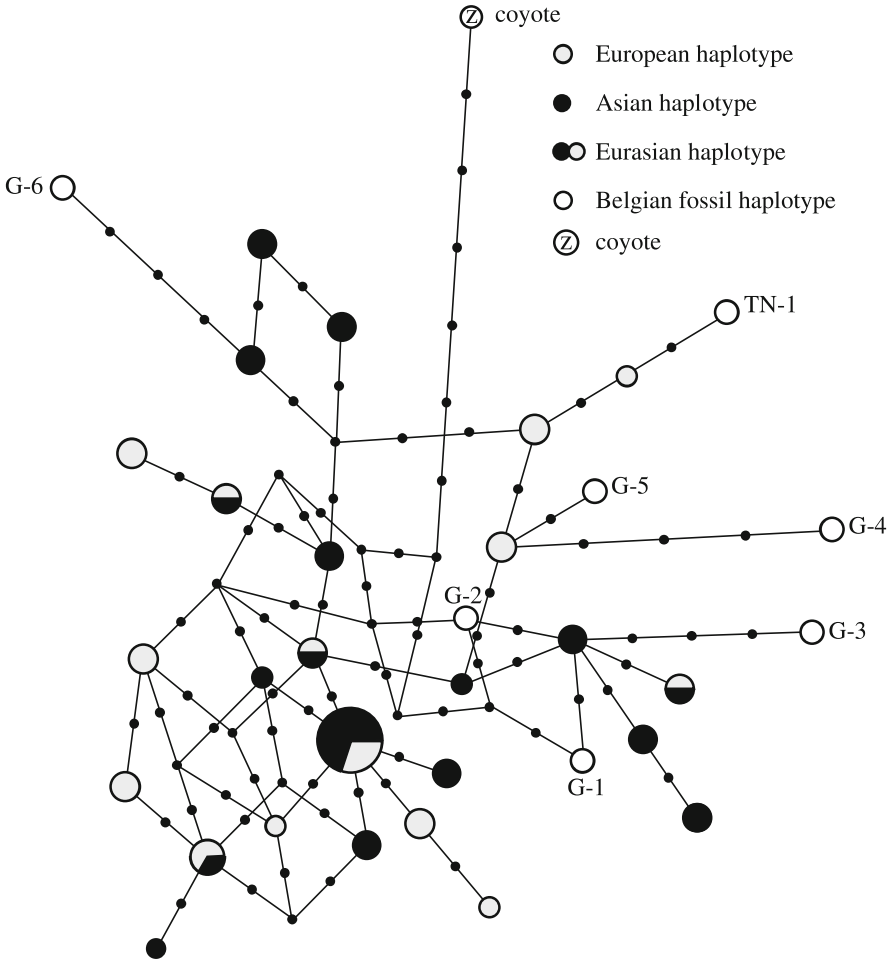

Fig. 13.8 Median-joining haplotype network depicting the phylogenetic relationships between recent European and Asian wolves as well as ancient Belgian large canids. The size of the *circles* indicates the number of individuals carrying a particular haplotype. See Fig. 13.7 for key to abbreviations. From Germonpré et al. (2009:482) and used by courtesy of the authors and Elsevier

This phylogenetic tree is a map of genetic distance. Those organisms least closely related are farthest apart and closely related organisms form a clade, which is a **monophyletic group** or cluster of organisms with a single ancestor that is not shared with members of other clades. **Paraphyletic groups** consist of the ancestral species and some, but not all of its descendants. Members of a **polyphyletic group** include members with different ancestors. Phylogenetic relationships, lineages, and clusters are depicted in the **median-joining haplotype network** in a form that appears very similar to a cobweb or star-like pattern (Fig. 13.8; Cai et al. 2009; Germonpré et al. 2009:482).

Site Formation Processes and Field Considerations

All of these materials and relationships involve complex biological, chemical, and physical phenomena. The age of the material and the temperature, moisture, and altitude of deposition are significant diagenetic influences, as they are in other aspects of organic taphonomy. Use of fossil fuels has altered atmospheric CO_2, hampering isotopic comparisons of modern organisms with those in the past. Many of the same site formation processes and field considerations reviewed in earlier chapters also influence stable isotopes, elements, and biomolecules such as lipids and DNA. In this section, some of these considerations are repeated, with emphasis on those aspects that are of particular concern for these materials.

Site Formation Processes

Different organic materials reflect different aspects of organisms' life histories. Each is susceptible to different site formation processes and each has different analytical potential. Many plant remains (e.g., roots, leaves) are ephemeral under common archaeological conditions. The remains of annual plants represent very short-term phenomena, whereas those of perennial plants, such as trees, may reflect long-term events. Enamel and dentine do not remodel but bone does, a difference that affects isotopic and elemental analysis (White et al. 2009). Keratin is relatively short-lived so that materials such as hair and nails are likely to represent short-term environmental conditions. There is some delay between a change in diet and evidence for that change in hair, but hair fibers grow sequentially in length, do not remodel, and retain their original geochemical signatures.

Many studies analyze organic residues that adhere to or are embedded in artifacts (e.g., Spangenberg et al. 2006). Relationships among residues from artifacts and the processes by which they became associated with those artifacts are unclear. It could be a direct relationship: the artifact was used to process the material. Residues become associated with sites and artifacts through other pathways, however, such as rain, percolation of water through the stratigraphy, and bioturbation. It is possible that the organism whose remains are found on artifacts once lived in the surrounding matrix, was part of the artifact, fed on organic residues adhering to the artifact, was introduced via pollen rain, or became associated with the object or matrix through other nonanthropogenic processes.

Bone mineral and collagen are used in many of these applications; thus the causes and consequences of diagenetic alterations of collagen should be assessed (e.g., Ambrose 1993; Nehlich and Richards 2009). It appears that elemental C:N ratios, $\delta^{13}C$ values, and $\delta^{15}N$ values may be stable until the point at which collagen contributes less than 1% of the bone weight (Dobberstein et al. 2009; Harbeck and Grupe 2009). Microorganisms such as bacteria and fungi consume amino acids and add their own, perhaps shifting $\delta^{13}C$ values to more negative levels and $\delta^{15}N$ values to more positive ones (e.g., Child 1995; Grupe 2001; Harbeck and Grupe 2009). The use of imported foods with nonlocal isotopic signatures, the influence of maternal

food and drink on breast milk, local climatic conditions, differences in access to water sources and foods, as well as complex ecological and geological settings are all sources of variations, as are individual, local, and regional factors.

Field Considerations

Just as field and laboratory staff should avoid contaminating samples that will be used for radiocarbon dating, they should avoid contaminating or damaging materials that will be used in geochemical and molecular studies. Anticipating archaeogenetic studies, field, and archival staff should avoid handling or otherwise contaminating materials that might be studied in this way (e.g., Yang and Watt 2005). Heat alters some relationships that are fundamental to geochemical and molecular studies (e.g., Andrus and Crowe 2002; Arndt et al. 2003). If there is evidence of such behavior (e.g., the specimens are from a hearth or there is evidence of a drying rack), this information should be communicated to all members of the research team. The project should have a plan that will limit handling human remains while maximizing the amount of in situ data recorded (e.g., Lieverse et al. 2006).

These applications should be anticipated by taking larger or more soil samples than seems necessary, taking them specifically from contexts associated with artifacts that might be examined for geochemical and molecular evidence and initiating geochemical and molecular studies before the soil samples are processed for other studies. Archiving unmodified samples for future comparative studies is highly recommended.

An additional precaution applies to a standard archaeological procedure: thoroughly cleaning and labeling artifacts, which requires extensive handling and washing. From a museum perspective, cleaning is an critical part of integrated pest management programs and is essential for the long-term care of an object. Nonetheless, most of the techniques reviewed in this chapter require that artifacts be handled as little as possible and that additional chemicals (e.g., inks, detergents, glues, paints, sunscreens, fizz from carbonated beverages) not be added. A great deal can be learned from debris lingering in the nooks and crannies of artifacts. If the object is cleaned as thoroughly as it ought to be for long-term curation, much of this debris will be removed, contaminated, or damaged. Artifacts should be examined for residues before they are cleaned to assess the potential for isotopic, elemental, and genetic analyses. Consulting with the curation facility before field work begins can ensure that geochemical and molecular studies can be conducted in the future, even if they are not anticipated as part of the current project.

Laboratory Considerations

Laboratory protocols for many of these procedures are just now being developed and much remains to be learned about the impact of depositional environments on geochemical and molecular evidence, the relative concentrations of this evidence in

different organic remains, the impact of sampling methods on this evidence, and the reliability of the results. Studies of ancient DNA, in particular, are in their infancy (e.g., Adler et al. 2011).

As with most research, it is difficult to be certain that geochemical and molecular evidence is contemporaneous with the object being studied. The problem of contemporaneity is not, of course, unique to this type of analysis and is difficult to resolve. Determining that residues and artifacts are contemporaneous, and of anthropogenic origin, requires considering multiple lines of evidence to separate residues that might be from different time periods or nonanthropogenic in origin (e.g., Hardy and Garufi 1998). Residues in adjacent soil samples or other types of materials should be compared with those from the artifact under study. Nonanthropogenic residues should be more abundant in noncultural contexts or in the matrix around the artifact than on the artifact itself. If the adhering residue is far more common on the artifact than in the adjacent matrix or on nonartifacts, the artifact and the residue probably were affiliated.

Use-wear provides an additional line of evidence about the function of the object. If the residue is consolidated in specific, functionally significant locations on the artifact, for example, on the edge of a cutting tool or in the central depression of a grinding stone, this may be evidence of intentional use and a clue to the function of the artifact itself. The residue may be consistent with the probable use of the artifact, for example, a projectile point with blood residue from a game animal or a sickle blade with residue from a grain. Sometimes we learn that tools were used for purposes other than expected, for example, chipped stone flakes and points used to process starchy plants (Mercader 2009) or amphora used for many purposes other than wine containers (Foley et al. 2012). In other cases, use-wear studies combined with analysis of organic and inorganic residues finds that tools were used for multiple functions. For example, backed artifacts from Mussel Shelter (Australia) were used to manufacture and maintain craft materials made of wood, nonwoody plants, and bone in addition to subsistence activities involving both animal and plant materials (Attenbrow et al. 2009).

Analyses of stable isotopes, elements, and organic molecules rely upon cross-comparisons among archaeological materials or comparisons of the archaeological materials with known standards, such as SMOW, AIR, or a genetic library such as Genbank. These studies often compare observations derived from one group of organisms or materials with observations of other organisms in the archaeological assemblages. Thus, collagen might be compared with apatite or $\delta^{13}C$ in animal collagen might be compared with that of a dominant plant in the archaeological assemblage; or archaeological results may be compared with modern phenomena. Often several isotopic or mineral proxies are compared with one another. When modern reference materials are unavailable, the study may begin by developing reference collections and conducting background studies of ambient water and geological properties.

Multiproxy comparisons are fundamental to these studies. It is common for biogeochemical signatures in human skeletal and dental remains to be compared with those in other organisms from the site (e.g., Commisso and Nelson 2007; Copley et al. 2005;

Fullagar et al. 2006; Shaw et al. 2009; Slovak et al. 2009). For example, Garcia-Guixé et al. (2009) compare $\delta^{13}C$ values and $\delta^{15}N$ values in human remains and herbivores recovered from Balma Guilanyà (Catalonia, Spain). Based on the similarity between $\delta^{13}C$ values in human and large terrestrial herbivore remains, they conclude that people living at this site during the Late Upper Palaeolithic consumed proteins primarily derived from terrestrial herbivores instead of from freshwater or marine resources. Leles et al. (2010) advocate that parasitological studies consider diagenesis, use of medicinal plants, and other aspects of human behaviors in addition to morphological and molecular analyses. Some differences between modern and archaeological proxies may be due to environmental changes that need to be evaluated (e.g., Alam et al. 2009; Webb et al. 1998).

Applications

Environmental interpretations rely upon ecological analogies and the fidelity of organisms to specific habitats. In their study of seaweed fly puparia (*Thoracochaeta zosterae*) from Medieval and Early Post-Medieval cesspits in Oxford (thirteenth to fourteenth century AD, UK), Webb et al. (1998) show that the presumption of fidelity may not be valid (see Leles et al. 2010). Modern pupae are found in wet decaying seaweed and have $\delta^{13}C$ values typical of marine invertebrates. Archaeological pupae have isotope ratios typical of nonmarine, terrestrial grazers. The $\delta^{15}N$ values indicate the archaeological pupae consumed decayed rather than fresh plant material, but there was no evidence that seaweed was present in the archaeological deposit. As their vernacular name implies, seaweed flies today are associated with seaweed, but the authors conclude that this has not always been the case. Medieval cess pits once provided the combination of moist and dry environments needed for fly development. Flies at one time took advantage of this habitat created by human sanitary facilities, a habitat not so readily available to them today.

Most lipid analyses assess diets, but they can be used to study other phenomena, such as the functions of activity areas and vessels (e.g., Evershed et al. 2003). Hjulström and Isaksson (2009) combine elemental analysis with lipid studies to examine how activity areas might be reflected in soils. Their study is based on soils from a reconstructed Iron Age house at the Lejre Experimental Centre (Roskilde, Denmark). Their knowledge of the functions of each activity area enables them to test the reliability of their combined organic–inorganic approach. Elemental analysis distinguishes among each activity area (i.e., dwelling, stable, smithy, Table 13.1; Hjulström and Isaksson 2009:177) and lipid analysis distinguishes between the dwelling area and other parts of the structure. Although element concentrations enable them to distinguish these activity areas, they note they would not have been able to do so without prior knowledge of the activities that produced each signature.

Connections between climatic and cultural histories are central topics in environmental archaeology. Alam et al. (2009) study phytoliths in late Holocene (AD 730–1080) soils from Somapura Mahavihara, associated with a Buddhist monastery in

Table 13.1 Mean element concentrations (mg kg^{-1}) in each activity area and total means with standard deviations from the Lejre Experimental Centre (Roskilde, Denmark)[a]

Area	Mn	Ca	Pb	K	Mg	Cu	Fe	Zn
Dwelling	218.9	23,176	134.7	15,262	632.4	12.4	21,913	36.9
Dwelling/cooking	222.4	23,048	133.8	17,199	627.4	12.3	21,778	37.3
Entrance	209.8	22,981	132.7	17,766	630.6	12.0	20,040	33.6
Stable	258.1	18,047	134.5	22,906	610.7	13.2	27,278	48.1
Smithy	293.3	5,965	135.2	10,367	642.8	12.3	16,944	38.4
Reference	241.6	23,615.0	933.0	20661.0	589.3	13.8	26159.0	33.3
Total	233 ± 48	21,861 ± 3,381	134 ± 4.5	17,940 ± 3,636	626 ± 19	12.5 ± 1.2	22,643 ± 4,953	37.5 ± 4.6

[a]Modified from Hjulström and Isaksson (2009:177) and used with permission of the authors and Elsevier

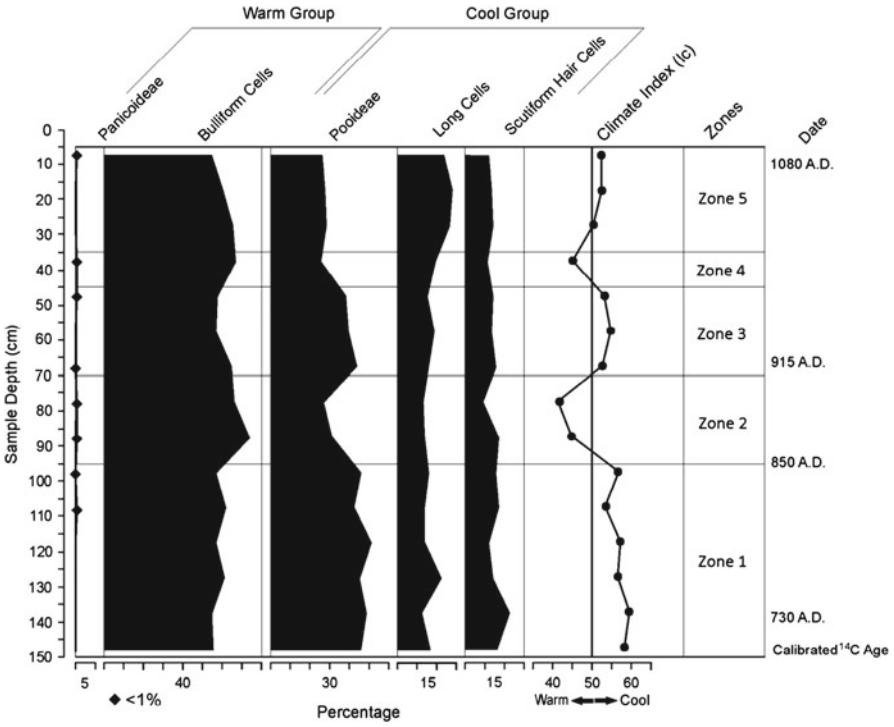

Fig. 13.9 Relative abundances of grass subfamily phytoliths from Somapura Mahavihara (Bangladesh). Zones are defined by dominant phytolith types and a climate index (lc) is derived from the ratio between cool-group phytoliths and cool-plus warm-group phytoliths. The climate index reflects the broad association of panicoid-type phytoliths with C_4 grasses and warm, humid areas; and pooid-type phytoliths primarily produced by C_3 grasses associated with cool seasons, high latitudes, or high altitudes. Zones indicate the five climatic periods. From Alam et al. (2009:510) and used by courtesy of the authors and Elsevier

the Paharpur area (Bangladesh), to assess climatic cycles in the region. The authors focus on short-cell phytoliths from two subfamilies: Pooideae (predominately C_3 grasses) and Panicoideae (predominantly C_4 grasses). Pooideae form a "cool" group and Panicoideae form a "warm" group. ("Warm" and "cool" are relative terms in this context.) A ratio of cool phytoliths to warm phytoliths provides a climate index: high values indicate a cooler climate (more C_3 grasses) and lower values indicate a warmer, semiarid to arid, sunny climate (more C_4 grasses). The authors find evidence for five climatic periods: three marked by cooler conditions and two marked by warmer ones (Fig. 13.9; Alam et al. 2009:510). Samples representing cool parts of the cycle are characterized by higher proportions of Pooideae phytoliths and samples representing temperate parts of the cycle contain higher proportions of Panicoideae phytoliths. The palaeoenvironmental data are consistent with local clay mineralogy and global temperature curves. Alam et al. (2009) query whether there is a link between climate change, El Niño Southern Oscillation (ENSO), and the cultural changes that occurred during the study period.

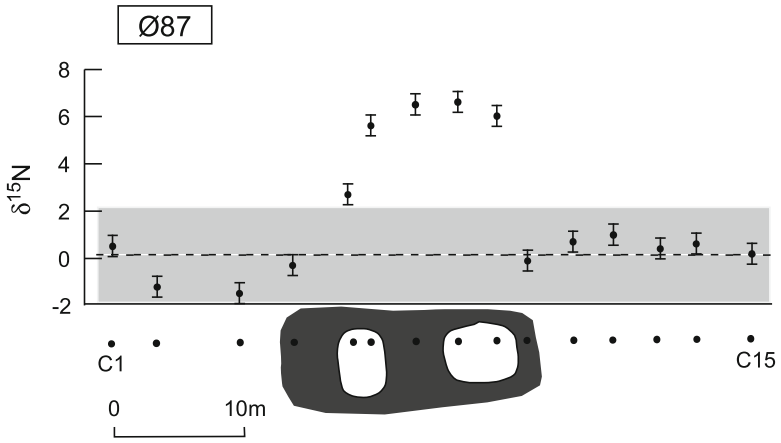

Fig. 13.10 Sketch map showing the sample locations (*filled circles*) along the transect (C1–C15) extending through the byre/stable at Ø87 (Greenland). Plot gives the $\delta^{15}N$ in ‰ for each sample location, with the byre and stable identified at the bottom of the image and their influence shown by the *dark gray* shading. The *horizontal dashed line* and *light gray* shading give the average and variability (1 standard deviation), respectively, for the natural grass and sedge (graminoid) samples. From Commisso and Nelson (2006:1175) and used by courtesy of the authors and Elsevier

Commisso and Nelson (2006, 2007) report that earlier human activities are reflected in the $\delta^{15}N$ values of plants currently growing near a Norse farm (Ø87, Greenland) abandoned prior to AD 1450. Limitations on farming and the discrete nature of farmsteads in Greenland made it possible to distinguish between anthropogenic and nonanthropogenic contexts, a circumstance that would not occur where there were complex histories of human landscape modifications. The $\delta^{15}N$ values in the natural plant samples deviate by only a few parts per mil from AIR, whereas those from archaeological contexts, such as the byre/stable represented in Fig. 13.10, are more variable but enriched (Commisso and Nelson 2007:1175). The authors argue that the elevated $\delta^{15}N$ values indicate the food chain was enriched by human activities in the past and that this ancient enrichment has persisted for centuries. Commisso and Nelson (2007) report differences in the $\delta^{15}N$ values among and within structures, perhaps reflecting different functions; a reminder that it is important to sample several contexts within a site. Although this study reinforces the correlation between nitrogen isotope ratios and human activity, it also means that nitrogen levels in modern plant reference collections may be mediated by much earlier human activities, such as gardening, manuring, and discarding organic waste.

Choy and Richards (2009) use stable isotopes to explore the significance of terrestrial and marine sources of protein by a farming population at the Nukdo shell midden site (550 BC to AD 1, South Korea). Of the cereals most likely to have been grown, rice is a C_3 plant and foxtail millet (*Setaria italica*) is a C_4 plant, though there is no evidence of a significant use of C_4 plants in the midden. The isotope ratios of the bone collagen from terrestrial herbivores in the assemblage fall in the range of C_3 consumers. The $\delta^{15}N$ and $\delta^{13}C$ values indicate that the protein sources were

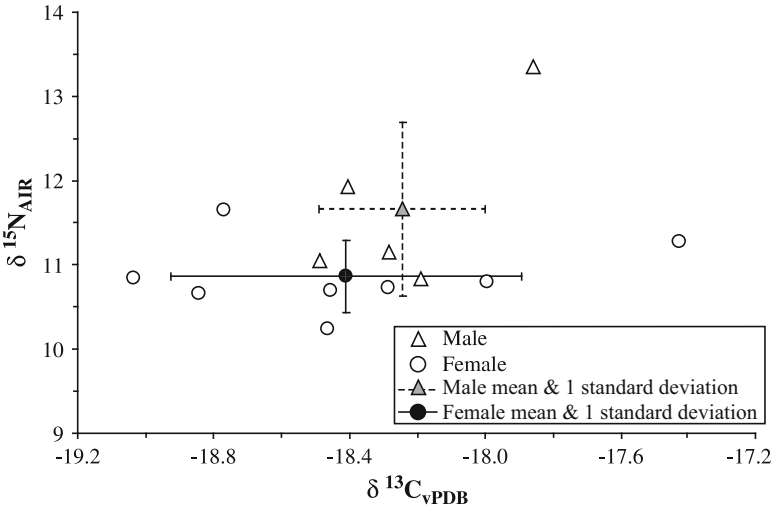

Fig. 13.11 Stable isotopic evidence of human diet at the Nukdo shell midden (South Korea): Includes all adult (>20 years) male and female collagen carbon and nitrogen values, as well as their means and 1 standard deviation. From Choy and Richards (2009:1316) and used by courtesy of the authors and Elsevier

mixed: most protein was from terrestrial sources and marine food consumption was limited, even on this coastal island. Choy and Richards (2009) report that the diets of some men and women were dissimilar (Fig. 13.11; Choy and Richards 2009:1316). They interpret differences in the nitrogen isotope ratios between mothers and children as evidence that weaning generally occurred before 1.5–2 years of age (Fig. 13.12; Choy and Richards 2009:1316).

Isotopes can be used to track migrations, transhumance, immigrations, and other aspects of mobility and residence patterns (e.g., Nehlich et al. 2009; Slovak et al. 2009). Turner et al. (2009) examine oxygen, strontium, and lead isotopes in human remains to study immigration and social class at Machu Picchu (Peru), an Inca-period site (AD 1438–1532). The Inca relocated individuals and communities to control people and their labor. Turner et al. (2009:324) use $\delta^{18}O$ values as proxies for the local environment (Fig. 13.4) and strontium and lead as proxies for the geological substrate experienced in childhood (Fig. 13.13; Turner et al. 2009:327). They report a wide variation in isotope ratios in the human remains, indicating substantial immigration to Machu Picchu. This interpretation is supported by ethnohistoric research, pollen analysis, and studies of other isotopes. The authors conclude that the Machu Picchu population included nonelite individuals brought to Machu Picchu from elsewhere to serve the Inca nobility. Some of these immigrants may have been from the southern Peruvian/Chilean coast and the Lake Titicaca region; others may have been from the coast of northern Peru or southern Ecuador. This pattern can be linked to class dynamics and social stratification.

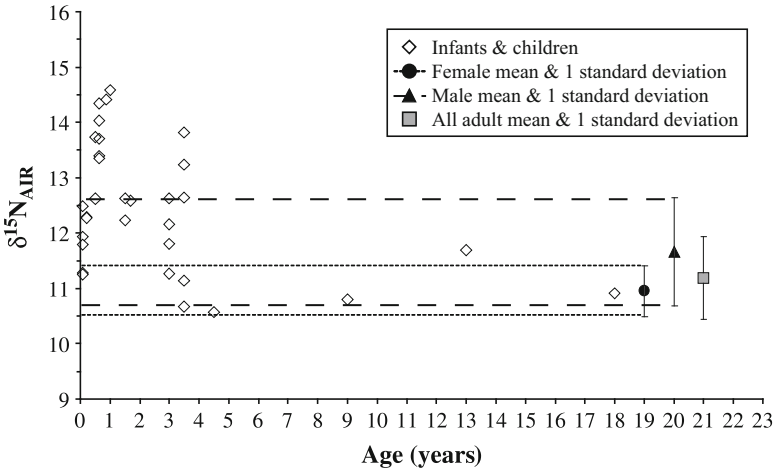

Fig. 13.12 Juvenile $\delta^{15}N$ collagen values plotted against age at death at the Nukdo shell midden (South Korea) compared with adult female and male means and 1 standard deviation. From Choy and Richards (2009:1316) and used by courtesy of the authors and Elsevier

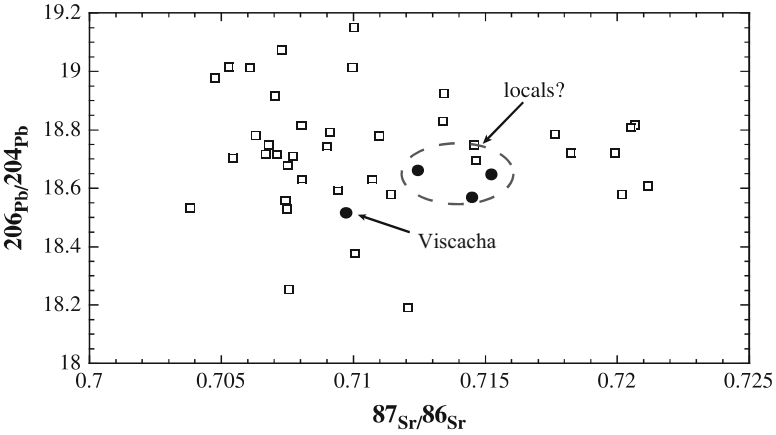

Fig. 13.13 $^{206}Pb/^{204}Pb$ vs. $^{87}Sr/^{86}Sr$ isotopic compositions of the Machu Picchu (Peru) human individuals compared with local animals. Human isotopic values (*white squares*) exhibit much wider variation compared with the isotopic values of nonhuman animals. Variation among three assumed local animals (*black circles*) in the Machu Picchu archaeological remains (Eaton 1916) may reflect local isotopic microvariations. The plains viscacha (*Lagostomus maximus*) identified by Eaton (1916:57; Miller 2003:13), and referred to by Turner et al. as *Lagostomus trichodactylus*, is presumed to be nonlocal; its present-day range is in Paraguay, Bolivia, and Argentina (Eisenberg and Redford 1999:469; Weir 1971). Human isotopic values compared with local animals suggest only a few, if any, of the Machu Picchu human remains are from people of local origin. From Turner et al. (2009:327) and used by courtesy of the authors and Elsevier

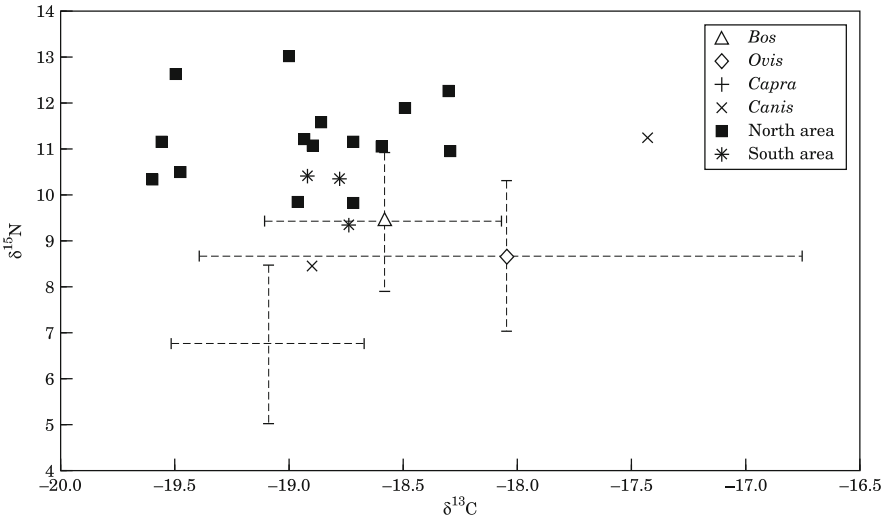

Fig. 13.14 Adult human collagen $\delta^{13}C$ and $\delta^{15}N$ values from the North and South areas of Çatalhöyük (Turkey) compared with cattle (*Bos*), sheep (*Ovis*), goat (*Capra*), and dog (*Canis*) (means and 1 standard deviation plotted). Human remains from the South area (roughly 8300–8000 BP) are earlier than those from the North area (ca. 7900–8000 BP; Richards et al. 2003:71). From Richards et al. (2003:72) and used by courtesy of the authors and Elsevier

Richards et al. (2003) report a previously unrecognized input of C_4 plants and a high degree of variability in human, plant, and animal remains from Çatalhöyük (7000–8000 BP, Turkey). They interpret this as evidence that some of the animals were domesticated and others were not. Sheep (*Ovis*) had a wide range of $\delta^{13}C$ and $\delta^{15}N$ values, indicating that some sheep consumed larger quantities of C_4 grasses than did others (Fig. 13.14; Richards et al. 2003:72). The broad range of $\delta^{13}C$ for sheep could be evidence that C_4 plants were part of their diet. C_4 grasses are now uncommon in the area, though the remains of C_4 genera are found in the site's deposits. Higher $\delta^{15}N$ values for cattle (*Bos*) compared with sheep suggest different herding practices were used for these two animals. Alternatively, this difference may indicate that the cattle were wild and the sheep were domesticated. Human isotope ratios from the North are differ from those of the South area, suggesting differences in mobility or access to protein between people in these two areas of the site. Given the broad range in nonhuman isotope ratios, the variability in human ratios may reflect the diverse diets of the animals themselves. It is unlikely that cattle were the main source of dietary protein for everyone, however. Richards et al. (2003) recommend expanding the study to include chemical analysis of strontium, lead, and sulfur, which are more closely linked to mobility.

Distinguishing between changes in material culture that indicate population movement and those linked to wealth, political influence, ethnicity, or social status is a challenge. In their study of the coastal site of Ancón (AD 550–1000, Peru), Slovak et al. (2009) combine analysis of $\delta^{13}C$, $\delta^{15}N$, and $^{87}Sr/^{86}Sr$ in human skeletal

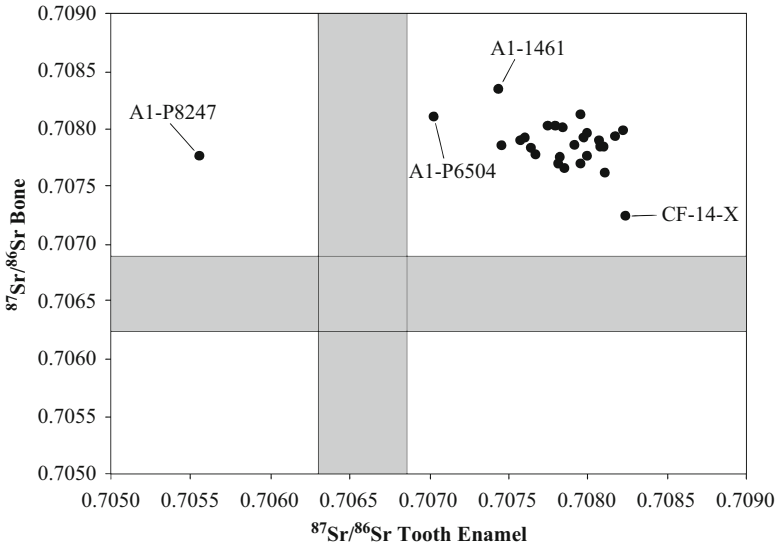

Fig. 13.15 Strontium isotopic ratios from human tooth enamel and bone from 27 Middle Horizon Ancón (Peru) individuals. The *shaded* area shows Ancón's biologically available strontium isotopic range in local fauna: $^{87}Sr/^{86}Sr = 0.7063–0.7068$. Higher strontium isotope values in human remains can be explained by their marine-based diet, but the low enamel signature for A1-P8247 cannot be. A1-P8247 is a teenage female with a tooth enamel value much lower than local terrestrial values. The other three labeled specimens have $^{87}Sr/^{86}Sr$ values slightly outside the Ancón cluster, but within Ancón's biologically available $^{87}Sr/^{86}Sr$ range for enamel. From Slovak et al. (2009:163) and used by courtesy of the authors and Elsevier

materials with baseline studies of diagenetic processes and isotope ratios of strontium in bedrock and soils. Biologically available strontium ratios were obtained from skeletal and enamel materials of modern and archaeological guinea pigs (cuyes, *Cavia porcellus*) from the Ancón region. They conclude that the $^{87}Sr/^{86}Sr$ ratios in human tooth enamel and bone reflect a mixed diet of primarily marine foods and C_4 plants instead of residential mobility because these ratios are higher than the biologically available strontium in regional fauna (Fig. 13.15; Slovak et al. 2009:163). This conclusion is supported by **external auditory exostoses** (a cranial abnormality found in people who fish and dive in cold waters), fishing gear, and the remains of marine mammals and shellfish. Slovak et al. (2009) conclude that most individuals were natives of the Ancón region, but identify one elite, nonlocal, teenage woman (A1-P8247) from her low strontium isotopic value (Slovak et al. 2009:163). She was buried in one of the elite tombs and may have been an immigrant.

The site at Star Carr (UK) is the focus of repeated studies testing hypotheses fundamental to archaeology (e.g., Clark 1954; Clutton-Brock and Noe-Nygaard 1990; Dark 2003; Day 1996; Legge and Rowley-Conwy 1988; Schulting and Richards 2002, 2009). These hypotheses pertain to foraging strategies, residential patterns, and environmental change. The roles of palaeolake Flixton and the nearby North Sea in residential patterns are tested by comparing present-day lacustrine and

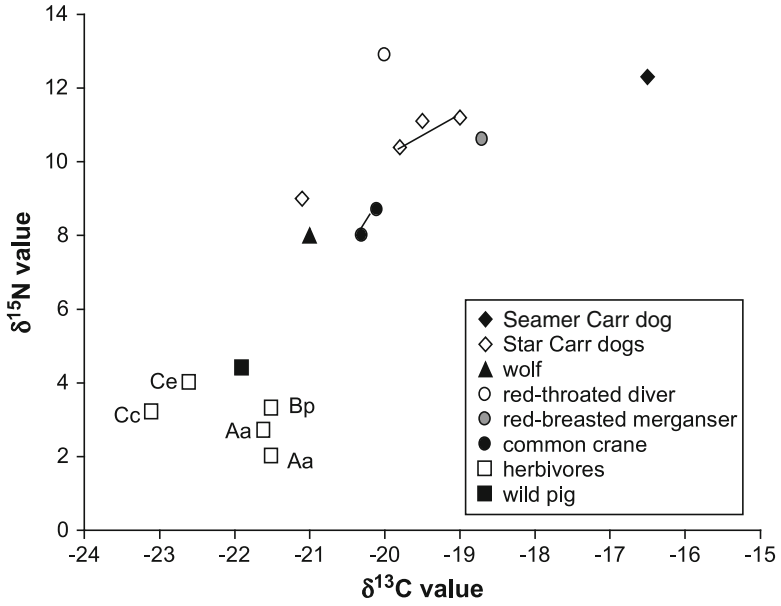

Fig. 13.16 Stable carbon and nitrogen isotopic values for bone collagen from Star and Seamer Carrs. The joined crane (*Grus grus*) values are from the same element; the joined Star Carr dog (*Canis familiaris*) values are from separate elements, but probably are from the same individual. The position of the Seamer Carr dog distinguishes it from the other animals. *Aa Alces alces*; *Bp Bos primigenius*; *Cc Capreolus capreolus*; *Ce Cervus elaphus*. From Schulting and Richards (2009:500) and used by courtesy of the authors and Elsevier

marine $\delta^{13}C$ and $\delta^{15}N$ values with archaeological data from Star Carr (9270–8840 cal BC) and nearby Seamer Carr (9390–8810 cal BC), using dogs as proxies for humans (compare Schulting and Richards 2009 with Day 1996). The two sites are about 5 km apart along the shoreline of the former lake, less than 1 km apart by water, and approximately 15 km from the former coastline (Clutton-Brock and Noe-Nygaard 1990). Schulting and Richards (2009) examine carbon and nitrogen isotope ratios in bone collagen from archaeological dogs, terrestrial herbivores, and birds to establish a comparative baseline signature and to determine whether freshwater or marine foods were consumed by these animals (Fig. 13.16; Schulting and Richards 2009:500). They report isotope ratios in the Seamer Carr dog that are consistent with a marine-influenced diet and ratios in the Star Carr dogs consistent with a nonmarine diet. The Seamer Carr dog is the only animal tested that has the elevated isotope ratios characteristic of marine input. Schulting and Richards (2002, 2009) interpret the Seamer Carr puppy (<9 months old) as a gift from a coastal community rather than as evidence for residential mobility. The different conclusions drawn by Schulting and Richards (2002, 2009), Dark (2003; Day 1996), and Clutton-Brock and Noe-Nygaard (1990) reflect the complex relationships among stable isotopes, ecosystems, trophic level effects, environmental changes, residential patterns, social ties, and laboratory analysis.

The sources, timing, and dispersal of people, crops, and domestic animals are important factors in environmental and cultural change. Genetic studies of domestic organisms and associated pests stimulate thought-provoking revisions (e.g., Cai et al. 2009; Deguilloux et al. 2009; Gongora et al. 2008; Harter et al. 2004; King et al. 2009; Storey et al. 2007; Vilà et al. 2001). Dogs are the most ubiquitous and oldest of the domestic animals. They probably were domesticated from ancestral wolves, perhaps several times over the past 14,000 years or longer. Some suggest that the scientific name of dogs should reflect this relationship (e.g., *Canis lupus domesticus*), though the International Commission on Zoological Nomenclature (ICZN) has ruled otherwise (Gentry 2006; Gentry et al. 2004). Savolainen et al. (2002) propose that most recent dogs evolved from approximately five East Asian mtDNA lineages and Vilà et al. (1997) suggest that dogs were domesticated as early as 40,000 years ago, though this early date is controversial (e.g., Pionnier-Capitan et al. 2011). Given this early date, Germonpré et al. (2009) reason that dogs might be present in European archaeological assemblages deposited between ca. 38000–10000 BC. Germonpré et al. (2009) combine a traditional morphometric study of large canids with stable isotope ($\delta^{13}C$, $\delta^{15}N$) and mtDNA analyses of Late Pleistocene canid skulls from Belgium, Ukraine, and Russia. They compare the archaeogenetic results with data for wolves and dogs archived in Genbank. They compare relevant traits in early canids with the same features in more recent archaeological dog specimens, as well as in recent wolves and dogs. The morphological study indicates that the oldest specimen in their data set ($31{,}680 \pm 250$ BP) is a dog, supporting the hypothesis for early domestication. The seven haplotypes studied were each unique and previously undescribed, suggesting to Germonpré et al. (2009) that the tested specimens were from wolves. They interpret novel genetic sequences and genetic diversity as evidence that wolf populations experienced a bottleneck at some point in the past.

Summary

With a few exceptions, such as aDNA and protein sequencing, these methods seldom are used for taxonomic attribution. Many applications transcend the level of the organism to explore combinations and interrelationships more compatible with cultural, ecological, and environmental dynamics. Multiproxy studies of isotopes, elements, organic molecules, and genetics bring us closer to one of the primary goals of environmental archaeology: to test multifaceted theories about the structure, function, and evolution of complex relationships among environments, ecosystem processes, and peoples. The perspectives reviewed in this chapter greatly expand the interpretative potential of inorganic and organic materials recovered from archaeological sites and offer links between archaeological data and modern environmental and conservation applications. Hjulström and Isaksson (2009), among others, caution that it is seldom possible to choose between known causes and associations when

working with archaeological materials, especially considering the impact of time-averaging. Without knowing the cause of the patterns observed in archaeological materials, they are difficult to interpret. These authors call for additional experimental work to examine relationships between specific processes and the signals they produce in archaeological materials.

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Chapter 14
Research Questions

Environmental archaeology is an interdisciplinary field that draws from many research traditions to define and explain long-term systemic associations among peoples and their abiotic and biotic environments; to explore synchronic and diachronic interpretations of environments and cultures; and to test theories about the phenomena being studied and the methods used to examine them. Studies of organic remains contribute insights into human behavior in specific environments at specific times that are generalized to other times and places. They expand our understanding of interactions among people, environments, and ecosystems, and the impact people have on the world in which they live. O'Connor and Evans (2005:29, 246–250) refer to this as the study of the **human niche** (functional role) and **human habitat** (where they live), a useful reminder that people, cultures, ecosystems, and environments are inseparable.

The preceding chapters summarize some of the basic knowledge needed to assess evidence for the causes and consequences of dynamic human behaviors in dynamic settings and the processes involved. Most of this volume focuses on taxonomy, anatomy, morphology, site formation processes, and methods of inquiry associated with organic remains contained within archaeological sites. This focus reflects the volume's purpose: to introduce the field to readers who wish to become familiar with basic concepts, terminologies, and procedures used by environmental archaeologists. Each topic is complex; an overview does not do justice to the many phenomena merged into that unique record of the past: the archaeological site. This final chapter reviews major research questions addressed by environmental archaeologists and contributions derived from integrating this evidence.

Questions and Contributions

As the applications summarized in the preceding chapters demonstrate, archaeological materials contain multiple categories of information that are best interpreted using theories and methods that cross academic boundaries. This requires familiarity

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with many anthropological, biological, chemical, ecological, and physical concepts. Underlying these applications are theories about the causes, processes, and outcomes of change and stasis and recognition that these phenomena do not occur, and cannot be studied, in isolation.

The questions and contributions of environmental archaeologists can be grouped into three areas: (1) environmental change and stasis; (2) human–environmental interactions; and (3) materials and methods. This list suggests nonexistent boundaries among related phenomena and does not capture the diversity of contributions made by environmental archaeologists. Knowledge that these phenomena are inseparable might be considered the first and most important contribution of environmental archaeology.

Environmental Change and Stasis

How incomplete and distorted is the archaeological evidence of environmental stasis and change? Are all changes in the archaeological record due to climatic or other environmental changes? How should we interpret evidence for environmental stasis? What ecosystem processes are evident in the archaeological record? In what ways do archaeological sites reflect long-term sustainability, short-term adaptations, and systemic resistance or resilience? How separable are the stimuli and consequences of nonanthropogenic changes, or stasis, on the one hand, and socioeconomic and historical events on the other? What roles did people play in changes or continuity, and what were their subsequent responses? Did people degrade environments, alter ecosystem processes, and overuse resources? If not, how did they avoid doing so? If so, how did people and ecosystems respond? Questions such as these are not solely of archaeological interest; answers to them are relevant to the management of endangered habitats and organisms today.

Archaeological interpretations require us to distinguish between changes stimulated by both nonclimatic factors and climate change. Today's landscapes are not the landscapes of the past; they are products of numerous, complex nonanthropogenic and anthropogenic forces, not single causes (e.g., Büntgen et al. 2011; Ohlson et al. 2011; Stinchcomb et al. 2011). Environmental archaeologists observe historical changes in body sizes and conformation in organisms; the biogeography of diseases and organisms associated with them; species abundances, including extinctions; population and community structures; the distribution of species, ecosystems, landscapes, and biomes; and landforms such as coastlines, rivers, and deserts; as well as changes in other clinal and temporal aspects of specific organisms. They find evidence for habitat loss and degradation. Documenting sequences of change and stasis relies upon combined information for climates, weather patterns, sediments, soils, and the organisms associated with them. Landscape reconstructions show that Holocene environments are more dynamic than previously thought and that organisms' responses to changes are highly variable (e.g., Dawson et al. 2011). Environmental proxies and ecological analogies must be applied with caution.

Complex feedback among climates, populations, communities, landscapes, death assemblages, and taphonomic pathways must be considered when evaluating archaeological materials for evidence of changes in environments and ecosystems. Human responses were complex but too diverse to be deterministic. The materials recovered from archaeological sites are products of multiple events or agents that could produce similar outcomes, but causes and consequences are difficult to isolate. People use resources out of proportion to their abundance in their environments and the materials recovered from sites are but a small fraction of what was originally used. The habit of people to manipulate organisms and landscapes, for any number of reasons, further complicates efforts to isolate organismal responses to ecosystem successions, clinal variations, and natural selection.

People are, in part, responsible for some changes in environments and ecosystems because their activities destroy, modify, and create diverse aspects of habitats. In other instances, people have no causal role. Either way, their responses are part of the site's environmental context and the culture's history. Distinguishing between cultural changes stimulated by nonanthropogenic environmental and ecosystem changes and those stimulated by internal dynamics of a cultural system is particularly challenging, compounded by the difficulty of chronological resolution and the spatial scales (e.g., Schulting 2010).

Human–Environmental Interactions

Change through time is the very fabric of the archaeological record and much archaeological research focuses on defining the degree to which such changes were due to external or internal cultural dynamics. What was the rate of human use of specific organisms? What were the consequences of use on those organisms and on human life? What did people do at the site and how did the activities at one site relate to other sites? Embedded in these questions are additional ones: were specific activity areas or the entire site occupied continuously or intermittently over the course of an annual cycle and by how many people? If intermittently, during which part of the annual cycle and where did people go if they went elsewhere during a seasonal round? What did they do, for how long, at each location? What drives major cultural innovations? Was there an environmental role in cultural change, and if so, what was it? Were major cultural changes, such as domestication, urbanization, and state formation stimulated by population movements (migration, immigration), trade in ideas or materials, or independent inventions? Why did people domesticate plants and animals? Why did they domesticate the specific suite of organisms familiar to us today? What were the origins of these plants and animals? What were the processes and consequences of domestication? How did cultural responses to change or stasis reflect or alter social interactions and people's perceptions of their world?

Among the most basic and dynamic human–environmental interactions are those that convert raw materials into goods and services. Economic decisions about which

resources to use, how, when, where, and by whom are based on far more than the nutritional value of a single organism. People acquire, alter, consume, and distribute a wide range of materials for a variety of purposes, interactions that affect organisms, the people that use them, environments, and ecosystems. Many organisms were used, not just as foods, drugs, and beverages, but as components in architecture, commerce, and multi-step manufacturing processes. Studying choices among products and how they were used yields insights into nutrition, diets, modes of production, distribution, and consumption, social structures, political systems, property ownership, inheritance, social values, ritual, ideology, and many other aspects of human life. These choices include decisions about which organisms were used, by whom, in what manner, the characteristics valued, the intensity of use, the acquisition methods employed, and the seasonal or annual schedule.

Residential patterns, sources of raw materials, manufacturing techniques, exchange systems, waste disposal, and water management have consequences for human life, the resources upon which people depend, and the environments in which they live. Both residential patterns and seasonal scheduling are more complex than previously thought. The degree of sedentism, population size and density at a specific site, the length of time the site was occupied, and the size and density of human communities making use of the same resource base cannot be considered to be "either/or" decisions and all had consequences. Residential patterns influence hygiene, sanitation, air and water quality, and the health of both people and the organisms associated with them. Diseases play important roles in human history, not only because they afflict human individuals and populations, but because of close ties among plants, animals, and people. The origins, timing, and dispersal of people, organisms, and diseases are important elements in environmental and cultural histories. Distinguishing among changes attributable to population increase, population movement, technological innovations, economic influences, and other cultural dynamics is a challenge. Many interpretations rely on evidence that links cultural changes with colonization and environmental changes as sources or stimuli for innovation.

Domestication is a continuum of interactions among peoples, organisms, and various aspects of environments. The transition was not unidirectional, universal, or rapid, and it took many different forms, but it was widespread. Identifying cultural and noncultural stimuli for domestication is a major goal of environmental archaeology. Theoretical dichotomies that sharply distinguish between mobile nonfarmers and sedentary farmers, and associate each with specific political and economic institutions, are unsupported by much of this research (e.g., Acemoglu and Robinson 2009). It is likely that people began to impact and manage resources during the late Pleistocene and clearly were doing so in the early Holocene. This might begin by clearing competing vegetation to encourage preferred plant and animal taxa or by supporting desirable seeds that sprout voluntarily in middens. In many cases, people continued to use wild resources in combination with domestic ones, even when the investment in storage, pastoralism, or farming infrastructure was significant (e.g., Kuijt and Finlayson 2009; Zheng et al. 2009). Environmental and cultural stimuli, trends, processes, chronologies, and outcomes associated with domestication

were not globally homogeneous; they exhibit a great deal of regional variation (e.g., Conolly et al. 2011). Tracing routes followed by early domestic plants and animals from multiple centers of domestication to other locations documents processes of diffusion, trade, migration, political influence, and colonization. In some cases, archaeological evidence suggests distinct episodes of introductions, each time of genetically different stock. Domestication was not necessarily advantageous for either the domesticates or the people; in some cases the health of either the domestic or human population declines markedly, or new health challenges replace earlier ones.

Some cultural institutions maintained stability in response to change of either anthropogenic or nonanthropogenic origin and others emphasized resilience. People by and large were successful in meeting their nutritional and reproductive needs; but they may have done so by considerably altering the structures and functions of ecosystems. In some cases, practices such as clearing land, plowing, terracing, irrigation, managing wild resources, and expanding settlements had substantial adverse impacts on populations, communities, and landscapes. In other cases, however, land-use strategies appear to have controlled erosion, limited over-exploitation, and contributed to ecological stability.

Materials and Methods

How should researchers manage the record of environments and human behavior that is spatially and temporally condensed into only a few meters and altered by so many unknown and unmanageable processes? How do life assemblages become study assemblages? Which organisms represent local communities and which do not? How closely do sample assemblages represent original environments and ecosystems? How accurately do the methods of environmental archaeologists capture the complexity and vagaries of the archaeological record? Can taxonomic attributions be made at a sufficiently low taxonomic level that cultural and environmental information can be obtained? Which of the materials recovered from archaeological sites represent human behavior?

Studies of environmental change and stasis and of human–environmental interactions rely upon familiarity with the materials recovered, particularly with variables that affect the survival of inorganic and organic remains and forces that alter archaeological deposits. Individual, population, and community variations in productivity, dispersal, and deposition are significant site formation processes, as are cultural institutions. These factors, and others, transform life assemblages into study assemblages. Cultural and noncultural site formation processes do not affect all materials within a site, or those at multiple sites within a region, in the same way, which results in differential preservation. Some of these processes are more accessible to observation and study than are others.

The traditional archaeological focus on those large plants and animals whose remains can be seen in the field significantly biases interpretations. Many interpretations

of hunting strategies combine prey ranking systems, optimal foraging theories, settlement patterns, and subsistence technologies, for example. High-ranking prey species often are defined as large-bodied animals. In some cases, however, small-bodied animals are not recovered because of inappropriate field methods or are not studied, leaving many aspects of prey-ranking systems unexplored. Acquiring water, fuel, food, and raw materials safely and reliably likely was more important in basic economic decisions than was obtaining large quantities of meat. Animals have social value that cannot be measured in terms of meat weight; they may be hunted out of proportion to their protein contribution because of the prestige their capture confers. Alternatively some animals might be spared to avoid ritual contamination or for other social reasons.

Beyond the focus on animals embedded in many optimal foraging studies, economies rely on organisms from a number of domains. The ability to recover and analyze these, however, is significantly limited by fundamental differences among the materials (e.g., Schibler and Jacomet 2010). Typically fungi, plant, and animal remains are recovered using methods that compromise comparability, and each of these groups of organisms have different numbers and kinds of parts that might survive, be recovered, and be studied. This is compounded by lack of coordination among the researchers who are studying these materials.

Distinguishing among stimuli for change or stasis requires multiple proxies and repeated tests of hypotheses about the materials and methods used. Interpreting biological remains from archaeological contexts draws upon theories and methods that enable researchers to identify factors active in environments today, to demonstrate that these same factors prevailed in the past, and to verify that ecological and ethnographic analogies are appropriate. Many of the methods used by environmental archaeologists are experiments that test theories about the biogeochemical world, human behavior, and the ways archaeological materials reflect these. To manage the materials and methods involved in testing these theories, environmental archaeologists emphasize criteria embedded in the scientific method: the requirement to test alternative theories, the need for appropriate research designs, and the importance of replicable methods. Training, technical skill, experience, comprehensive reference materials, and reanalyses are fundamental to verifiable, replicable studies. Environmental archaeologists rely upon their knowledge of the strengths and weaknesses of their methods and materials and of their effects on primary and secondary data.

Field methods, and, in some cases, routine museum practices, assist or impede these studies. Poorly planned and executed field work biases archaeological evidence, hampers studies such as those highlighted in this volume, and is particularly frustrating because many of these could be avoided. Environmental archaeologists should be included in project planning, and either be in the field or be informed of excavation decisions and progress. They should be provided with samples carefully selected based on the research questions, accompanied by pertinent and accurate site information.

It is largely as an effort to overcome weaknesses and biases found in specific materials and methods that environmental archaeologists strongly advocate regional,

interdisciplinary, multi-proxy studies. It is important to validate interpretations by additional observations from different perspectives, as well as to conduct controlled experiments with the methods and materials themselves.

Nature Conservation and Heritage Management

Resource managers are aware that they need global data from time periods prior to the twenty-first century CE upon which to base management decisions. This is particularly the case as they realize that their benchmarks for so-called "natural" or "original" conditions, which they hope to restore, are not being achieved. Some of these benchmarks are based on inaccurate assessments of human–environmental interactions during the Holocene or on concepts about Holocene environments that are inconsistent with archaeological evidence (e.g., Barton et al. 2004; Whitehouse and Smith 2004). The study of "tree islands" in the Florida Everglades (USA) is but one example of the influence previous human behavior had on interpretations of the age and formation of landforms, biodiversity, wetland ecology, and other palaeoenvironmental features (Bernhardt 2011; Graf et al. 2008).

Environmental archaeologists are in unique positions to provide historical and global perspectives on environmental issues to the public, community leaders, conservation biologists, resource managers, and policy makers. Environmental data from archaeological sites have significant applications today due to the temporal and spatial reach of these studies (Butler and O'Connor 2004; Lauwerier and Plug 2004; Lyman and Cannon 2004; Nicholson and O'Connor 2000; Roseff 2001). For many years, archaeological evidence for biogeography, environmental change, health and disease, pollution histories, and pre-industrial traditions in resource use was largely applied to anthropological and biological research. Environmental archaeologists might observe in the course of their inquiries that present-day management decisions were based on assumptions about the past that were not supported by archaeological evidence, but rarely applied this knowledge to the public debate about environmental change, sustainability, and resilience. As evidence accumulates regarding the human role in environmental change, environmental archaeologists increasingly contribute to discussions about historical and global trends.

The archaeological record reveals historical trends in population and community ecology for the late Pleistocene and the Holocene rarely available from other sources. Many changes in ecosystems once were thought to be largely caused by European expansion, the industrial revolution, or twentieth-century CE economic practices. The archaeological record contains even earlier evidence of plant and animal population sizes, densities, distributions, and structures that represent much earlier events. The time depth of archaeology shows that, in many cases, alterations of environments and ecosystems occurred due to human actions (e.g., Masseti et al. 2010; Stinchcomb et al. 2011) and at other times, the relationship was more complex (Alam et al. 2009; Djamali et al. 2009). This record demonstrates that the

Holocene was not as stable as once thought and that many environmental changes happened long before the recent expansion of European influence (e.g., Kenward 2004; Sandweiss et al. 2004; Stinchcomb et al. 2011).

Environmental archaeologists increasingly engage in applied research because of their knowledge of the recent past (geologically speaking) and long-term perspectives (ecologically speaking). Combining data from Pleistocene and early Holocene specimens with those from modern organisms document climate regimes, provide a historical basis for present-day distributions of organisms, supply materials and information needed for conservation genetics, describe ancient breeds and their histories, and inform decisions about the management of rare or endangered species (e.g., Ceiridwen et al. 2011). Environmental archaeologists participate in civic and political actions, economic development initiatives, and the legislative process by providing information to community advocates and policy makers regarding conservation issues, sustainable levels of harvesting wild resources, and heritage genomes of plants and animals. They collaborate with law enforcement agencies and forensic scientists in the implementation of laws and treaties pertaining to the protection of species and trade in organisms or their products. They may testify in legal cases or before governmental panels. The implications of these contributions to the public debate and decision-making process underscore the importance of sound scientific methods during identification and analysis, informed by diverse lines of evidence, to ensure that data provided are as accurate as current theories and knowledge permit and can withstand the scrutiny of judicial and legislative systems.

Resource managers need to examine their assumptions carefully in light of archaeological evidence for relationships between environments and cultures. For example, ancient fishing was not a simple, inflexible strategy (Andrus et al. 2002; Reitz 2004; Sandweiss et al. 2004). In Peru, some changes in fishing strategy probably were responses to nonanthropogenic changes in the resource base associated with fluctuations in El Nino/Southern Oscillation (ENSO) as well as other atmospheric, geological, and oceanic phenomena. The primary role ascribed to nonanthropogenic factors for changes in the ancient Peruvian fishery may or may not be supported by additional research, but the important point is that the fishing strategy, and probably the structure of the fishery itself, changed markedly in the twentieth century CE and impacted an ecosystem that otherwise appeared resilient.

Some cautions need to be repeated for resource managers unfamiliar with the strengths and weaknesses of the archaeological record, however. Most environmental archaeologists have been asked to tell a wildlife manager whether a specific plant or animal was present or absent in the past, usually to decide whether the organism should be introduced to or eliminated from a management area. As this volume demonstrates, reconstructing biogeographical ranges is not as simple as it might seem.

Some resource managers labor under the mistaken impression that "primitive man" ate anything that could be caught using simple, inefficient tools, and had no impact on the environment. The archaeological record does not support the image of random scavengers living in perfect harmony with pristine, unaltered environments.

People in the past were highly selective. They did not use whatever they could find and they controlled what they acquired by managing when, where, and how they acquired it. People modified their environment in the past, intentionally or unintentionally (e.g., Fowler 2008; Jackson et al. 2001; Redman 1999; Summerhayes et al. 2010). Such choices and resource modifications reflect dynamic, systemic responses balancing diverse biological, cultural, and geological imperatives.

Environments are equally dynamic. Essentially, the Holocene is a record of human interactions with environments and many aspects of today's environments reflect that history (e.g., Stinchcomb et al. 2011). Some changes are consequences of human actions and others are not. Outcomes of this interaction were not necessarily inconsequential and make it difficult to say an organism should or should not be "reintroduced" or eliminated as invasive or what a "natural" landscape or habitat might have been at any given point in time.

Interpretations that affect conservation and heritage management need rigorous testing; this is problematic for archaeological data. Nonetheless, the need for a historical perspective in conservation biology and resource management is clear. Environmental archaeologists may not be able to answer questions about a species' former range or abundance easily or to conclusively reconstruct environmental conditions in every case, but we know that the last century does not represent the previous 10,000 years. For whatever reasons, the twentieth century CE is not typical of preceding centuries, which are themselves not unbiased examples of a stable, benign relationship with Mother Nature. Managers need to examine the greatest temporal and spatial spans possible to determine whether a species or habitat is appropriate and which accompanying variables are necessary to sustain them in today's environment.

Archiving Samples and Data

Excavation is expensive in time and funds; often it is difficult to return to sites. Many sites are examined just before they are destroyed by large-scale construction or agricultural projects, rising sea level, erosion, siltation, looting, or other assaults. New questions, however, may arise long after the initial analysis is finished. This argues for collecting as much material as possible while in the field. If the recommendations made in this volume are followed, many more samples will be collected from this vanishing record of our heritage than can be investigated during the original project. At the same time, samples degrade under poor archival conditions, and it may be inadvisable to collect samples for which no research question is apparent. Sampling strategies, archiving studied and unstudied samples, documentation, and data are topics of increasing concern to all archaeologists (e.g., Orton 2000:191–192).

Prior to excavation, project directors should enter into formal agreements with an official repository to safeguard materials, related documents, and data, as a public trust for the benefit of society. The mission of these public repositories, or similar

facilities, should be caring for collections, enabling access to collections for study, and disseminating knowledge derived from collection-based research to scholars and the public. This mission should be reflected in formal, written collection management policies for acquisition, removal, de-accession, loan, and access such as those recommended by the International Council of Museums (ICOM), the American Association of Museums (AAM), and similar organizations. These management policies should specify standards of care in terms of facilities, financial resources, personnel, conservation, and other activities associated with collection stewardship. Although limited space and the costs of curation sometimes are used to justify discarding unstudied remains or those deemed "unidentifiable" during the initial study, random implementation of this irreversible, destructive practice should be avoided. De-accessioning should be based on evaluations of samples in terms of the quality of the archaeological context, recovery method, and potential for further research. All attempts should be made to preserve complete archaeological assemblages for future research, preferably in the same institution. Many records and specimens need special handling for long-term preservation and the repository should be prepared to address these needs.

Archaeological samples, associated documents, and data are irreplaceable, and should receive the same high-quality care provided to all vouchers for original research. Copies of documents and data should be archived with the samples along with information about which samples were and were not included in previous studies. It is essential that both materials and records be accessible for re-study when new questions and methods emerge (e.g., Orton 2000:191–192). Formal documentation of loans sent to researchers for analysis and samples removed for destructive analysis (e.g., isotopic, genetic) should be maintained. Loaned materials should be returned to the permanent repository when analysis is complete, in addition to archival-quality copies of notes, reports, and publications.

Environmental archaeologists have responsibilities, too. They should keep clear, well-organized records that can be used by other scholars when the original researcher is unavailable. They should record notes and raw data on the highest-quality media available. If archival-quality media cannot be obtained, the media selected should be curated so as to minimize risk of damage and human error. Special thought should be given to using digital media because many digital formats are unlikely to remain accessible without regular updates, which impose an additional archival cost.

Summary and Future Directions

Given the vagaries of environments, ecosystem processes, organismal behaviors, site formation processes, and analytical methods, one may lose sight of some consensus opinions confirmed by much of the research conducted by environmental archaeologists. These consensus opinions, of course, are hypotheses that will be

tested through additional research, but it may be helpful to conclude this volume by listing some widely accepted hypotheses.

1. Sites are complex records of human behavior and environments. The relationships among people, environments, and ecosystems are systemic, dynamic ones, not ones of simple causality or unilinear evolution. Their connections are reflected in scheduling decisions, residential patterns, population size and density, labor management, exchange systems, political organization, health, activity patterns, belief systems, and other aspects of biological and social life.
2. Environments prior to the twentieth century CE were not "natural," pristine, or unmodified by human behavior. All people influence soil formation, landscape evolution, and the distribution of plants and animals, and have done so throughout the Holocene, regardless of the complexity of economic, political, ideological, or other social institutions.
3. Abiotic and biotic remains recovered from archaeological sites are largely artifacts of human behavior at a specific time and place.
4. People were never random scavengers. They make choices among the resources available to them, selecting those that enable them to balance risk against return for effort, to meet nutritional requirements, and to maintain an expected style of social life.
5. Both mobility and sedentism have consequences for environments, ecosystems, and cultures. Resource acquisition schedules, domestication, population size, and population density are not the only significant variables in residential patterns. Domestication is not necessary for sedentism and does not insulate human societies from environmental impacts.
6. Many traditional anthropological categories useful for organizing ethnographies and textbooks (e.g., sedentism, mobility, foraging, hunting and gathering, horticulture, agriculture) are misleading if used as fixed stages for the evolution of human behavior. There is no single, discrete, universal model; transitions from foraging to farming and pastoralism were not necessarily absolute, inevitable, beneficial, or irreversible.
7. More environmental and cultural information is contained within and adjacent to archaeological sites than is ever visible to the unassisted eye or untrained field staff. Once excavated, such information is effectively lost forever if not sampled and studied.
8. Good research begins with testable theories, problem-oriented research designs, and appropriate methods. Poorly designed field and laboratory techniques bias our understanding of the past. The archaeological contexts studied should be well-defined and understood by everyone involved in their analysis.
9. To develop a coherent view of environments, ecosystems, and cultures, diverse, independent lines of evidence should be pursued. Only regional, multi-proxy studies can assess the causes, processes, and consequences of change or stasis in the archaeological record. Interdisciplinary research is an important tool in evaluating and interpreting data; corroborating and elaborating findings; and revising hypotheses to be tested by further research.

Not all environmental archaeologists agree with each of these hypotheses, and much careful work needs to be done to test and refine them. It is increasingly clear, however, that they cannot be tested and refined by continuing a serendipitous approach to studies of inorganic and organic remains from archaeological sites and their surroundings. It is important to combine data from as many different sources as possible within the parameters of well-structured research designs.

A Final Note

Environmental archaeology is based upon the theory that organisms are dependent on ecosystem processes and that this relationship informs systemic associations among peoples and environments. Because the archaeological record is a human artifact, traditional distinctions between environments, ecosystems, and cultures, or between abiotic and biotic phenomena, often necessary to organize publications and educational materials, are unsatisfactory. These are, in reality, inseparable, integrated aspects of the Holocene and of our species' history. People are part of environments, cannot be separated from environments, and have their own perceptions of what that means. Sediments, soils, and organic materials from archaeological sites are as much products of these human–environmental relationships as are ceramic vessels and stone tools. These materials reflect human decisions and interventions at various spatial and temporal scales. They should not be studied in isolation, segregated from each other, or separated from other classes of observations. To interpret archaeological materials accurately and fully, they should be investigated as integrated biological, cultural, and geological phenomena through exchanges of information with colleagues exploring other aspects of the archaeological record. This objective is extremely difficult to achieve; encouraging such interchange is a goal of this volume.

Much of the research trajectory of modern environmental archaeology can be traced to the contributions of a few key figures. One of these is Karl W. Butzer. In advocating a more critical study of the environmental history of Crete, Butzer and Harris (2007:1950) observe the following:

> Environments are complex, and identifying, let alone interpreting, change depends on how well we can separate the impact of background climate change, the sporadic or sustained intervention of people and land use, and the many potential feedbacks intrinsic to the environment in response to natural or human inputs. There are no simple answers or diagnostic tests. Environmental history requires multiple readings, attention to interlinear clues, discourse, and deconstruction of accepted truths.

Most environmental archaeologists would agree with this statement. Many would expand upon it by observing that cultures, too, are complex.

Environmental archaeology enhances our understanding of the past by providing access to additional reservoirs of information and environmental archaeologists continue to develop new perspectives on that past. When environmental archaeologists are criticized for their focus on details of identification and appear to be

overwhelmed by the limitations of their materials and methods, it should be understood that they have learned to be cautious and conservative, and justifiably so. In almost every case, an alternative explanation seems possible and every study is plagued by underlying flaws which we cannot resolve, or of which we may be unaware. Nonetheless, truly important contributions are made when everything goes right. Making everything go right requires the active participation of a team of researchers skilled in their disciplines, committed to communication, and aware of the needs of other members of the team. For solid environmental and cultural studies, examining multiple types of materials is a critical ingredient, as is truly interdisciplinary scholarship accompanied, in truth, by curiosity, good questions, and a bit of luck.

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Appendix: List of Some Scientific and English Vernacular Names

Abelmoschus esculentus (okra)
Acacia spp. (acacia)
Acanthocephala (thorny-headed worm)
Acanthopleura granulata (West Indian fuzzy chiton)
Acarina (mite, tick)
Acer spp. (maple)
Acrocladium cuspidatum (bryophyte, moss; now known as *Calliergonella cuspidata*)
Actinopterygii (ray-finned fish)
Aedes aegypti (mosquito, vector for yellow fever)
Aedes africanus (mosquito, vector for yellow fever)
Aegopinella spp. (terrestrial gastropod)
Agavaceae (agave, lechuguilla, yucca)
Agave lechuguilla (agave, lechuguilla)
Agave sisalana (sisal hemp)
Aglenus brunneus (beetle)
Agnatha (hagfish, lamprey)
Alces alces (elk [Europe]; moose [N. America])
Alligatoridae (alligator)
Allium cepa (onion)
Alnus spp. (alder)
Amanita caesarea (Basidiomycota fungus, Caesar's mushroom)
Amanita muscaria (fly agaric)
Amaranthaceae (pigweed)
Amaranthus spp. (amaranth, pigweed)
Amphibia (amphibian, salamander, frog)
Amoeba spp. (protist)
Ananas comosus (pineapple)
Ancylostoma duodenale (nematode, hookworm)
Anisus spp. (aquatic gastropod)
Annelida (segmented worm, earthworm, leech)

E.J. Reitz and M. Shackley, *Environmental Archaeology*, Manuals in Archaeological Method, Theory and Technique, DOI 10.1007/978-1-4614-3339-2

Anomura (hermit crab)
Anopheles spp. (mosquito, vector for malaria)
Antheraea spp. (silkmoth, wild)
Anthocerotophyta (hornwort)
Anthozoa (sea anemone, coral)
Antilocapra americana (pronghorn antelope)
Apiaceae [Umbelliferae] (carrot, parsley)
Apis mellifera (honey bee)
Apium spp. (celery)
Aquila adalberti (Spanish Imperial eagle)
Arachis hypogaea (peanut)
Arachnida (spider, tick, mite, scorpion)
Araneae (spider)
Arbutus spp. (madrone)
Arcanobacterium pyogenes (bacterium)
Archaea (prokaryote domain)
Arecaceae (palm)
Aridius bifasciatus (mould beetle)
Arthropoda (centipede, millipede, insect, crustacean, spider)
Artiodactyla (ungulate, deer, pig, moose)
Ascaris lumbricoides (nematode, roundworm, maw worm)
Ascomycota (fungus, sac fungus, truffle)
Ashfordia granulata (terrestrial gastropod)
Aspergillus flavus (fungus)
Aspergillus oryzae (fungus)
Aspergillus parasiticus (fungus)
Astacidea (crayfish)
Asteraceae [Compositae] (sunflower, aster)
Asteroidea (sea star)
Athyrium filix-femina (common ladyfern)
Atteva spp. (ailanthus webworm)
Avena sativa (common oat)
Avena sterilis (animated oat)
Aves (bird)
Axis axis (axis deer, chital)
Bacillus anthracis (bacterium, anthrax)
Bacillus licheniformis (bacterial source of α-amylase enzyme)
Bacteria (prokaryote domain, bacterium)
Balanus spp. (barnacle)
Basidiomycota (club fungus, rust, smut, shelf fungus)
Batrachochytrium dendrobatidis (chytrid fungus)
Belemnitella (extinct cephalopod)
Beta vulgaris (beet, chard)
Betula spp. (birch)
Bison bison (buffalo)

Bivalvia (pelecypod, clam)
Blattaria (cockroach)
Boletus edulis (mushroom, penny bun)
Bombyx mori (silkmoth, domestic)
Bordetella pertussis (bacterium, whooping cough, pertussis)
Boonea impressa (impressed odostome)
Borrelia burgdorferi (bacterium, Lyme disease)
Bos primigenius (aurochs, wild cattle)
Bos taurus (cattle, domestic)
Bosmina spp. (water flea)
Bovidae (cattle family)
Bovista nigrescens (puffball)
Brachiopoda (lamp shell)
Brachythecium rutabulum (bryophyte, brachythecium moss)
Branchiopoda (water fleas)
Brachyura ("true" crab)
Brassicaceae [Cruciferae] (mustard)
Bromeliaceae (bromeliad)
Brucella abortus (bacterium, brucellosis)
Bryophyta (moss)
Bryophytes (nonvascular plant, liverwort, hornwort, moss)
Bryozoa (colonial animal, bryozoa)
Busycon carica (knobbed whelk)
Cactaceae (cactus)
Caenorhabditis elegans (soil nematode)
Calathea allouia (llerén)
Calluna vulgaris (ling, heather)
Calvatia utriformis (puffball)
Camellia japonica (camellia)
Cancer magister (Dungeness crab)
Canis familiaris (dog, domestic)
Canis lupus (gray wolf)
Canis [lupus] domesticus (or *C. l. familiaris*; alternate names for domestic dog)
Canna spp. (canna lily)
Canna [*edulis*] *indica* (achira, Indian shot)
Cannabis sativa (hemp)
Cantharellus cibarius (Basidiomycota fungus, chanterelle)
Capillaria spp. (nematode, roundworm)
Capra hircus (goat)
Capra ibex (ibex)
Capreolus capreolus (roe deer)
Capreolinae (deer subfamily, moose, brocket deer, caribou, white-tailed deer)
Capsicum spp. (cayenne pepper)
Carassius auratus (goldfish)
Carnivora (carnivore, dog, bear, cat, walrus)

Carpinus spp. (hornbeam)
Carya spp. (hickory, pecan)
Carychium minimum (terrestrial gastropod)
Carychium tridentatum (terrestrial gastropod)
Castor canadensis (beaver)
Cavia aperea (guinea pig, wild)
Cavia porcellus (guinea pig, domestic)
Centaurea spp. (knapweed)
Cephalochordata (lancelet)
Cephalopoda (octopus, squid)
Cercophora spp. (Ascomycota fungus)
Cervidae (deer)
Cervinae (deer subfamily, elk, wapiti, red deer, fallow deer)
Cervus spp. (elk, wapiti, red deer)
Cervus elaphus (red deer [Europe]; elk, wapiti [N. America])
Cestoda (tapeworm)
Cetacea (whale, dolphin, porpoise)
Chaetomium spp. (Ascomycota fungus)
Chelicerata (horseshoe crab, spider, tick, mite)
Chenopodium spp. (chenopod, goosefoot)
Chenopodium quinoa ssp. *milleanum* (quinoa, goosefoot)
Chilopoda (centipede)
Chironomidae (midge, chironomid)
Chlamydia trachomatis (bacterium, chlamydia)
Chloridoideae (subfamily of grasses)
Chlorophyta (green algae)
Chlorostoma spp. (sea snail)
Chondrichthyes (cartilaginous fish, shark, ray)
Chordata (lancelet, tunicate, vertebrate)
Chytridiomycota (chytrid fungus)
Cicer judaicum (chickpea)
Cinnamomum verum (cinnamon)
Cirripedia (barnacle)
Citrullus spp. (citron melon, watermelon)
Cladium spp. (sawgrass)
Cladocera (water flea)
Claviceps purpurea (Ascomycota fungus, ergot of rye)
Clinocardium nuttallii (cockle)
Clitellata (earthworm, leech)
Clostridium botulinum (bacterium, botulism)
Clostridium isatidis (indigo-reducing bacterium)
Clostridium tetani (bacterium, tetanus)
Cnidaria (sea anemone, corals, jellies)
Cochlicopa lubrica (terrestrial gastropod)
Cocos nucifera (coconut palm)

Coenobita clypeatus (hermit crab)
Coleoptera (beetle)
Colocasia esculenta (taro, coco yam)
Compositae [Asteraceae] (sunflower, aster)
Coniochaeta spp. (Ascomycota fungus)
Consolida spp. (knight's-spur)
Copepoda (copepod)
Corchorus spp. (jute)
Corylus spp. (hazelnut)
Corynebacteria (bacterium, diphtheria)
Craniata (animals with a cranium)
Crassostrea virginica (eastern oyster)
Cruciferae [Brassicaceae] (mustard)
Crustacea (water flea, ostracod, copepod, barnacle, crab)
Cryptosporidium parvum (protozoa)
Ctenophora (comb jelly, sea walnut)
Cucurbita spp. (gourd/squash)
Cupressaceae (cypress)
Cymbella sp. (diatom)
Cymbula granatina (limpet)
Cyperaceae (sedge)
Cyperus papyrus (papyrus)
Cyprinidae (carp, minnow)
Cypriniformes (minnow)
Cyprinus spp. (carp)
Cythereis [Rehacythereis] luermannae luermannae (ostracod)
Dactylopius coccus (cochineal)
Dama spp. (fallow deer)
Damalinia bovis (biting louse)
Daphnia spp. (water flea)
Dasylirion spp. (sotol)
Daucus carota (carrot, Queen Anne's lace)
Decapoda (shrimp, crab, lobster)
Diodontidae (porcupinefish)
Dioscorea esculenta (yam)
Diphyllobothrium latum (fish tapeworm)
Diplopoda (millipede)
Diptera (fly, mosquito)
Dryopteris spp. (woodfern)
Dugong dugon (dugong)
Echinochloa esculenta (barnyard or Japanese millet)
Echinococcus granulosus (tapeworm, hydatid disease)
Echinodermata (sea star, brittle star, sea urchin)
Echinoidea (sand dollar, sea urchin)
Echinus spp. (sea urchin)

Eipthemia sp. (diatom)
Elephantidae (elephant)
Engraulidae (anchovy)
Entamoeba [*Escherichia*] *coli* (bacterium in human digestive system)
Entamoeba histolytica (protist, amoebic dysentery)
Entognatha (springtail)
Enterobius vermicularis (nematode, human pinworm)
Equidae (equid)
Equus asinus (donkey, domestic)
Equus caballus (horse, domestic)
Equus ferus (horse, wild)
Equus zebra (zebra)
Ericaceae (heather)
Ericales (a dicotyledon plant order)
Eriophorum spp. (cottongrass)
Euconulus spp. (terrestrial gastropod)
Euglena spp. (protist)
Eukarya (eukaryote domain, multicellular organisms)
Euphausiacea (krill)
Euphorbiaceae (spurge, rubber tree, manioc, castorbean)
Fabaceae [Leguminosae] (legume, pulse, algarrobo)
Fagus spp. (beech)
Fasciola hepatica (liver fluke)
Felidae (cat)
Felis catus (cat, domestic)
Felis chaus (jungle cat)
Felis silvestris (wild cat)
Ficus carica (fig)
Filarioidea (nematode, filarial worm)
Fissurellidae (limpet)
Fistulina hepatica (beefsteak fungus)
Fomes fomentarius (bracket fungus)
Fragaria spp. (strawberry)
Fraxinus spp. (ash)
Fungi (rust, smut, chytrid, mushroom)
Fungi Imperfecti (informal group of fungi)
Gadiformes (codfish, hake)
Gadus morhua (cod)
Galliformes (gallinaceous bird)
Gallus gallus (chicken)
Gastropoda (univalve mollusc, snail)
Gazella gazella (gazelle)
Gecarcinidae (land crab)
Giardia duodenalis (protist)
Giardia intestinalis (also known as *G. lamblia*; protist, diarrhea)

Ginkgo biloba (maidenhair tree)
Gladiolus spp. (gladiolus)
Glossina spp. (tsetse fly, vector for sleeping sickness)
Glycine max (soybean)
Gossypium spp. (cotton)
Gnathostomata (shark, bony fish, tetrapod)
Gomphonema truncatum (diatom)
Gomphonema gracile (diatom)
Gramineae [Poaceae] (grass)
Grus grus (crane)
Gymnosperms ("naked" seed-bearing plants)
Haemagogus spp. (mosquito, vector for yellow fever)
Haematoxylon campechianum (logwood)
Haemophilus pneumoniae (bacterium, pneumonia)
Haliotididae (abalone)
Haliotis midae (abalone)
Hedera helix (English ivy)
Helianthus annuus (sunflower)
Helicobacter pylori (bacterium, chronic peptic ulcers)
Heliconia spp. (parakeetflower)
Hemiptera (true bug)
Hemithiris spp. (brachiopod)
Hepaticophyta (liverwort)
Herpes spp. (virus, shingles, chicken pox)
Heterohelix reussi (foraminifera)
Hexapoda (springtail, insect)
Hirudinida (leech)
Homo sapiens sapiens (anatomically modern human)
Hordeum bulbosum (bulbous barley)
Hordeum marinum (seaside barley)
Hordeum pusillum (little barley)
Hordeum spontaneum (barley, wild)
Hordeum vulgare (barley, domestic)
Hordeum vulgare ssp. *nudum* (naked barley)
Hylocomium splendens (bryophyte, moss)
Hymenoptera (ant, bee, wasp)
Hydrozoa (Portuguese man-of-war, hydra, some corals)
Ilex spp. (holly)
Insecta (louse, beetle, ant, butterfly, flea)
Ipomoea batatas (sweet potato)
Isatis tinctoria (dyer's woad)
Isopoda (pill bug, wood louse)
Iva annua (sumpweed, marsh elder)
Jubaea chilensis (Chilean coco palm)
Juglans spp. (walnut)

Juncaceae (rush)
Kalanchöe spp. (life plant, bryophyllum)
Karenia brevis (dinoflagellate, marine toxin)
Lagenaria siceraria (bottle gourd)
Lagostomus maximus (viscacha)
Lagurus ovatus (harestail grass)
Lama glama (llama)
Lama guanicoe (guanaco)
Laminariales (sea kelp)
Laminaria spp. (brown algae, Japanese kombu)
Lactuceae (Cichorieae; lettuce, chicory, salsify, dandelion)
Larix spp. (larch, tamarack)
Leguminosae [Fabaceae] (legume, pulse, algarrobo)
Lens esculenta (lentil)
Lens [*esculenta*] *culinaris* (lentil)
Lens odemensis (lentil, wild)
Lens orientalis (lentil, wild)
Lenticulina rotula (foraminifera)
Leporidae (rabbit, hare)
Lepidoptera (butterfly, moth)
Lepisosteidae (gar fish)
Liguliflorae (Compositae [Asteraceae], sow thistle)
Liliaceae (lily)
Limacidae (terrestrial gastropod)
Linum usitatissimum (common flax, linseed)
Lithodidae (stone crab, king crab)
Lithospermum officinale (common gromwell, stoneseed)
Lumbricidae (earthworm)
Lumbricus terrestris (earthworm)
Lycoperdales (puffball)
Lycopodium spp. (club moss)
Lymnaea spp. (terrestrial gastropod)
Lynx pardinus (Iberian lynx)
Macoma nasuta (bent-nosed clam)
Magnolia grandiflora (magnolia)
Magnoliophyta (flowering vascular plants)
Malacostraca (shrimp, lobster, crab)
Malus spp. (apple)
Malus sylvestris (crab apple)
Mammalia (artiodactyl, carnivore, primate, etc.)
Manihot esculenta (manioc, cassava, yuca)
Manilkara zapota (sapodilla)
Marantaceae (arrowroot)
Maxillopoda (barnacle, copepod)
Mazama spp. (brocket deer)

Medicago sativa (alfalfa)
Meleagris gallopavo (turkey)
Melosira varians (diatom)
Menippe mercenaria (Florida stone crab)
Mercenaria campechiensis (southern quahog)
Mercenaria mercenaria (northern quahog)
Meridion sp. (diatom)
Merostomata (horseshoe crab)
Mesodesma donacium (surf clam)
Mimosa cf. *aculeaticarpa* var. *biuncifera* (catclaw mimosa)
Mnium undulatum (bryophyte, moss)
Mollusca (chiton, gastropod, bivalve, squid, octopus)
Moniliformis clarki (thorny-headed worm)
Monogenea (monogenea fluke)
Murex [*Hexaplex*] *trunculus* (banded dye-murex)
Muridae (rodent, mice, rat)
Musa spp. (banana, plantain)
Musa textilis (manila hemp, abaca)
Musca domestica (house fly)
Mycobacterium bovis (bacterium, tuberculosis)
Mycobacterium leprae (bacterium, leprosy, Hansen's disease)
Mycobacterium tuberculosis (bacterium, tuberculosis)
Myrica spp. (sweetgale, bayberry)
Myriophyllum spp. (watermilfoil)
Myriapoda (centipede, millipede)
Myrtus spp. (myrtle)
Mysticeti (baleen whale)
Mytilidae (mussel)
Mytilus californianus (California mussel)
Myxinidae (hagfish)
Myxogastrida (slime mold)
Nautilus spp. (chambered nautilus)
Navicula decussis (diatom)
Necator americanus (nematode, hookworm)
Neisseria gonorrhoeae (bacterium, gonorrhea)
Nematoda (roundworm, threadworm, pinworm, hookworm)
Nemertea (ribbon worm)
Nesovitrea hammonis (terrestrial gastropod)
Nicotiana tabacum (tobacco)
Nitzschia sp. (diatom)
Nymphaeaceae (water lily)
Odocoileus virginianus (white-tailed deer)
Olea europaea (olive)
Oligochaeta (segmented worm, earthworm)
Oliva bulbosa (swollen olive)

Oomycota (water mold)
Opisthobranchia (sea slug)
Opuntia spp. (cholla cactus [cylindro], prickly pear [platy])
Orchidaceae (orchid)
Oribatida (oribatid mite)
Ornithorhynchus anatinus (duck-billed platypus)
Orthoptera (grasshopper)
Oryctolagus cuniculus (European rabbit)
Oryza sativa (rice)
Osteichthyes (bony fish)
Ostraciidae (boxfish)
Ostracoda (ostracod, seed shrimp)
Ostreidae (oyster)
Ostrya spp. (hophornbeam)
Ovis aries (sheep)
Pachyrhizus tuberosus (jicama, ajipo)
Palinura (spiny lobster)
Pan spp. (chimpanzee)
Panicum miliaceum (broomcorn millet, common millet)
Panicoideae (predominantly C_4 grasses)
Panthera leo (lion)
Paracentrotus lividus (purple sea urchin)
Paramecium spp. (protist)
Papaver somniferum (opium poppy)
Pectinidae (scallop)
Pediculus humanus capitus (head louse)
Pediculus humanus humanus (upper body louse)
Pelecypoda (bivalve, clam, oyster)
Penaeus spp. (shrimp)
Penicillium spp. (fungus)
Penicillium camemberti (fungus)
Penicillium roqueforti (fungus)
Pennisetum glaucum (pearl millet)
Perciformes (perciform fishes)
Petromyzontidae (lamprey)
Phaseolus vulgaris (common bean, kidney bean)
Philosamia spp. (silkmoth, wild)
Phoenicopterus ruber (greater flamingo)
Phoenix dactylifera (date palm)
Phoronida (tube-dwelling worm, phoronid, horseshoe worm)
Phragmites spp. (reed)
Phthiraptera (louse)
Phytophthora infestans (protist, late-blight in potatoes)
Picea spp. (spruce)
Pinnipedia (seal, sea lion, walrus)

Pinnularia sp. (diatom)
Pinus spp. (pine)
Pinus aristata (bristlecone pine)
Piper nigrum (black pepper)
Pisces (shark, ray, bony fish)
Pistacia spp. (pistache)
Pisum sativum (garden pea)
Plantago spp. (plantain)
Plasmodium falciparum (protist, malaria)
Platanus spp. (sycamore)
Platyhelminthes (flatworm, tapeworm, fluke, trematode)
Pleuronectiformes (flatfish)
Pleurozium schreberi (bryophyte, Schreber's big red stem moss)
Poaceae [Gramineae] (grass)
Pollicipes pollicipes (leaf, goose, or goose neck barnacle)
Polychaeta (segmented marine worm)
Polygonum aviculare (knotweed)
Polyplacophora (chiton)
Polypodium spp. (polypody fern)
Pomatias elegans (terrestrial snail)
Pooideae (predominately C_3 grasses)
Populus spp. (aspen, poplar, cottonwood)
Populus tremuloides (quaking aspen)
Porifera (sponge)
Porosphaera [*Coscinopora*] *globularis* (fossil sponge)
Porphyra spp. (red algae, Japanese nori)
Portunidae (swimming crab)
Praebulimina sp. (foraminifera)
Praebulimina reussi (foraminifera)
Procyon lotor (raccoon)
Prosopis spp. (mesquite, algarrobo)
Protist (eukaryote)
Protozoa (protist)
Prowazekii typhus (rickettsiae, epidemic typhus)
Prunus spp. (almond, plum, peach, cherry, apricot)
Pseudophoxinus spp. (carp)
Pseudotsuga menziesii (Douglas fir)
Pteridium spp. (bracken fern)
Pteridophytes (seedless vascular plant, club moss, fern)
Pteropus spp. (fruit bat, flying fox)
Pthirus pubis (pubic louse)
Puccinia graminis (black stem rust of wheat)
Pulmonata (land snail, slug)
Punctum spp. (terrestrial gastropod)
Pyrus communis (pear)

Quercus spp. (oak)
Rangifer tarandus (caribou, reindeer)
Rattus exulans (Pacific rat)
Rattus norvegicus (Norway rat)
Rattus rattus (black rat)
Reduviidae (assassin bug)
Rhea spp. (rhea)
Reptilia (turtle, lizard, snake)
Rhinovirus (virus, colds)
Rhizopoda (testate amoeba)
Rhizopus stolonifer (black bread mold)
Rhododendron spp. (rhododendron, azalea)
Rhopalodia sp. (diatom)
Rhytidiadelphus squarrosus (bryophyte, square goose neck moss)
Ricinus communis (castorbean)
Rickettsia spp. (bacterium, typhus)
RNA Enterovirus (virus, poliomyelitis)
RNA Flavivirus (virus, yellow fever)
RNA Morbillivirus (virus, rinderpest, distemper, measles)
RNA Paramyxoviruses (virus, mumps)
RNA Rhabdovirus (virus, rabies)
Rosa spp. (rose)
Rotifera (rotifer)
Rubia tinctorum (dyer's madder)
Rubivirus sp. (virus, rubella)
Rubus fruticosus (blackberry)
Rubus idaeus (raspberry)
Saccharomyces cerevisiae (fungus, yeast)
Saccharum officinarum (sugarcane)
Salix spp. (willow)
Salmonella typhi (bacterium, typhoid fever)
Sarcodina (protist, amoeba, radiolarian, foraminifera)
Saxidomus giganteus (butter clam)
Scarabaeidae (dung beetle)
Scaphopoda (tusk shell)
Schistosoma spp. (fluke, bilharzia, schistosomiasis)
Sciaena spp. (drum)
Sciaenidae (drum, fish)
Scorpiones (scorpion)
Scutellastra granularis (limpet)
Scyphozoa (jellyfish, sea wasp, sea nettle)
Secale cereale (cereal rye)
Selaginella spp. (spike moss)
Semibalanus cariosus (thatched barnacle)
Sepioida (cuttlefish)

Serpentes (snake)
Setaria italica ssp. *italica* (foxtail millet)
Shigella dysenteriae (bacterium, dysentery)
Siphonaptera (flea)
Sirenia (siren, manatee, dugong)
Solanum [*Lycopersicon*] *lycopersicum* (tomato)
Solanum tuberosum (white potato)
Sorghum bicolor (sorghum)
Sphaeroceridae (dung fly)
Sphagnum spp. (peat moss)
Sporormiella spp. (Ascomycota fungus)
Staphylococcus aureus (bacterium, osteomyelitis)
Staphylococcus epidermis (bacterium on human skin)
Stomoxys calcitrans (stable fly)
Streptococcus spp. (bacteria, strep throat)
Stronglocentrotus fransiscanus (red sea urchin)
Strongyloides stercoralis (nematode, wireworm)
Struthio camelus (ostrich)
Stylommatophora (land snail)
Succineidae (terrestrial gastropod)
Suidae (pig, peccary)
Surirella sp. (diatom)
Sus domesticus (pig, domestic)
Sus scrofa (pig, wild)
Synedra ulna (diatom)
Tachyglossidae (echidna)
Taenia saginata (beef tapeworm)
Taenia solium (pork tapeworm)
Tamarix aphylla (tamarisk)
Tetrapoda (amphibian, reptile, bird, mammal)
Thoracochaeta zosterae (dung fly)
Thuidium tamariscinum (bryophyte, tamarisk thuidium moss)
Tilia spp. (basswood)
Tinca tinca (tench)
Toxoplasmosis gondii (protist, toxoplasmosis)
Tracheobionta (vascular plant)
Trematoda (fluke, trematode)
Treponema pallidum (bacterium, syphilis, yaws, pinta)
Triatoma spp. (kissing bug, vector for Chagas' disease)
Trichia hispida (terrestrial gastropod)
Trichinella spiralis (nematode, roundworm, trichina worm, trichinosis)
Tricholoma spp. (mushroom)
Trichomonas vaginalis (protist, trichomoniasis)
Trichoptera (caddis fly)
Trichuris trichiura (nematode, whipworm)

Trifolium spp. (clover)
Trilobitomorpha (trilobite)
Triticum aestivum (common wheat, free-threshing bread wheat)
Triticum boeoticum ssp. *thauodar* (two-grained einkorn, wild)
Triticum dicoccon (or *dicoccum*; emmer wheat, domestic)
Triticum durum (free-threshing durum or hard wheat, domestic)
Triticum monococcum (einkorn)
Trypanosoma brucei (protist, sleeping sickness)
Trypanosoma cruzi (protist, Chagas' disease)
Tsuga spp. (hemlock)
Tuber melanosporum (truffle)
Turbellaria (flatworm, helminth, planarian)
Ulmus spp. (elm)
Umbelliferae [Apiaceae] (carrot, parsley)
Urochordata (tunicate, sea squirt)
Ursus maritimus (polar bear)
Ursus spelaeus (European cave bear)
Ustilago maydis (maize smut)
Vanilla planifolia (vanilla)
Vallonia costata (terrestrial gastropod)
Vallonia excentrica (terrestrial gastropod)
Vallonia pulchella (terrestrial gastropod)
Variola virus (virus, smallpox)
Vertebrata (animals that protect the spinal cord with bone)
Vertigo pygmaea (crested vertigo)
Vibrio cholerae (bacterium, cholera)
Vicia faba (broad bean, horse bean)
Vitis vinifera (grape, domestic)
Vitrea spp. (terrestrial gastropod)
Xenopsylla cheopis (common flea, vector for plague)
Yersinia pestis (bacterium, plague, Black Death)
Yucca spp. (yucca, century plant)
Zea mays (maize, corn)
Zingiber officinale (ginger)
Zonitoides nitidus (terrestrial gastropod)
Zygomycota (zygote fungus)

Index

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