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Lithostratigraphy of Sicily

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DI PALERMO

Springer

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ISSN 2366-7516 ISSN 2366-7524 (electronic)
UNIPA Springer Series
ISBN 978-3-319-73941-0 ISBN 978-3-319-73942-7 (eBook)
https://doi.org/10.1007/978-3-319-73942-7

Library of Congress Control Number: 2017963855

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

The extended, well-documented and richly illustrated monograph dedicated to *Lithostratigraphy of Sicily*, written by Luca Basilone from the University of Palermo, deserves a special presentation. It displays the results of over ten years of fieldwork carried out under the expert and careful guidance of Raimondo Catalano and from related detailed sedimentologic, micropaleontologic and microfacies analysis. The work is pertinent in particular to several geological sheets of the new geologic map at the scale 1:50,000 of the Italian CARG project, but it has a much broader context, that extends well beyond the sheets boundaries.

Indeed, Sicily, the largest island of the Mediterranean, is situated just in the middle of this small ocean basin that is surrounded and crossed by a series of mountain ranges created during the Alpine orogeny. In terms of plate tectonics, Sicily is dissected by a W-E-directed plate boundary that separates the two major plates Eurasia and Africa, the latter subject to a counterclockwise rotation.

Collisional mountain ranges are developed on the northern border of the island and terminate towards ENE with the Peloritani Mountains (Calabrian arc with a metamorphic basal unit). Westward, the complex chain is SSE vergent and displays a thickness of up to 15 km. Three units are distinguished, as follows: Peloritani units, Sicilidi units and Maghrebian units. The collision is related to the Alpine orogeny and is Paleogene–Miocene in age. The western Mediterranean (remnant of the Mesozoic Tethys) was entirely consumed ("lost ocean") after the Alpine orogeny, and the Balearic basin was created by the counterclockwise rotation of the Corsica/Sardinia block. This happened in late Oligocene/early Miocene time. The counterclockwise rotation of the Italian peninsula initiated during the Messinian salinity crisis and is still active today.

But well before the conceptual model of plate tectonics was formulated in the late 1960s of last century, the rich fossil faunas of various ages attracted the attention of local palaeontologists, first of all Gemmellaro (from 1872). The existence of the highest active volcano in Europe was another strong attraction of Sicily for geologists and volcanologists even in the early days of science. Finally, mining geology with special reference to the exploitation of the Gessoso–Solfifera Formation played an important role starting from the second half of the eighteenth century (Mottura, 1871, Baldacci, 1886) and, more recently, are documented by the prominent work of Ogniben (1957) and Decima (1975).

Oil exploration started in Sicily during World War II, soon after the American troops disembarked near Gela on 10 July 1943. Gela proved to be an important oil field, and the influence of Hollis Hedberg, who was vice-chair of Gulf Oil Co. at that time, is strongly felt in the modern, practical approach to lithostratigraphy (Schmidt di Friedberg, 1964–65), predating the publication of the International Guide of Stratigraphic Nomenclature. Meanwhile, structural geologists concentrated their efforts in deciphering the northern chains (Broquet, Mascle, Caflisch) where richly fossiliferous Mesozoic successions are exposed and document important facies changes.

A new interest in Sicilian geology derived from the first deep-sea exploration of the Mediterranean by the R/V GLOMAR CHALLENGER in 1970 and the unexpected discovery that evaporites quite similar to those outcropping in Sicily (Gessoso–Solfifera Formation) were present in the sub-bottom of the Balearic, Tyrrhenian, Ionian and Levantine basin, directly underlying the Trubi formation. As a follow-up of the discovery, a conceptual model for a deep-sea desiccation model was formulated and the "Messinian salinity crisis" became a major subject of multidisciplinary, interdisciplinary, high-resolution multinational researches that greatly contributed to improve the late Neogene stratigraphy notwithstanding the inherent difficulties deriving from the complicated geodynamic situation. Indeed, the investigations carried out on the outcrops bordering the Sicily channel from Capo Bianco through Capo Rossello to Falconara and Gela originated astrocyclostratigraphy (of Hilgen, 1991 and the Utrecht school) and are considered the template for the Pliocene timescale (MB. Cita and colleagues). But some aspects of the model (s) are still controversial, after over forty years and over 1000 publications, as the role and precise location of the sills separating the various subbasins, the timing of the desiccation phase, the speed of the final filling, the source of the "lago mare".

In the monograph compiled by Luca Basilone 71 formations are described, of which 43 have already been formalized. Ten are emended in the present paper, and ten more are proposed as new. The seven sinthems follow the usage adopted by CARG for the sediments that represent the youngest deposits that cover the substrate, are non-marine in origin, are usually unfossiliferous and thus difficult to date (as alluvial fan, beach rock, cemented debris, eluvial deposits). Sinthems in principle should be bounded by erosional surfaces of regional significance.

The lithostratigraphy of the Sicilian rocks described by Luca Basilone is based on outcrops and also on subsurface data derived by borehole stratigraphy calibrated by the interpretation of seismic reflection profiles.

The monograph is open to new and future integrations useful to improve our knowledge of the Sicilian geology.

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Preface

The paper introduces the fundamentals of the lithostratigraphy of Sicily, as acquired from recent researches. This note aims at illustrating stratigraphic terminology, the geological lexicon and the main stratigraphic subdivisions that are not familiar to Sicilian geologists.

The work carried out consists in a series of sheets describing the main features of Sicilian lithostratigraphic units. Each of the 77 worksheets describes the lithological characteristics, sedimentological and laboratory features, thickness, depositional environments and regional geographic distribution of the Sicilian formations according to the standard stratigraphic procedure and nomenclature rules provided by the International Commission on Stratigraphy (ICS).

Most of the many previously defined formations are revised and amended here, and several new formations are proposed for their formalization. The seven systems follow the usage adopted by Carg for the sediments that represent the youngest continental and marine deposits that cover the substrate that are bounded by erosional surfaces of regional significance.

The description of the units is based on data collected during recent years through the analysis of several sedimentary successions outcropping in Sicily and by the reinterpretation of hydrocarbon exploration well logs. Lithostratigraphic methods, facies analysis and physical stratigraphy accompanied by biostratigraphy and numerical age-dating coming from the literature have been used to define the outcropping carbonate and terrigenous rock bodies. The acquisition and elaboration of the stratigraphic data have been also integrated with information obtained from a careful review of literature existing on stratigraphy, lithostratigraphy, palaeontology and tectonics since the late nineteenth century.

In the present paper, the rocks outcropping along the large belt extending from the North to the South of Sicily, as represented in the large-scale field map provided in Fig. 1.1, are schematically illustrated. A general background feature has been summarized based on the recently available stratigraphy of the Sicilian Fold and Thrust Belt (FTB) and its foreland and is illustrated in the schematic diagrams of Figs. 1.6, 1.7, 2.1, 2.2, 2.7, 2.22 and 2.72, which show the lateral (heteropic)-to-vertical relationships of the Permo-Triassic clastics, the Mesozoic–Paleogene carbonates and the Miocene–Pleistocene clastic–evaporite–carbonate deposits. These schemes are supported by recent biostratigraphic and chronostratigraphic studies developed in Sicily. Furthermore, a conceptual scheme (Fig. 2.97) that shows the geometric relationships of the Quaternary marine and continental deposits, recently defined as unconformity-bounded stratigraphic units (UBSUs), is also presented.

Sicilian successions consist of carbonate and clastic deposits spanning the Permian-to-Quaternary time interval and can be subdivided into two main rock assemblages. The Palaeozoic-to-Palaeogene clastics and carbonates represent the sedimentary cover of the original ancient passive continental margin (i.e. African margin) of the "Mesozoic Tethyan realm". After the detachment from their basement, the geological bodies were deformed and are, at present, exposed in the Sicilian FTB to form a stack of tectonic units. The Miocene-to-Pleistocene rocks assemblage, consisting of clastic, evaporite and carbonate deposits, represent the sedimentary cover of the thrust-top basins developing during the orogeny phases and forming the present Alpine collisional continental margin. Finally, the Pleistocene–Holocene rocks assemblage, consisting of marine and continental deposits, fills the basins that are mostly located in the northern Sicily coastal belt and its offshore. They were formed in an extensional regime related to the opening of the Tyrrhenian Sea.

Palermo, Italy Luca Basilone

Acknowledgements

A special thanks to M.B. Cita (President of the CIS) whose support and interest in the issues of the Sicilian lithostratigraphy promoted the realization of this work.

I wish to thank the following persons for reading part or whole of this text or its early plan and for giving me the benefits of their constructive and critical reactions: R. Catalano, B. D'Argenio, C. Doglioni, E. Patacca, L. Montanari, C. Di Maggio, R. Maniscalco, R. Sprovieri, E. Di Stefano, A. Sulli.

My colleagues A. Contino, M. Agate, G. Avellone, A. Caruso, A. Bonfardeci, S. Bonomo, M. Gasparo Morticelli, C. Gugliotta, C. Gennaro, have helped in the field and laboratory, and especially with much-needed encouragement.

I am grateful to Prof. C. Amenta and the staff of Unipa Springer Series, and two anonymous reviewers for their critical suggestions.

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*New units
°Amended units

Synonyms

AB 4	Enna marls
Ancient flysch	Mufara Formation
Amerillo unit	Amerillo Formation
Arenaceous-glauconitic Lower Miocene	Corleone calcarenites
Barbara and San Cataldo unit	Terravecchia formation
Barracù formation	Amerillo Formation
Bellolampo limestone	Inici Formation
Biancone Veneto	Lattimusa
Blue clays	Monte Narbone Formation
Bluish clays	Enna marls
Bonifato formation	San Cipirello marls
Bonifato pp formation	Corleone calcarenites
Brancaleone formation	*Exogira* marls
Busambra member	Lattimusa
Butera formation	Agrigento Formation
Calabianca unit	Lattimusa
Calcare Massiccio	Inici Formation
Calcareous molassa post nappe	Terravecchia formation
Calpionellid limestone	Lattimusa
Carnian flysch	Mufara Formation
Casale limestone	Inici Formation
Carrozza Formation	Baucina Formation
Cefalù Formation	Pellegrino Formation
Cenomanian African facies	*Exogira* marls
Cherty limestone	Scillato Formation
Chiarastella unit	Scillato Formation
Chiaromonte formation	Lattimusa
Clayey-arenaceous flysch	Lercara complex
Clayey limestone unit	Mufara Formation
Clays and brown sandstones	Numidian flysch

Collesano Formation	Numidian flysch
Concretionated limestone	Calcare di base member of Cattolica Formation
Coral limestone	Baucina Formation
Coral and sponge biolitites	Cozzo di Lupo Formation
Cozzo Terravecchia formation	Terravecchia Formation
Crystalline limestone	Inici Formation
Cuminello formation	Caltavuturo Formation
Ellipsactinie and *Nerinea* biolitites	Piano Battaglia reef limestone
Entrochi limestone	Crinoidal limestone
Eo-miocene flysch	Caltavuturo Formation
Facies astiana	Agrigento Formation
Facies piacenziana	Monte Narbone Formation
Flysch antico	Lercara complex
Fusulinid limestone	Sosio limestone
Garbata formation	Tavernola Formation
Gela formation	Sciacca Formation
Gessoso–Solfifera Formation	Gessoso-solfifero group
Giardinello formation	Caltavuturo Formation
Giardini Formation	Buccheri Formation
Gibellina formation	Ciminna Formation
Globigerina clays	San Cipirello marls
Grey and black cherty limestone	Scillato Formation
Gypsum series	Gessoso-solfifero Group
Halobids limestone	Mufara Formation
Hybla member	Hybla Formation
Jurassic detritic-organogen limestone	Inici Formation
Kungurian Flysch	Cozzo S Filippo sandstone
Leptaena beds	Crinoidal limestone
Lower and upper scaly clays	Varicoloured clays
Lower Scillato formation	Mufara Formation
Marly limestone unit	Caltavuturo Formation
Megalodontid limestone	Capo Rama Formation
Mesozoic calcareous-dolomitic reef	Cozzo di Lupo Formation
Messinian evaporites	Gessoso-solfifero Group
Messinian reef of Salemi	Baucina Formation
Mirabella formation	Scillato Formation
Monte Balatelle formation	Amerillo Formation
Monte dei Cervi formation	Crisanti Formation
Naftia formation	Sciacca Formation
Nerinee and Diceratids limestone	Pizzo Manolfo limestone
Norian-Rhaetian dolostone	Fanusi Formation
Olistostroma	Varicoloured clays

Olistostroma Napola	Terravecchia Formation
Oolitic limestone	Inici Formation
Palma formation	Trubi
Permian flysch	Cozzo S Filippo sandstone
Permian of Sosio	Sosio limestone
Pettineo formation	Reitano Formation
Pietra di Salomone limestone	Sosio limestone
Pizzo Canna limestone	Piano Battaglia reef limestone
Portella Arena formation	Mufara Formation
Radiolaritic and calcareous-spongholitic formations	Crisanti Formation
Recattivo reef limestone	Landro member of the Terravecchia formation
Red Unit	Buccheri Formation
Reef Cretaceous limestone	Pellegrino Formation
Reefoid unit	Cozzo di Lupo Formation
Reefoide unit pp	Inici Formation
Rhaetian dolostone	Fanusi Formation
Rosignano limestone	Baucina Formation
Rosso Ammonitico	Buccheri Formation
Rudistid limestone	Pellegrino Formation
Saheliano cycle deposits	Terravecchia Formation
San Calogero Flysch	Cozzo S Filippo sandstone
Scaglia	Amerillo Formation
Scaly clays	Varicoloured clays
Segesta formation	Sciacca Formation
Siliceous limestone unit	Crisanti Formation
Siliceous schists and calcareous intercalations	Crisanti Formation
Siracusa formation	Inici Formation
Solfifera formation	Gessoso-solfifero group
Sosio Megablocks	Sosio limestone
Stromatolitic dolostone	Sciacca Formation
Taormina formation	Sciacca Formation
Tithonian detritic-organogen limestone	Piano Battaglia reef limestone
Tortonian parautocton	Castellana Sicula Formation
Tortonian semialloctonhous	Castellana Sicula Formation
Trapani and Alcamo limestone	Bonifato Formation
Triassic limestone	Cozzo di Lupo Formation
Trias dolomitized limestone	Scillato Formation
Troina-Tusa flysch	Troina sandstone
Troina formation	Troina sandstone
Troina sandstone formation	Troina sandstone
Trubi member	Trubi
Tufi palombini	Trubi

Tufo calcareous of the Congerie Zone	Pasquasia Formation
Tufo fossiliferous and yellow sands	Baucina Formation
Tufo with Pecten	Baucina Formation
Ultradetritic zone	Pellegrino Formation
Upper dolostone	Fanusi Formation
Upper Miocene (pp)	Terravecchia Formation
Upper Triassic carbonate platform deposits	Sciacca Formation
Vacuolar-organogen limestone	Baucina Formation
Variegated clays	Varicoloured clays
Villagonia formation	Inici Formation
Vizzini pp formation	Sciacca Formation

Acronyms

AFL	Capo Plaia synthem
AMM	Amerillo Formation
AMM_m	Calcareous megabreccias of the Amerillo Formation
AMM_a	Red scaglia of the Amerillo Formation
AMM_b	White scaglia of the Amerillo Formation
AMM_d	Ichnites limestone of the Amerillo Formation
AUC	Calcarenites and marls of Sauci
AVF	Varicoloured clays
AVF_a	Exogyra marls
AVF_b	Caprinid breccias
β	Basalts
BAU	Baucina formation
BAU_a	*Porites* reef limestone of the Baucina formation
BAU_b	Forereef limestone of the Baucina formation
BAX	Bauxites of Spinasanta
BCH	Buccheri Formation
BCH_1	Lower Rosso Ammonitico member of the Buccheri Formation
BCH_2	Radiolarite member of the Buccheri Formation
BCH_3	Upper Rosso Ammonitico member of the Buccheri Formation
BCO	Monte Bosco formation
BLC	Marly arenaceous Belice formation
BLT	Polisano synthem
BON	Bonifato formation
CAL	Caltavuturo Formation
CAL_a	Nummulitid breccias of the Caltavuturo Formation
CCR	Corleone calcarenites
CDR	Brachiopod limestone
CII	Ciminna formation
CIP	San Cipirello marls

CZP	Cozzo di Lupo formation
CRI	Crisanti Formation
CRI_1	Radiolarite member of the Crisanti Formation
CRI_2	*Ellipsactinia* breccias member of the Crisanti Formation
CRI_3	Spongholitic member of the Crisanti Formation
CRI_4	Rudistid breccias member of the Crisanti Formation
CTI	Pizzo Manolfo limestone
FRM	Capo Rama formation
FUN	Fanusi formation
FYN	Numidian flysch
FYN_2	Portella Colla member of the Numidian flysch
FYN_5	Geraci Siculo member of the Numidian flysch
GS	Gessoso-solfifero group
GPQ	Pasquasia Formation
GPQ_1	Gessarenites member of the Pasquasia Formation
GPQ_2	Marly gypsum member of the Pasquasia Formation
GPQ_3	*Congerie* limestone member of the Pasquasia Formation
GPQ_4	Fanglomerates member of the Pasquasia Formation
GPQ_5	Arenazzolo member of the Pasquasia Formation
GTL	Cattolica Formation
GTL_1	Calcare di base member of the Cattolica Formation
GTL_2	Selenitic member of the Cattolica Formation
GTL_3	Salt member of the Cattolica Formation
GRT	Gratteri formation
HIO	Mischio
HYB	Hybla Formation
INI	Inici Formation
IMR	Imera synthem
ITO	Marabito limestone
LER	Lercara complex
LER_a	Cozzo San Filippo sandstone
LER_b	Sosio limestone
LTM	Lattimusa
LUO	Monte Luziano formation
MCD	Crinoidal limestone
MCD_a	Altofonte breccias
LEG	Pellegrino formation
MUF	Mufara Formation
MRS	Marsala synthem
PNB	Piano Battaglia reef limestone
PNB_a	Reef lithofacies of the Piano Battaglia reef limestone
PNB_b	Forereef lithofacies of the Piano Battaglia reef limestone
POZ	Polizzi Formation
RDE	Cardellia marls

REI	Reitano Formation
RFR	Raffo Rosso synthem
RND	Crinoidal limestone
SCT	Scillato Formation
SIA	Sciacca Formation
SIC	Castellana Sicula formation
SIT	Barcarello synthem
SNP	Buonfornello synthem
SOR	Monte Soro flysch
TAV	Tavernola Formation
TAV_a	*Lucina* limestone of the Tavernola Formation
TRB	Trubi
TRB_1	Lascari member of Trubi
TRP	Tripoli
TRV	Terravecchia Formation
TRV_1	Conglomerate member of the Terravecchia Formation
TRV_2	Sandstone member of the Terravecchia Formation
TRV_3	Pelitic member of the Terravecchia Formation
TUT	Tusa tuffites
VSI	Valdesi formation

Chapter 1
Introduction to the Geology of Sicily

Abstract This introductive section regards a synthetic description of the regional geological setting of the Sicily island. The main stratigraphy and regional distribution of the Sicilian rock units and the paleogeography and paleo-tectonics of the Permo-Mesozoic carbonates is included. Furthermore, an overview on the stratigraphic classification principles is provided to facilitate the reader in understanding the terminology used in the main body of text.

Sicily, located between the Calabrian Arc and the chains of North Africa is considered a key area for an understanding of the very complex geological history of the Central Mediterranean. It is characterised by different rocks, a large variety of sedimentary sequences, volcanism and tectonic structures developed during the Paleozoic–Quaternary time interval (Fig. 1.1). Metamorphic, igneous and sedimentary rocks pertaining to different geological domains (Europe, Africa and Tethys) and widely outcropping in Sicily have promoted several geological research projects since the end of the 1800s, which have had a strong impact on the description and definition both of the Sicilian regional geological setting and sedimentary sequences.

The complexity of the sedimentary successions lies in the understanding of their manner, time and place of formation and therefore must be analysed by considering various aspects and according to different criteria (see Bosellini et al. 1989). The simplest and most immediate way to differentiate the rocks of a sedimentary succession is by taking account of their lithological differences. This method allows a sedimentary body within a given area and in a specific stratigraphic sequence to be distinguished and defined. This method, which requires specific criteria based on physical observations, is defined as the lithostratigraphic classification.

Generally, the advancement of geological knowledge, which includes the stratigraphic knowledge of the Sicilian sedimentary sequences, has always corresponded to historical moments of human progress, during which significant economic and social benefits were produced. At the end of the 1800s, the progress of geological research in Italy was accelerated by the realization of the Geological Map of Italy at 1:100,000 scale (proposed by the Royal Italian Geological

L. Basilone, *Lithostratigraphy of Sicily*, UNIPA Springer Series,
https://doi.org/10.1007/978-3-319-73942-7_1

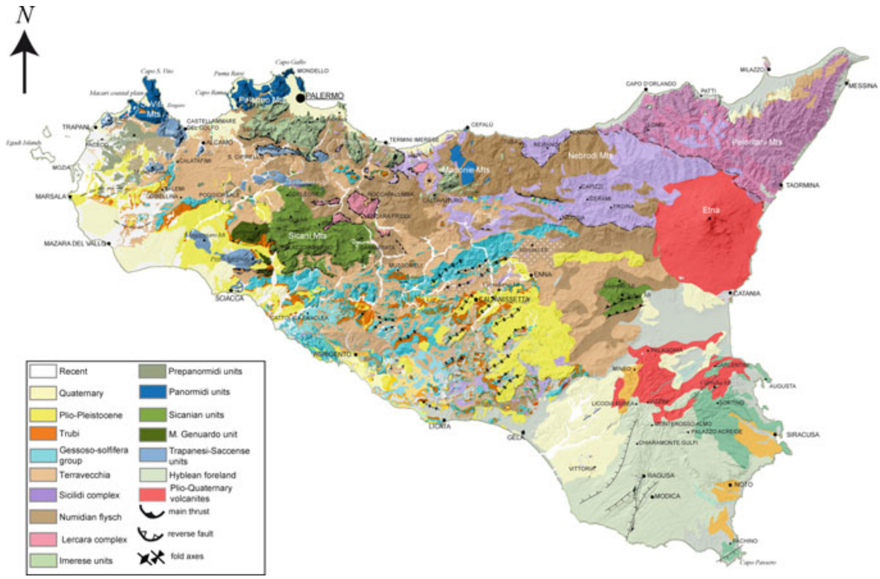


Fig. 1.1 Simplified geological map of Sicily (from Catalano et al. 2004a) showing the distribution of the main lithotectonic assemblages and their tectonic relationships

Committee), which in Sicily was responsible for producing the first regional geological map of the new Kingdom of Italy. It consists of 27 Geological Sheets and was performed by the eminent field geologists S. Mottura, R. Travaglia and L. Baldacci, under the scientific supervision of G. G. Gemmellaro.

Since the nineteenth century, several stratigraphic, structural and palaeontological research studies were conducted in Sicily and adjacent regions (G. G. Gemmellaro 1872, 1878, 1880, 1886, 1887–1899, 1902, 1904; Seguenza 1873–1882, 1873, 1880, 1882; Ciofalo 1878, 1909; Capellini 1880–1881; Baldacci 1884, 1886; Di Stefano 1886, 1900a, 1900b, 1903; Carapezza and Tagliarini 1894; De Amicis 1895; Mottura 1871, 1910; Checchia Rispoli 1903, 1905, 1909a, b, 1910, 1911a, 1911b, c, 1936; Silvestri 1904; M. Gemmellaro 1912, 1921, 1922; Arambourg 1925; Renz 1925; Di Salvo 1933; Tricomi 1939; Fabiani 1925, 1926, 1929a, b, 1933, 1941; Fabiani and Ruiz 1932a, b; Ruiz 1928; Floridia 1931; Borghi 1937; Trevisan 1935, 1937a, b; Fabiani and Trevisan 1940; De Stefani 1948, 1952, 1954; Beneo 1950; Moretti 1954; Petrocchi and Bruschi 1954; Jacobacci 1954; Warmann and Arkell 1954; Gaffurini 1954; Crescenzi and Gaffurini 1955; Coggi and Bruschi 1955; Baggio 1956; Ogniben 1957, 1960, 1963a, b; Gianotti 1958; Gianotti and Petrocchi 1960; Ruggieri 1961; Sgrosso 1986; D'Argenio and Scandone 1970). These studies, defining with precise observations the lithological characteristics of the outcropping stratigraphic units, their lateral-vertical relationships, their dating by means of the recognition and definition of numerous new fossil species and their cartographic representation, led to the coining of several new stratigraphic terms (e.g. "cherty limestone", "lattimusa", "scisti silicei", "gessoso-solfifera", etc.) that form the historical lexicon of Sicilian geology. Many of these scientific papers have been collected by Floridia (1950, 1956) in a miscellaneous collection (*Floridia miscellanea*), currently archived in the library of the School of Science of the University of Palermo, and they were later implemented by Stramondo (1962) in his work. These collections are useful manuals for the consultation of the historic geological bibliography of Sicily.

Later, in the '50s and '60s, with the development of oil exploration in Sicily, the analysis of cuttings and cores collected from the deep exploration boreholes provided new data on the Sicilian rock successions. In this view, a reorganization of the Sicilian formations was necessary in order to use a common terminology to describe the outcropping and buried lithologies. Several petroleum geologists, such as E. Beneo, P. Schmidt of Friedberg, F. Barbieri, C. Giannini, P. Petrocchi, were involved in the lithostratigraphic classification of Sicilian rock successions, following internationally consolidated methods and criteria (Hedberg 1954).

Lithostratigraphic units were defined by Rigo and Barbieri (1959) from the study of outcropping sections in Eastern Sicily. In Central-Western Sicily, in studying mostly the Madonie and Nebrodi Mountains, the lithostratigraphic classification was improved by Ogniben (1955, 1957, 1960, 1963a, b, 1964), Schmidt di Friedberg et al. (1960), Ceretti (1960, 1962, 1965), Ceretti and Ciabatti (1965), Marchetti (1956, 1960), Flores (1959), Accordi (1958, 1959), Colacicchi (1958, 1960), Campisi (1958, 1960).

The collection of the Sicilian formational units, according to the rules and procedures proposed by the newly-born ICS (Hedberg 1954) and edited in the first edition of the International Stratigraphic Guide (Hedberg 1976), was summarized in the papers of Schmidt di Friedberg (1964–1965), Rigo and Barbieri (1959) and Patacca et al. (1979). The latter, studying the buried Mesozoic-Paleogene carbonate successions of the Hyblean Plateau, amended the several previously defined units and tentatively completed the previous classification. Subsequently, the geological research was aimed mainly at producing field data and there was a proliferation of several geological maps at various scale based on the new Sicilian lithostratigraphic nomenclature (Beneo 1956; Beneo et al. 1956; Motta 1957, 1958; Caflisch 1966; Montanari 1966; Broquet 1968; Truillet 1968; Duèe 1969; Lentini and Vezzani 1974; Grasso et al. 1978, 1998, 2004; Catalano and Montanari 1979; Mascle 1979; Abate et al. 1988a, b, 1991a, b, 1996; Bommarito 1981, 1982; Di Stefano and Vitale 1993; D'Angelo and Vernuccio 1994, 1995; Bommarito et al. 1995; Mauz and Renda 1991, 1995; Grasso 1997; Lentini et al. 2000; Basilone 2012).

Since the '70s, the application of facies analysis to the Mesozoic carbonates, widely outcropping in Central-Western Sicily, has provided a new approach to the stratigraphic classification by considering also the paleoenvironmental significance of the rock bodies and the paleogeographic setting (Catalano et al. 1973, 1974a, b, c; Catalano and Abate 1974; Abate et al. 1977, 1982a; Grasso et al. 1978; Catalano and D'Argenio 1978, 1982a, b; Di Stefano 1981a, b, 1990). In this view, a large amount of stratigraphic data has provided new definitions and descriptions of the outcropping lithological units. However, at the same time, these studies have produced several new synonyms and descriptive generalizations (either for local variations in the lithological content or due to the lack of regional geological knowledge), inducing terminological and conceptual confusion that have complicated the regional lithostratigraphic classification and nomenclature.

A reorganization of the old Sicilian lithostratigraphic classification began when, with the start of the CARG project, lithostratigraphy and relative units were chosen as the preferred method to classify the outcropping geological bodies and produce 1:50,000-scale geological maps.

Coordinated by the CIS, a synthetic scheme to uniform the Eastern and Western Sicilian lithostratigraphic classification and nomenclature—with the purpose of offer an unambiguous read of the 1:50,000 geological maps—was developed. This lithostratigraphic scheme, proposed by Basilone et al. (2001) at the Meeting of the CIS hosted by the University of Palermo, was accepted and used to reorganize the Sicilian formations and their cartographic representation. Some of the results are reported in the Italian Formations Catalogue (Cita et al. 2007a, b), available online at www.accordo-carg.it, where several worksheets describing the Sicilian lithostratigraphic units used in the published CARG maps are included (Carbone et al. 2010, 2011a, b; Catalano et al. 2010a, b, c, 2011a, b, 2013a, b; Grasso et al. 2010; Tortorici et al. 2010; Di Stefano et al. 2011; Basilone 2012), available online at www.isprambiente.gov.it/MEDIA/carg/sicilia.

The aim of this book is to offer as complete an overview as possible on the lithostratigraphy of Sicily, taking into account the multiplicity of existing formational and terminological variability developed over more than a century of studies and publications. The new stratigraphic methods and the required use of formations as mapping units have prompted the acquisition of new lithostratigraphic data, the review of the previous units and their comparison with the new collected data, enabling the definition of some new lithostratigraphic units.

The results have been summarized in 77 worksheets containing the most important information regarding the lithological, sedimentological and microfacies characteristics, the measured thicknesses, areal extent and the regional aspects, the paleoenvironmental, paleogeographic and paleo-tectonics setting, compiled according to standard procedures and nomenclature (Salvador 1994).

The worksheets are grouped in a generally chronological order and the complete list is shown in table of contents. In each chronologic group the worksheets of the described formations are organized in alphabetic order. The Permo-Triassic units, consisting of mainly clastic and carbonate sequences, represent the oldest deposits outcropping in Sicily that originated during the early stages of the Southern Tethyan continental rifting; the Mesozoic-Cenozoic carbonate units, consisting of shallow- and deep-water carbonate, clastic-carbonate and siliceous deposits, were formed along the continental margin during the opening stages of the Tethys Ocean. They represent the sedimentary sequences of the various stratigraphic successions differentiated in the field along the Sicilian outcrops that were considered the infilling sequences of the several Meso-Cenozoic paleogeographic domains that were structured, since the Triassic, along the Sicilian sector of the Southern Tethyan continental margin. The deposits of the Sicilide Complex (Tethyan units) and the

Tertiary clastics (Numidian flysch) are grouped separately. The Miocene and the Plio-Pleistocene units, consisting of clastics, evaporites and pelagic carbonates, representing the sedimentary cover of the wedge-top basins formed during the construction of the Sicilian FTB, are described in different chapters. The Quaternary units, consisting of the most recent continental and marine deposits, are classified as Unconformity-Bounded Stratigraphic Units (UBSUs) and were deposited mainly along the coastal belts of the island of Sicily.

The worksheets are accompanied by several illustrations showing the main lithological, textural and paleontological characteristics of the rock units from outcrop and microscope observations and by several synoptic sketches, supported by the updated biostratigraphic and chronostratigraphic data, which display the lateral (heteropic)-vertical stratigraphic distribution of the described units.

The nomenclature used here follows the directives of the International Nomenclature Codes listed in the International Stratigraphic Guide (ISG, Salvador 1994). For easier reading of the individual worksheet, it should be noted that the units in upper case in the text have been validated, while the units in lower case are informal or as yet unvalidated units. Finally, as suggested by the ISG, the historical names have been maintained (e.g., Lattimusa, Tripoli, Inici, etc.).

An introductive section about the synthetic regional geological setting of Sicily, the main stratigraphy and regional distribution of the Sicilian rock units and the paleogeography and paleo-tectonics of the Permo-Mesozoic carbonates is included. Furthermore, an overview on the stratigraphic classification principles is provided to facilitate the reader in understanding the terminology used in the main body of text.

1.1 Sicily Regional Geological Setting

As a premise, a brief introduction about the regional geological setting of Sicily is necessary to understand the stratigraphic framework described in the following.

Sicily is part of the western central Mediterranean and is developing along the African-European plate boundary. It is a segment linking the African Maghrebides with the Southern Apennines across the Calabrian accretionary wedge (Fig. 1.2). The chain and its submerged western and northern extensions are partly located between the Sardinia block and the Pelagian-Ionian sector and partly beneath the central southern Tyrrhenian Sea (Fig. 1.3).

In this sector of the Mediterranean area, the main compressional movements, after the Paleogene Alpine orogeny, began with the latest Oligocene-Early Miocene counter-clockwise rotation of Corsica-Sardinia, believed to represent a volcanic arc and its collision with the African continental margin. Thrusting occurred in connection with the westward subduction of the Adriatic and Ionian lithosphere beneath the Corsica-Sardinia block. At present-day, a north-dipping Benioff zone, as deep as 400 km, located west of Calabria and the Apennines and the related calc-alkaline volcanism in the Aeolian Islands, indicates a westward subduction

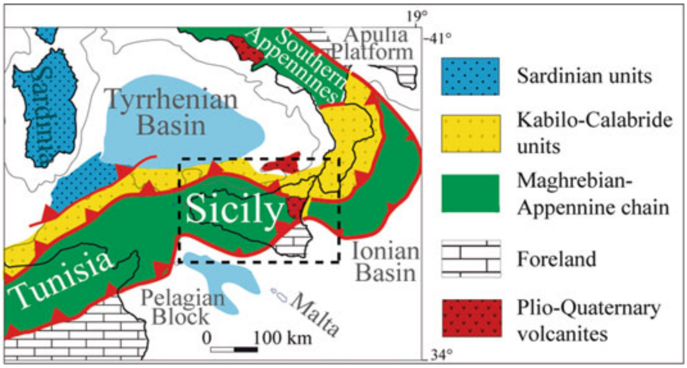


Fig. 1.2 Schematic structural map of Central Mediterranean (from Catalano et al. 2013c)

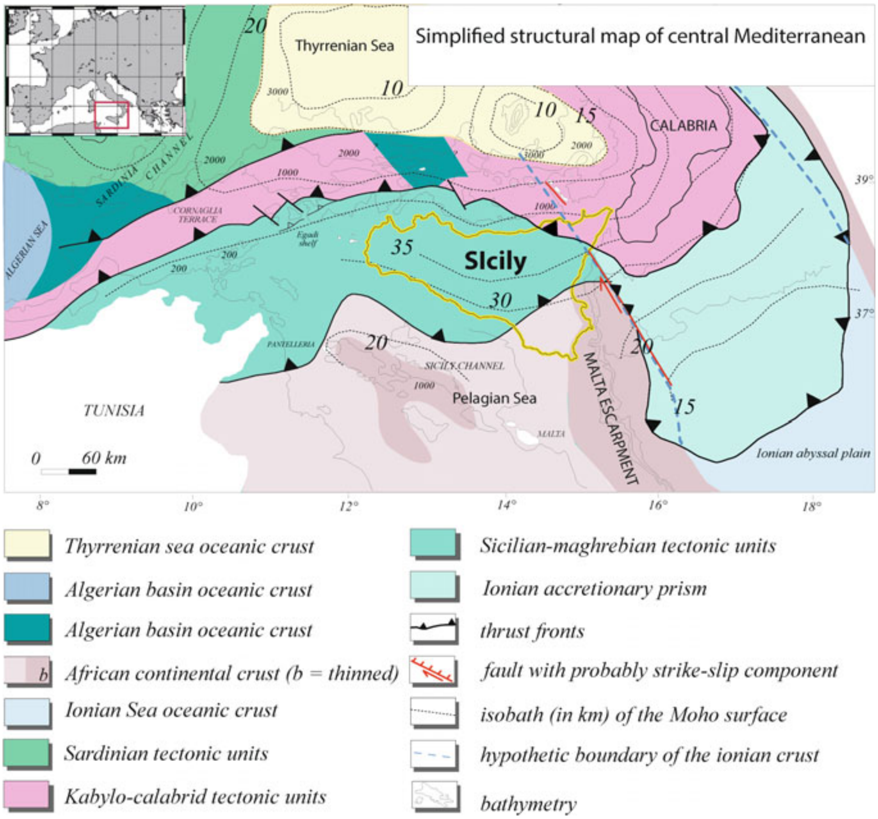


Fig. 1.3 Structural map showing the main tectonic elements of the Central Mediterranean Sea (from Catalano et al. 2013c)

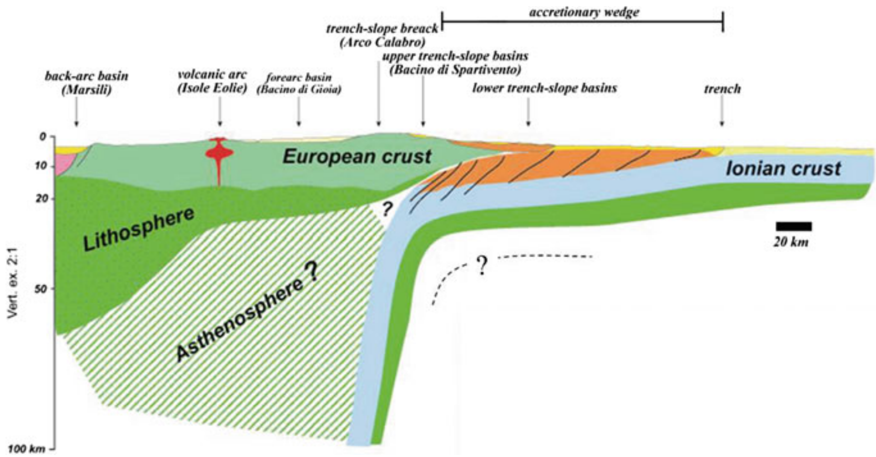


Fig. 1.4 Geological sketch of the Ionian-Thyrrenian subduction system (from Catalano et al. 2013c)

(Fig. 1.4). Subduction and thrusting are contemporaneous with rotations and back arc-type extensions in the Tyrrhenian Sea (Channel et al. 1980; Ghisetti and Vezzani 1984; Finetti and Del Ben 1986; Finetti et al. 1996, 2005; Rehault et al. 1987; Malinverno and Ryan 1986; Catalano et al. 1989a, b; Faccenna et al. 1996; Roure et al. 1990, 2002; Gueguen et al. 1998; Chamot-Rooke et al. 2005; Finetti 2005).

Recent interpretations of several reflection seismic profiles (Bornati et al. 1997; Catalano et al. 1998b, 2000a, 2004a, b, 2008a, b, 2011c, 2013c, d; Bello et al. 2000; Accaino et al. 2011) and the available stratigraphic, paleomagnetic and structural surface data derived from new geological maps (Catalano et al. 2010a, b, 2011a, b, 2013a, b, 2014) as well as those from substantially reinterpreted hydrocarbon exploration well logs (Basilone et al. 2011, 2016a) help to reconstruct the structure of mainland Sicily.

1.1.1 The Collisional Complex of Sicily

Three elements characterised the "collisional" complex of Sicily and adjacent off-shore areas (Fig. 1.3):

– a complex chain of thrust imbricates outcrops in Sicily and is locally more than 15 km thick (Fig. 1.5); it consists (from internal to external) of a "European" element (Peloritani Units with a metamorphic basement) a "Tethyan" element (Sicilide Units) and an African element (Maghrebian-Apennine Units). The tectonic units derived primarily from the deformation of a number of original paleogeographic domains (carbonate basinal and platform successions) that

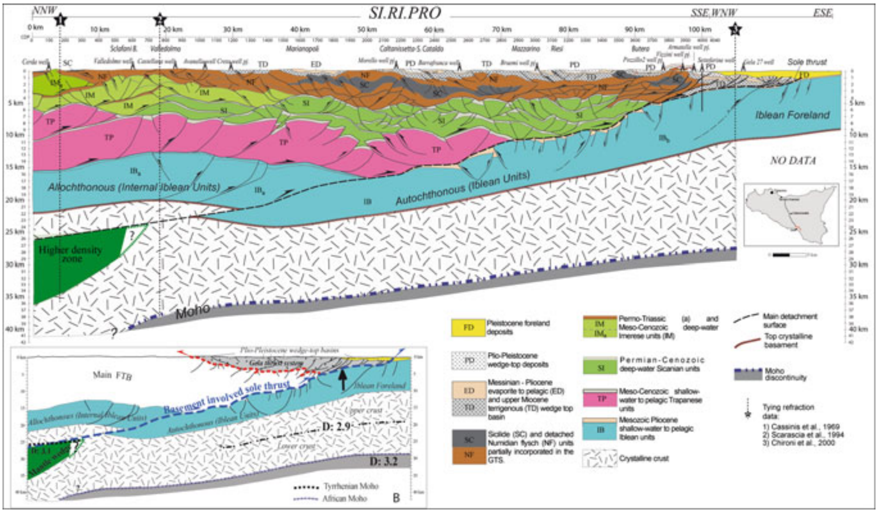


Fig. 1.5 Geological cross-section resulting from the interpretation of the seismic stack section of the SI.RI.PRO. Crustal profile and its southeastern commercial multichannel seismic extension (from Catalano et al. 2013d). The geological cross-section reconstruction benefits from the main geophysical (refraction and gravity) data. Geological sketch illustrating the regional monocline that underlies the whole orogenic wedge (B). The latter includes a basement-involved fault that merges into the overlying allochthonous units. The thrust emanates from the leading edge of the northern basement-involved fault. It carries the leading edge of the units of the overlying orogenic wedge to emerge as a thrust plane that underlies the external units of the GTS. The dark arrow indicates the arching of the basal detachment

developed during the Meso-Cenozoic interval in the Sicilian sector of the African continental margin. The distribution of the main lithotectonic assemblages and their tectonic relationships are illustrated in a general structural map of Sicily (Fig. 1.1);

- a foredeep basin developed between the chain and the foreland area and it extends from the Gela basin to offshore Sicily in the Sicily Channel. The sediments are late Miocene-to-Pleistocene in age and include the Messinian formations of the "Gessoso-Solfifero" Group and the overlying Trubi and Monte Narbone formations. The Gela nappe was displaced in the early Pleistocene;
- a foreland area belonging to the African plate developed in south-eastern Sicily (Hyblean). The sedimentary succession is 7/8 km thick and includes Triassic and Jurassic carbonates indicative of shelf and a slope-to-basin environment; late Jurassic and Cretaceous-to-Miocene pelagic carbonates followed upwards by clastic open platform deposits.

1.2 Main Stratigraphy, Facies Domains and Regional Distribution

Stratigraphic studies carried out in Sicily have highlighted the presence of lithological successions characterised by different sedimentary facies pertaining to relevant sedimentation domains (Ogniben 1960; Caflisch 1966; Broquet 1968, 1970, 1972; Giunta and Liguori 1972, 1973; Lentini and Vezzani 1974; Grasso et al. 1978; Di Geronimo et al. 1978; Catalano and D'Argenio 1978, 1982a, b; Abate et al. 1978, 1982b; Mascle 1970, 1979; Catalano and Montanari 1979; Montanari 1989; Catalano et al. 1989a, b, 1995, 1996, 1998a, 2000a, b, 2004a, 2010a, b, 2011a, b, 2013a, b; Mauz and Renda 1991, 1995, 1996; Agate et al. 1998a, b; Di Stefano 2002; Di Stefano et al. 2002a, b; Nigro and Renda 1999, 2002; Basilone 2009a, b, 2011, 2011b, 2017; Basilone et al. 2010, 2011, 2016a, b, c; Gasparo Morticelli et al. 2017).

The structural model proposed in the '60s evidenced the occurrence of a tectonic edifice superimposed on the so-called autochtonous "Basal Complex" (Ogniben 1960). The latter consists of a stratigraphic sequence also described as "Western Madonie sequence" by Schmidt di Friedberg et al. (1960), "paleo-autochton sequence" by Ceretti and Ciabatti (1965), "Sclafani succession" by Broquet (1968) and corresponds to the present-day Imerese succession (Catalano and D'Argenio 1978).

Broquet et al. (1966) and Broquet (1968, 1972) suggest the existence of a tectonic edifice resulting from the deformation of an original area occupying the southern sector of the belt named Cammarata Zone (the external chain) superimposed by the tectonic units of the Sclafani Zone and Internal Flysch (represented by the Monte Soro flysch and Varicoloured clays), outcropping in the northern and internal sectors of the Sicilian chain.

Facies analysis, physical stratigraphy and biostratigraphy have been used since the '70s to define the outcropping carbonate and terrigenous rock bodies in Sicily. This approach has allowed (Catalano and D'Argenio 1978, 1982a) to define the concept of paleogeographic units (large original rock bodies deposited in specific paleogeographic domains, a group of 'isopic zones' not yet deformed by tectogenesis). As a consequence, the study has envisaged the occurrence of different Paleozoic-Neogene successions representing the sedimentary cover of distinct crustal paleodomains belonging to the "Tethyan" Ocean and the African continental margin.

The lithological successions exposed in Sicily (Fig. 1.1) can be grouped into: (i) passive margin sequences, represented by the Permo-Triassic clastic and the Mesozoic-Cenozoic carbonates, which represent the sedimentary fill of different basins developed along the stretched African continental margin and the Tethys ocean before the onset of orogenic deformation; (ii) the active margin sequences, represented by the terrigenous deposits of the Oligo-Miocene turbiditic sedimentation (Numidian flysch), believed to be the product of the dismantling of the chain during its deformation and by the Mio-Pleistocene rocks, consisting of clastics, evaporites and pelagic carbonates. The latter, developed during and after the deformation of the compressional margin, were progressively deposited in wedge-top basins and lie unconformably on the older units.

1.2.1 The "Tethyan" Rock Units

The rock units widely outcropping in the Nebrodi Mountains consist of rock bodies derived from the deformation of the so-called Sicilide domain (Ogniben 1960). The sedimentary successions, characterized by Upper Jurassic-Oligocene basinal carbonates and sandy mudstones (Monte Soro sandstones and clays, Varicoloured clays, Troina sandstones and Polizzi Formation, Figs. 2.61–2.79), also include Upper Oligocene-Lower Miocene, terrigenous turbiditic sequences and tuffitic marlstones (Reitano formation and Tusa tuffites, Figs. 2.65–2.82). This succession, generally detached from its substrate, is believed to have developed above the Tethyan oceanic crust.

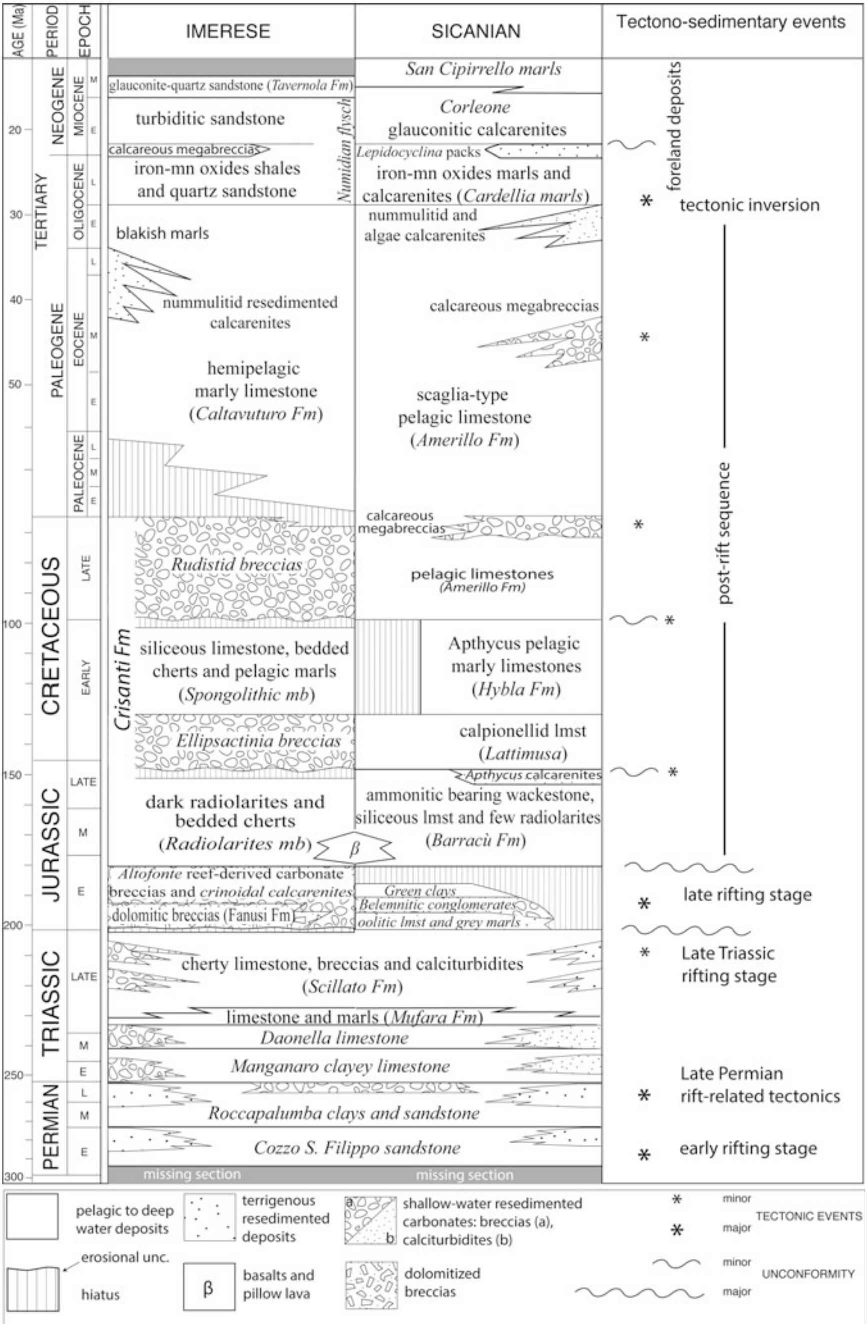
1.2.2 The African Rock Units

The sedimentary successions (now forming the main tectonic units of the Sicilian FTB) are Mesozoic-Lower Miocene, deep-water carbonates and siliceous limestone, locally named Imerese and Sicanian (Fig. 2.1) and Meso-Cenozoic shelf carbonates (Pre-Panormide, Panormide, Trapanese, Saccense and Hyblean).

1.2.2.1 Meso-Cenozoic Deep-Water Carbonate Successions

(1) Lower Permian-to-Middle Triassic, deep-water, clastic-to-carbonate deposits and turbidites (the several units that are included in the Lercara complex, Figs. 2.2 and 2.3), with resedimented shallow-water carbonates (Sosio limestone), are considered to be the older units of the deep-water Sicanian and Imerese successions (Fig. 1.6, Basilone et al. 2016a). The allochthonous thick wedge largely outcrops in the Cerda and Lercara regions and is buried beneath the Valledolmo region, where it has been drilled by several boreholes for hundreds of meters (Fig. 1.7).

(2) The Imerese type succession (Figs. 1.6 and 2.35) consists of Triassic (Carnian) to Oligocene, thin-bedded deep-water limestone, radiolarites and bedded cherts (Mufara, Scillato, Crisanti and Caltavuturo formations, Plates 8, 9, 22 and 27), with Jurassic-Eocene carbonate platform-generated debris flows (Fanusi formation, *Ellipsactinia* and rudistid breccia members of the Crisanti formation, Plates 27, 28, 29and 15). The carbonate succession is unconformably covered



AGE (Ma)
PERIOD
EPOCH
IMERESE
SICANIAN
Tectono-sedimentary events
20
30
40
50
100
150
200
250
300
TERTIARY
NEOGENE
MIOCENE
OLIGOCENE
PALEOGENE
EOCENE
PALEOCENE
CRETACEOUS
LATE
EARLY
JURASSIC
TRIASSIC
PERMIAN
M
L
E
glauconite-quartz sandstone (Tavernola Fm)
turbiditic sandstone
calcareous megabreccias
iron-mn oxides shales and quartz sandstone
Numidian flysch
blakish marls
nummulitid resedimented calcarenites
hemipelagic marly limestone (Caltavuturo Fm)
Rudistid breccias
Crisanti Fm
siliceous limestone, bedded cherts and pelagic marls (Spongolithic mb)
Ellipsactinia breccias
dark radiolarites and bedded cherts (Radiolarites mb)
β
Altofonte reef-derived carbonate breccias and crinoidal calcarenites
dolomitic breccias (Fanusi Fm)
San Cipirrello marls
Corleone glauconitic calcarenites
Lepidocyclina packs
iron-mn oxides marls and calcarenites (Cardellia marls)
nummulitid and algae calcarenites
calcareous megabreccias
scaglia-type pelagic limestone (Amerillo Fm)
calcareous megabreccias
pelagic limestones (Amerillo Fm)
Apthycus pelagic marly limestones (Hybla Fm)
calpionellid lmst (Lattimusa)
Apthycus calcarenites
ammonitic bearing wackestone, siliceous lmst and few radiolarites (Barracù Fm)
Green clays
Belemnitic conglomerates
oolitic lmst and grey marls
cherty limestone, breccias and calciturbidites (Scillato Fm)
limestone and marls (Mufara Fm)
Daonella limestone
Manganaro clayey limestone
Roccapalumba clays and sandstone
Cozzo S. Filippo sandstone
missing section
missing section
foreland deposits
tectonic inversion
post-rift sequence
late rifting stage
Late Triassic rifting stage
Late Permian rift-related tectonics
early rifting stage
pelagic to deep water deposits
terrigenous resedimented deposits
shallow-water resedimented carbonates: breccias (a), calciturbidites (b)
erosional unc.
hiatus
basalts and pillow lava
dolomitized breccias
minor
major
TECTONIC EVENTS
minor
major
UNCONFORMITY

◂**Fig. 1.6** Timetable of tectono-sedimentary events recognized along the new subdivision of the Permian-Cenozoic Imerese and Sicanian deep-water carbonate successions, based on outcrop and well data (from Basilone et al. 2016a). Time scale according to Gradstein et al. (2004)

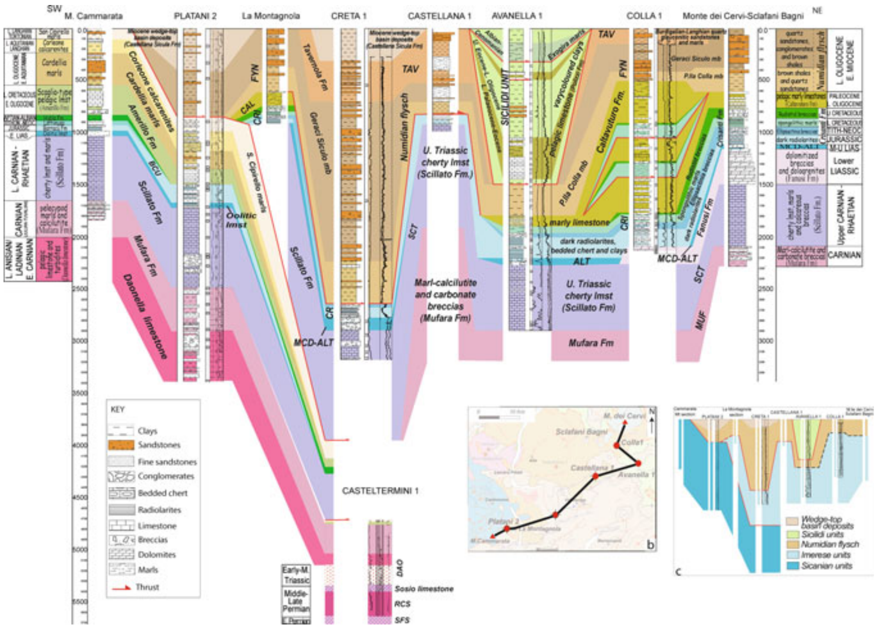


Fig. 1.7 Comparison and correlation of the outcropping deep-water sections and the synthetic log stratigraphy of some boreholes drilled in Central Sicily (from Basilone et al. 2016a). Inset figures display boreholes and field sections location (Basilone et al. 2016b) and the tectonic relationships among the drilled units (Basilone et al. 2016c)

by the Upper Oligocene-Lower Miocene siliciclastic deposits (marly shales, turbiditic sandstones and quartz-arenites Figs. 2.68–2.86 and Plate 28). The Lower Miocene rock-interval, corresponding to the Numidian flysch sensu *strictu*, often appears detached from the older substrate. The Imerese rock units outcrop mostly in the area of north-western Sicily, especially in the Western Madonie Mountains, Termini Imerese and Trabia Mountains and in the southern Palermo Mountains (Figs. 1.1 and 1.8).

(3) The main bulk of the Sicanian rock assemblage (Figs. 1.6, 2.1, 2.9 and 2.25) consists of deep-water Carnian-to-Lower Oligocene mudstones, carbonates and pelagic marlstones (Mufara, Scillato, Barracù, Lattimusa, Hybla and Amerillo formations, Figs. 2.1, 2.6 and Plates 4, 21, 22, 27), with locally resedimented carbonate breccias (Lower Jurassic Prizzi breccias and oolitic crinoidal calcarenites), followed by Upper Oligocene-Middle Miocene clastic carbonates and marls (Cardellia marls, Corleone calcarenites and San Cipirello marls, Figs. 2.25–2.27 and Plate 12). They are exposed in western Sicily in a large

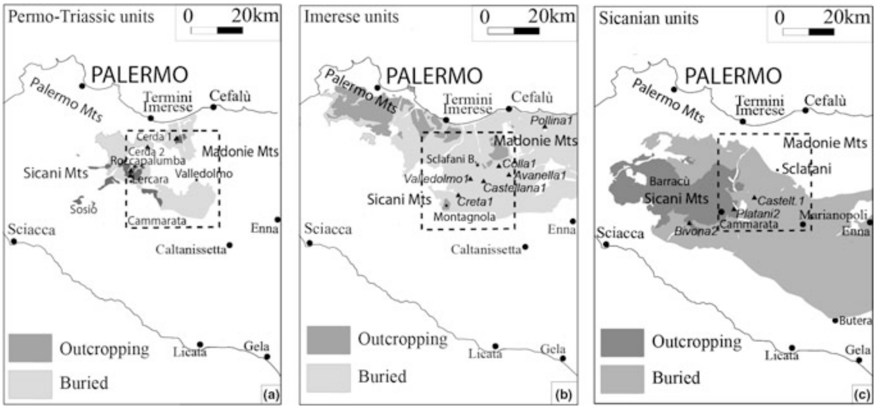


Fig. 1.8 Surface and subsurface distribution in Central Sicily of the Permian-Triassic (**a**), Imerese (**b**) and Sicanian (**c**) successions (from Basilone et al. 2016a)

area represented by the Sicanian Mountains (Figs. 1.1 and 1.8). In eastern Sicily, they outcrop in the Judica and Scalpello Mountains.

A comparison of the Imerese and Sicanian deep-water successions shows they share the same basal lithologies consisting of Permian to Upper Triassic clastics, marls and cherty limestone (Lercara complex, Mufara and Scillato Formations). They differ in their Jurassic-Cretaceous and Oligocene rock intervals, which at show quite different sedimentological and depositional characters (Figs. 1.6, 2.1, 2.9a, b and 2.35). The Sicanian succession clearly lacks the Jurassic-Eocene resedimented shallow-water carbonates and the Upper Oligocene-Lower Miocene Numidian flysch type strata that are typical lithologies of the Imerese sequence.

1.2.2.2 Meso-cenozoic Shallow-Water Carbonate Successions

(1) The so-called Pre-Panormide succession, cropping out in western Sicily (Trapani Mountains), is made up of: (a) Triassic-Lower Liassic carbonate platform dolostones and limestone (Sciacca and Inici formations do not outcrop and can be recognized in the subsurface by well log stratigraphy and seismic profiles), grading upwards into Jurassic, slope-to-basin or pelagic carbonate platform deposits; (b) Lower Cretaceous-to-Eocene cherty, turbiditic limestone (Amerillo Formation equivalent). Oligocene-Lower Miocene marly limestone, nummulitid-bearing glauconitic biocalcarenites and quartz-arenites (Monte Bosco formation) and Lower-to-Middle Miocene shallow-water glauconitic limestone and marls (Monte Luziano formation) follow unconformably (Fig. 2.46).

(2) The Panormide carbonate platform successions crop out, from West to East, in the San Vito Lo Capo Mountains, in the northernmost sector of the Palermo

Mountains and in the eastern Madonie Mountains (Fig. 1.1). The Panormide type succession (Figs. 2.4, 2.22 and 2.24) consists of Upper Triassic to Lower Miocene, 900–1200 m-thick body, mostly characterized by shelf facies, with periodic subaerial exposure and pelagic sedimentation episodes. The Panormide is considered as a Bahamian-type carbonate platform with inner-platform to reef margin environments during the Late Triassic (Figs. 2.21 and 2.23), and an open-platform with ramp geometries during Late Jurassic, Cretaceous and Eocene (Catalano et al. 1974a, b; Abate et al. 1977; Di Stefano 1981b; Catalano and D'Argenio 1982a; Vorös et al. 1986; Di Stefano and Ruberti 2000; Basilone and Di Maggio 2016; Basilone and Sulli 2016, 2018; Basilone et al. 2017). The Panormide succession can be differentiated into two main lithofacies assemblages reflecting the inner-platform and reef margin depositional environment (Abate et al. 1978). Several formations, recently revised and amended (Basilone et al. 2001; Catalano et al. 2011a, b, c), compose the lithostratigraphic columns reconstructed for the study area. The inner platform lithofacies assemblage consists of Upper Triassic dolomites with megalodontids and marl layers (Sciacca Formation), Norian-lower Liassic peritidal cycle dolomitized limestone (Capo Rama formation, Plate 10); Jurassic pelagic condensed rocks (Buccheri Formation corresponding to the well-known Rosso Ammonitico beds) and bauxite clays (Spinasanta bauxites); upper Jurassic-lowermost Cretaceous gastropods and algae limestone and stromatolites (Pizzo Manolfo limestone, Plates 25 and 26); lower Cretaceous requienid limestone (Capo Gallo limestone, Plate 9); upper Cretaceous rudistid reef deposits (Pellegrino Formation, Plate 24); upper Cretaceous-Eocene red and white pelagic limestone (Amerillo Formation, Plate 5); Eocene nummulitid limestone (Valdesi formation, Plate 7). The reef margin lithofacies assemblage shows: upper Triassic spongid reef limestone and doloarenites (Cozzo di Lupo formation, Plate 13); Jurassic crinoid, brachiopod and ammonite bearing-limestone (crinoidal limestone and Buccheri Formation); coralgal reef limestone with *Ellipsactinia* sp. and fore-reef breccias and calcarenites (Piano Battaglia reef limestone, Plates 25 and 26); Upper Cretaceous-Eocene red and white pelagic limestone (Amerillo Formation); Upper Eocene-Lowermost Oligocene slope limestone (Gratteri formation). Lower Miocene open shelf limestone (Mischio, Plate 7) unconformably covers the eroded Meso-Cenozoic carbonates.

(3) The Trapanese type succession (Figs. 2.1, 2.5, 2.15 and 2.16) crops out in western Sicily (Trapani, Castellammare and Alcamo Mountains, Kumeta and Busambra ridge, see Fig. 1.1) and has been drilled in oil exploration. Upper Triassic-middle Liassic carbonate platform dolomites and limestone (Sciacca and Inici formations, Pizzo Marabito limestone, Plates 13, 20 and 21) are followed by Jurassic condensed to pelagic deposits. These deposits, informally named Rosso Ammonitico beds, are comprised in the Buccheri Formation (Figs. 2.6, 2.7, Table 2.1 and Plates 2, 12 and 17) and are characterised by Fe–Mn crusts, condensed facies also filling a dense network of Neptunian dykes. The Upper Jurassic-Eocene pelagic carbonates are compised in the Lattimusa calpionellid limestone (Fig. 2.44), Hybla and Amerillo Formations. Lower

Miocene resedimented biocalcarenites, coastal glauconitic calcarenites and open shelf marls (Corleone calcarenites and San Cipirrello Marls) unconformably cover the Meso-Cenozoic carbonates.

(4) The carbonate platform rock bodies that crop out to the Southwest, in the Magaggiaro-Sciacca area and buried in South-Western Sicily (boreholes in the Castelvetrano-Mazara del Vallo area) and its offshore (NW Sicily Channel), have been described as pertaining to the Saccense domain (Catalano and D'Argenio 1978). They have been compared and correlated to those pertaining to the Hyblean foreland (Frixa et al. 2000). Saccense and Hyblean foreland successions are similar to the Trapanese one; the main differences consist in the occurrence of Oligocene-Lower Miocene shallow-water deposits (Ragusa Formation) in the Hyblean and Saccense successions. Moreover, local differences consist in the presence of Triassic-Liassic deep-water deposits (Streppenosa and Modica Formations) in the Ragusa belt, as the consequence of synsedimentary extensional tectonics (Patacca et al. 1979).

1.2.3 Miocene Units

Both in Western and Eastern Sicily, Serravallian-to-Tortonian terrigenous deposits (Castellana formation), mostly clays, marls and sandstones, crop out throughout Sicily, overlying paraconformably the Lower Miocene clastic cover of the Trapanese-Saccense and Sicanian carbonates, and unconformably overlap the already-deformed Panormide-Imerese rock units and the Numidian flysch-Sicilide nappes. This sandy marls unit is capped unconformably by reddish-to-yellow polygenic conglomerates, clayey sandstone and marls (Terravecchia formation, Upper Tortonian-Lower Messinian). Both units are interpreted as a deformed molassa-type filling wedge-top basins (Gugliotta 2011b; Gasparo Morticelli et al. 2015); the units widely outcrop in Central and North-Western Sicily, and at present are highly deformed.

Large bodies of Lower Messinian coral (*Porites* sp.) reef limestone (Baucina formation) lie over an eroded sandy substratum of the Terravecchia formation. Messinian evaporites (Gessoso-Solfifero Group) overlap an erosional surface, cutting the underlying strata. The Messinian evaporitic succession (Cattolica and Pasquasia formations) is predominantly eroded in the northern areas, becoming widespread towards Central and Southern Sicily.

1.2.4 Pliocene-Pleistocene Units

The Lower Pliocene Trubi formation, which is characterized by pelagic marl-limestone couplets, overlie unconformably the Messinian evaporites. A thick sedimentary wedge of mostly carbonate-clastic rocks overlies the Trubi limestone both in western and eastern Sicily. From the base upwards, these rocks are composed of Upper Pliocene-Pleistocene terrigenous and carbonate-clastic deposits (hemipelagic shales with interbedded calcarenites of the Enna marls and fine turbiditic sandstone and biocalcarenites of the Capodarso calcarenites) characterizing the infilling of the thrust-top basins, widely outcropping in the Caltanissetta-Enna region, in the Gela area and its offshore. Most of these deposits are involved in the local Gela nappe tectonics. In westernmost and southern Sicily, their chrono-equivalent deposits are represented by the "marly-arenaceous of Belice" formation and by the units comprised in the Ribera group that consists of Upper Pliocene sapropels and marls of Monte Narbone formation unconformably followed by bioclastic calcarenites of the Agrigento formation.

1.2.5 Quaternary Units

Continental-to-marine Quaternary deposits outcrop in thin and patchy exposed successions mostly along the Sicily coastal belt (Agate et al. 2017). These deposits were recently grouped in sedimentary units bounded by unconformity surfaces, i.e., UBSUs (Di Maggio et al. 2009). The detected unconformities, often of regional extent, allow us to define seven main synthems: (a) the Marsala synthem is a Lower Pleistocene 2–80 m-thick body of marine/coastal calcarenites; (b) the Piana di Partinico synthem is made up of 1–5 m thick marine/continental clastics located on several marine terraces related to sea level highstand phases of Middle Pleistocene (Marine Isotopic Stages—MISs 17–7); (c) the Polisano synthem consists of Aeolian sands, 1–10 m-thick, of late Middle Pleistocene (MIS 6); (d) the Barcarello synthem encompasses 1–2 m thick marine/coastal deposits, laterally passing into 1–5 m thick colluvial deposits, whose age is correlated with the MIS 5; (e) the Imera Settentrionale synthem is made up of Middle–Upper Pleistocene 1–3 m-thick fluvial deposits located on river terraces; (f) the Raffo Rosso synthem is composed of Aeolian sands, colluvial, gravitational and stratified slope deposits (MISs 4–2); (g) the Capo Plaia synthem consists of Holocene coastal-to-continental deposits (MIS 2–1).

The processes of deposition or erosion producing sedimentary bodies or unconformity surfaces, respectively, seem to be triggered by significant environmental changes due to tectonic movements and climatic fluctuations.

1.3 Permo-Cenozoic Paleogeography and Paleotectonic

The Permian-Cenozoic paleotectonic and sedimentary evolution is here described through three broad chronological stages, representing the main steps of the evolution of a continental margin of the Southern Tethys realm (Fig. 1.9):

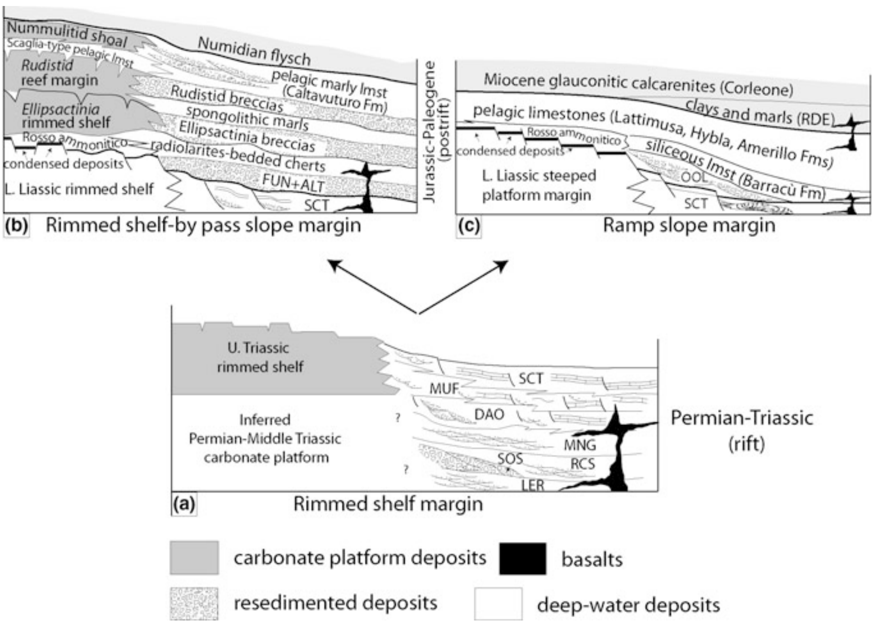


Fig. 1.9 Paleogeographic sketches illustrating the sedimentary evolution of the platform-to-basin systems throughout the main time interval evolution stages (from Basilone et al. 2016a): **a** Permian-Triassic rift stage during which a subsident rifting basin was bordered by a carbonate platform rimmed by reefs; Jurassic-Paleogene postrift stage during which a rimmed shelf-by pass slope (Imerese) margin (**b**) and a ramp-slope (Sicanian) margin (**c**) were developed

1.3.1 Permian-Triassic Stage

Depositional features of the Permian-Middle Triassic stratigraphic units reflect the evolution of a subsident rifting area, already believed to be an intracontinental basin (referred to as the "Lercara basin" in Catalano and D'Argenio 1978), or an open and deep pelagic realm which was the westward continuation of the oceanic Tethys (the "Permian Sicanian domain" in Catalano et al. 1991) or a passive margin of the westward prolongation of the Neotethys (Stampfli and Borel 2002; Stampfli 2005). This slope to very deep-water basin (Fig. 1.9a) was bordered by (i) carbonate reefs (e.g., Permian Tunisian deposits, Toomey 1991; Rigo 1998), which periodically supplied the deeper-water areas with calciturbiditic to gravity flow sediments (see also Flügel et al. 1991; Robertson 2006) and (ii) an emerged continental region (Robertson 2006 and references thereinafter) which could have been the source area of the previous mentioned terrigenous clastic deposits. Similar depositional patterns, described in other European (Duval et al. 1998; Jacquin and De Graciansky 1998), Alpine Tethys (Stampfli et al. 2002; Berra and Carminati 2010) and African regions (Bouaziz et al. 1999, 2002; Gabtni et al. 2009; Carminati et al. 2013; Passeri et al. 2014), have been correlated to the evolution of the Southern margin of the Tethys.

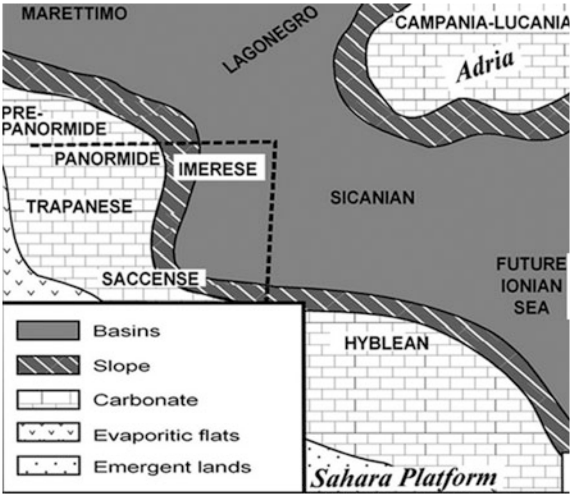


Fig. 1.10 Paleogeographic reconstruction of the Sicilian sector of the Southern Tethyan continental margin during the Late Triassic (from Catalano et al. 1996)

Up to the end of the Triassic, this basin, filled by a pelagic sedimentation in continuity with the Lower and Middle Triassic rocks illustrated above (Fig. 1.6), was bordered by a wide carbonate platform domain (Fig. 1.10, Catalano et al. 1996), whose progradational margins fragmented by extensional tectonics (see also Di Stefano et al. 1990, 2010) fed the monotonous pelagic sedimentation with detrital materials (Fig. 1.9a). The many synsedimentary faults and gravity slide features affecting the Upper Triassic cherty limestone (Basilone 2009b, 2017; Basilone et al. 2014, 2016b) document the occurrence of active tectonics that may be related to the latest Triassic rifting episode of this continental margin (Fig. 1.9a).

Elsewhere in Sicily, the absence of ophiolites, such as those reported from Eastern Mediterranean and Oman regions (Blendinger et al. 1990; Robertson 2002 and references thereinafter) and the nature of the basalts included in the Permian-Triassic rocks succession (believed to be due to a tholeiitic-fractionated magmatism, Censi et al. 2000; Cirrincione et al. 2014), weigh in favour of a rifting basin developed on a stretched continental crust. The hypothesis that lithospheric thinning processes (with associated magmatic underplating of the lower-crust and/or ductile deformation) that could have affected the Southern margin of the Tethyan realm in the same time interval can also be inferred for the central-southern Sicily sector due to a distinctive signature of seismic reflectivity in the lower crust and upper mantle (Valenti et al. 2015).

Finally, we are in favour of the hypothesis that Sicily pertained to a region whose Permian-Early Jurassic history was punctuated by several rifting phases which predate the spreading of the Neotethys in the Ionian sector (Bernoulli et al. 1990; Catalano et al. 2001; Stampfli and Borel 2002, 2004; Robertson 2006; Handy et al. 2010; Frizon de Lamotte et al. 2011).

1.3.2 Jurassic-Paleogene Stage

The impressive shallow-water resedimented carbonate debris events, which occurred during the Early and Middle Liassic time (Fanusi Formation breccias, Altofonte breccias and Belemnitic breccias, Fig. 1.6), evidence the active subaerial erosion of the carbonate platform source area as a consequence of the earliest Jurassic extensional tectonics (Fig. 1.9b, c). This Jurassic rifting stage of the continental margin (Manatschal and Bernoulli 1998; Stampfli and Borel 2002; Schettino and Turco 2010) in Sicily produced the dislocation of the original wide carbonate platform area (Fig. 1.11, the so-called "platform disintegration", Jenkyns 1970). In this view, our results prompt us to suggest that this rifting event could have caused the structuration of the previous Permian-Triassic basin in two different separated domains (Imerese and Sicanian), whose Mesozoic sedimentary evolution was strictly related to the tectono-stratigraphic setting of the relative adjacent carbonate platform margins (Fig. 1.9b, c). The formation of a rimmed carbonate platform may have fed a large amount of resedimented materials into the nearby basin (Fig. 1.9b) in the frame of a "bypass-to-depositional slope margin" (McIlreath and James 1978). In this view, the Panormide carbonate platform is believed to be the source area for the resedimented materials in the Imerese basin (according to Abate et al. 1982c; Basilone 2009b). Conversely, a carbonate shelf with stepped margins could have influenced the pelagic sedimentation in the nearby Sicanian deep-water basin, developing a "ramp-slope" margin (Fig. 1.9c, Basilone et al. 2010, 2014, 2016c; Basilone 2017). This hypothesis suggests that during the Mesozoic the Sicanian basin was proximal to an already-drowned carbonate platform (i.e., the Hyblean, Saccense and Trapanese drowning platforms, Fig. 1.11).

The original location of the Panormide carbonate platform along the Tethyan Mesozoic margin is the subject of different interpretations. A geodynamic model is based on the concept that the Adria was an independent microplate and the Ionian Tethys oceanic branch was connected to the Alpine Tethys, separating the Adria from Africa (Channel et al. 1979; Argiryadis et al. 1980; Ziegler 1988; Rosenbaum and Lister 2004; Dercourt et al. 1986, 2000; Catalano et al. 1991, 1996, 2001; Di Stefano 2002; Bosellini 2002; Stampfli and Borel 2002, 2004; Stampfli et al. 2002; Finetti 2005). A second model is based on the hypothesis that Adria was a Mesozoic "African promontory" with two different oceanic domains, the Alpine Tethys and the Ionian Tethys, separated by a continental sector (Stampfli and Borel 2002; Rosenbaum and Lister 2004). In this model, the Panormide platform is considered as a continental bridge between Africa and Adria (Turco et al. 1986, 2007; Zarcone et al. 2010).

Sequence stratigraphy studies of the Triassic-Paleogene Imerese and Panormide carbonate successions have allowed us to correlate and compare deposits and unconformity surfaces, sedimentary and tectonic events, and reconstruct a sedimentary cyclicity induced by relative sea level oscillations (Fig. 1.12, Basilone 1998, 2000, 2009b; Basilone and Lo Cicero 2002). Four main transgressive/regressive cycles (sensu Vail et al. 1977, 1991; Vail 1987; Haq et al. 1987;

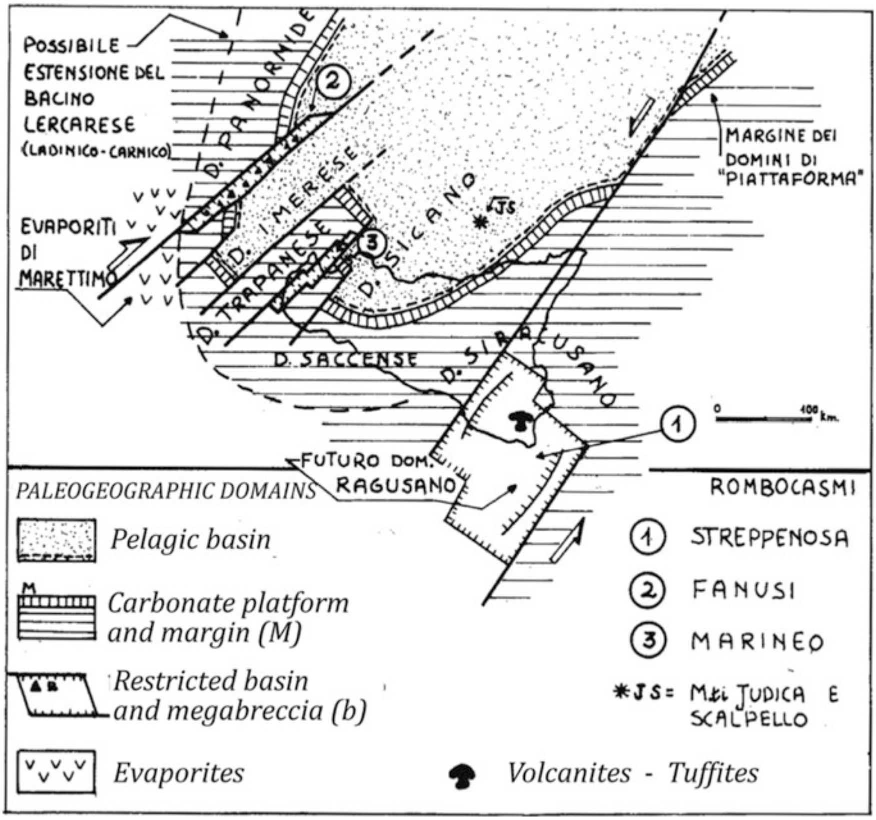


Fig. 1.11 Palinspastic map displaying the Mesozoic paleogeographic setting of Sicily (from Catalano and D'Argenio 1982a)

Jacquin and De Graciansky 1998; Catuneanu et al. 2009) encompassed in the Upper Triassic Paleogene interval have been recognised. Each cycle is bounded by tectonically enhanced unconformity erosional surfaces. These unconformities are accompanied by subaerial exposure, paleokarst, Neptunian dykes, synsedimentary faults and uplifting processes. Major downlap surfaces separate the regressive from transgressive deposits.

Recent studies conducted in the areas of Busambra and Kumeta ridges (i.e., Trapanese succession, Basilone et al. 2010), where the excellent exposition of the products of the Mesozoic volcanism and synsedimentary tectonics (Fig. 1.13) suggests that these areas pertain to the edge of the continental shelf. The latter was characterised by a steeped faulted margin (Santantonio 1993, 1994), evolving to a drowning platform (Schlager 1981) with tilted and faulted blocks characterised by condensed sedimentation (Rocca Busambra, Mascle 1973; Basilone 2009a; Basilone et al. 2010, 2016c, 2017), horst and graben-type structures (Figs. 1–3 of Plate 21), channelized megabreccias (Fig. 7 of Plate 21), structural lows with thick

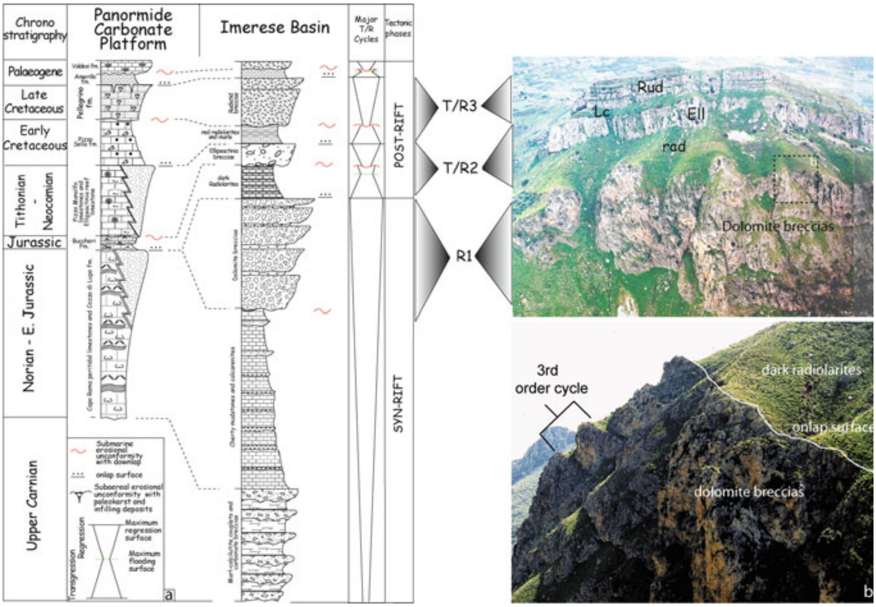


Fig. 1.12 Correlation and cyclic organization of the Triassic-Paleogene Panormide and Imerese successions (from Basilone 2009b)

pelagic succession and pillow lava (Monte Balatelle) and volcanic highs characterized by volcaniclastic sequences covered by carbonate rocks (Roccapalumba and Vicari sections), indicative of the presence of seamounts and submarine atolls.

On the whole, the depositional features of the Middle Jurassic-Paleogene deep-water successions reflect the evolution of subsident post-rift basins (Fig. 1.9b, c), as is well-documented in other peri-Mediterranean regions (e.g. Bernoulli and Jenkyns 1974; Bosellini and Winterer 1975; Bertotti et al. 1993).

1.3.3 Oligo-Miocene Stage

The aforementioned different location of the two deep-water domains is also confirmed by the occurrence of strongly different Oligo-Miocene deposits (Fig. 1.6). The Upper Oligocene-Lower Miocene Numidian flysch density flow deposits developed in a foreland basin (the so-called “Maghrebian Flysch Basin”, Frizon de

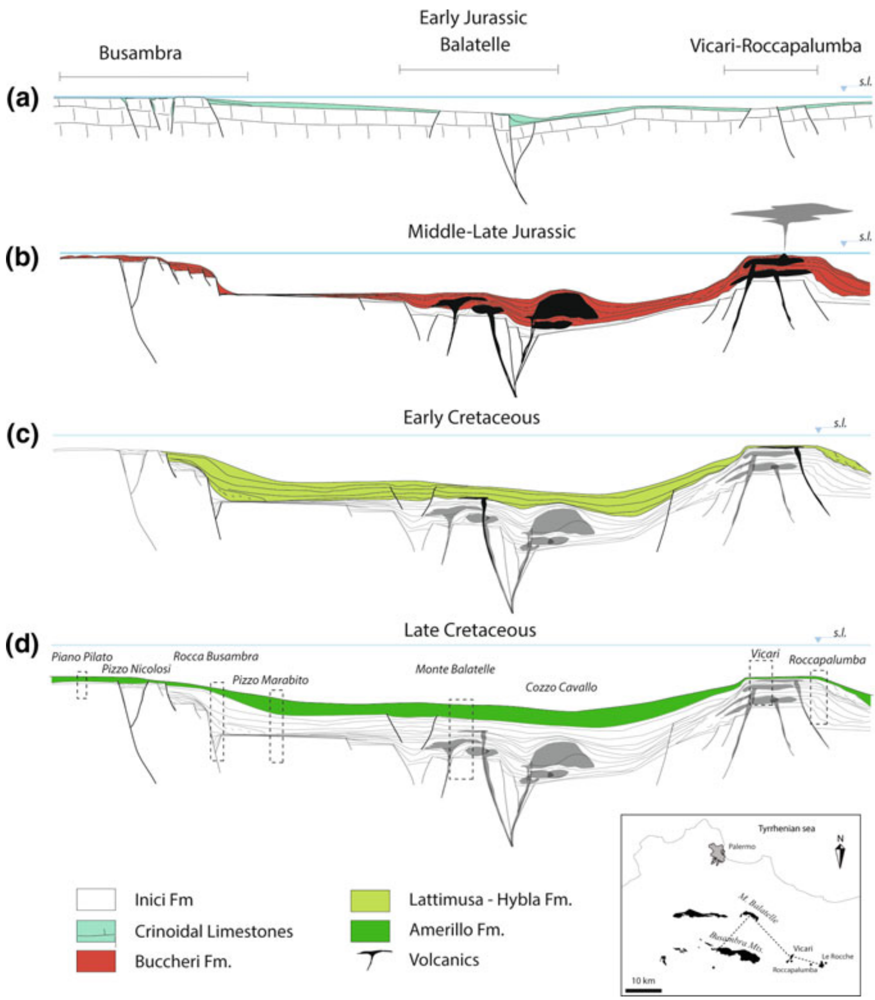


Fig. 1.13 Essay of paleogeographic restoration of a sector of the Trapanese domain during the Mesozoic, reconstructing from the Rocca Busambra, Monte Balatelle e Vicari-Roccapalumba outcropping sections (from Basilone et al. 2010)

Lamotte et al. 2000), which resided in the western Alpine Tethys realm between a growing accretionary prism (Calabrian Arc) to the north and the passive African margin to the south (see Handy et al. 2010; Thomas et al. 2010 and references thereinafter). Conversely, the Sicanian Oligo-Miocene open-shelf/slope succession (Fig. 1.6) developed in a still-undeformed foreland of the Sicilian margin.

1.4 Principles of Stratigraphic Classification and Nomenclature

In this section, we schematically summarize some general definitions and procedures regarding the most used stratigraphic classification terminology, in order to provide a useful reference tool for reading the descriptive worksheets.

Stratigraphy is the science that studies the arrangement in space and time of the rocky bodies and the events that they represent, in order to reconstruct the history and evolution of the Earth (Azzaroli and Cita 1968). Stratigraphy spans a wide field of investigation, including temporal and spatial components. Thus, chronostratigraphy is based on the time of formation of the rock bodies and it has a corresponding geochronology (the geological time) and is used for the determination of temporal relationships on a global scale. Lithostratigraphy, biostratigraphy, chemical stratigraphy, etc. concern the physical features of the rock bodies, including lithology, paleontological content, geochemical characteristics, etc. and their distribution in space (paleoenvironmental study).

The main aim of stratigraphic classification is the description of the rock bodies forming the earth's crust and their organization into useful and mappable separate units, based on their intrinsic properties (Hedberg 1976). Rocks have many different properties, such as lithology, fossil content, magnetic polarity, seismic response, electrical and geochemical properties, etc., which can also be used individually for their classification. The stratigraphic position of change of any single property or attribute does not necessarily coincide with that of any other. Consequently, the boundaries of units based on different properties commonly cut across each other (Fig. 1.14).

The stratigraphic units must be materialized by rock volumes, but some of them also include innumerable gaps. The evidence of these missing intervals carried by the rocks is in itself a part of stratigraphy and a very important contribution to the understanding of Earth history (Salvador 1994).

1.4.1 Chronostratigraphic Units

Chronostratigraphy is that part of stratigraphy that deals with the relative time relations and ages of rock bodies. The purpose of chronostratigraphic classification is to systematically organize the rocks forming the Earth's crust into named units (chronostratigraphic units) corresponding to intervals of geologic time, and to build a Standard Global Chronostratigraphic Scale which can promote the temporal correlation and comparison of coeval successions deposited in geographically different areas.

A chronostratigraphic unit (Fig. 1.15, Eonothem, Erathem, Sistem, Series, Stage, Substage) corresponds to a body of rocks formed during a specific interval of geological time. The basic working unit of chronostratigraphy is the Stage. It is

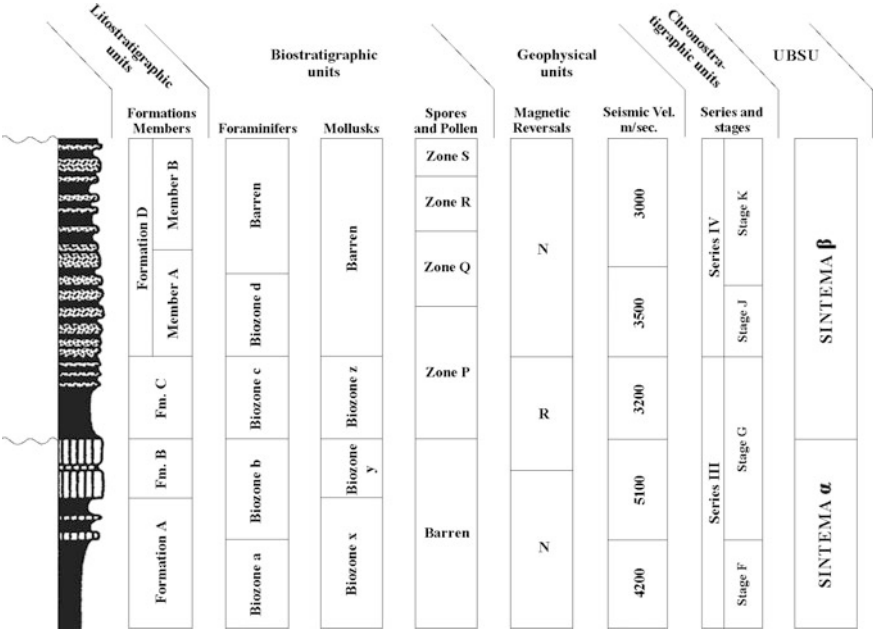


Fig. 1.14 Illustration of the differences in position in a stratigraphic section of stratigraphic boundaries based on different properties or attributes of the rocks (from Salvador 1994)

chosen because "it is suited in scope and rank to the practical needs and purpose of intraregional chronostratigraphic classification and it is the smallest unit that can be recognized on a global scale" (Hedberg 1976; Salvador 1994). The time interval corresponding to the rocky body comprised in a chronostratigraphic unit is a geochronological unit (Eon, Era, Period, Epoch, Age, Subage). The geochronological equivalent of the Stage is the Age.

A chronostratigraphic unit is comprised by isochronous horizons, which are well defined on a global scale and designated through the identification of the boundary-stratotypes. A stage is identified by its lower boundary-stratotype, defined as "*Global Boundary Stratotype Section and Point*" (GSSP, Cowie et al. 1986; Cowie 1986, Remane et al. 1996). In this view, each chronostratigraphic unit is defined in a particular location by its stratotype and the stratotype of the overlying unit. According to this concept, a GSSP, materialized with the so-called *Golden spike* (Aubry et al. 2000; Remane 2000), represents a point in stratotype defined in its proximity to the most useful event for global correlations (e.g., an evolutionary event, a magnetic inversion, a geochemical signal, etc.); consequently, this study requires the choice of chronostratigraphic correlation tools of an integrated multi-disciplinary approach (e.g., biostratigraphy, cyclostratigraphy, isotope stratigraphy, etc.).

In Sicily, due to good exposition of Neogene successions, several stratotypes of the chronostratigraphic units comprised in the Miocene, Pliocene and Quaternary

Stratigraphic Categories	Principal Stratigraphic Unit-terms	Equivalent Geochronologic Units
Lithostratigraphic	Group Formation Member Bed(s), Flow(s)	
Unconformity-bounded	Synthem	
Biostratigraphic	Biozones: Range zones Interval zones Lineage zones Assemblage zones Abundance zones Other kinds of biozones	
Magnetostratigraphic polarity	Polarity zone	
Other (informal) stratigraphic categories (mineralogic, stable isotope, environmental, seismic, etc.)	-zone (with appropriate prefix)	
Chronostratigraphic	Eonothem Erathem System Series Stage Substage (Chronozone)	Eon Era Period Epoch Age Subage (or Age) (Chron)

* *If additional ranks are needed, prefixes Sub and Super may be used with unit-terms when appropriate, although restraint is recommended to avoid complicating the nomenclature unnecessarily.*

Fig. 1.15 Summary of Categories and unit-terms in stratigraphic classification (from Salvador 1994)

intervals, have been proposed (Cita et al. 2006). Capo Rossello composite section (AG) is the most studied section in the world for the study of the Pliocene. It was proposed by Cita (1975a, b) as the stratotype of the Zanclean and for the Miocene/Pliocene boundary, placed at the base of the Trubi Formation. In the same section, Hilgen and Langereis (1988) calibrated the Miocene/Pliocene boundary using magnetostratigraphic methods. It is considered a reference section to calibrate the Astronomical Time Scale (orbital cyclostratigraphy, Hilgen 1991; Fisher and Garrison 2009 and references therein). The Punta Piccola section (part of the composite section of Capo Rossello) was selected for the definition of Piacenzian GSSP (middle Pliocene), which is placed in correspondence with the Trubi and Monte Narbone formations boundary (Cita et al. 1996; Castradori et al. 1998; Van Couvering et al. 1998, 2000). The section of Monte San Nicola

(Butera, CL) has been studied to define the Gelasian, whose proposed GSSP has been placed within the sapropelitic couplets of the Monte Narbone formation (Rio et al. 1994, 1998a, b). A detailed study, including quantitative calcareous nannofossil and planktonic foraminifer biostratigraphy, paleomagnetism and $CaCO_3$ content, of a 33 m-thick borehole succession in SE Sicily (Contrada Pesciarello well) of carbonates belonging to the Ragusa Formation has permitted to propose the GSSP for the Langhian (Di Sefano et al. 2011).

1.4.2 Lithostratigraphic Units

A lithostratigraphic is "a rock body defined and recognized on the basis of its distinctive lithologic properties (composition, texture, structure, colour, etc.) or their combination, its stratigraphic relations and the overall lithologic homogeneity on its aerial extension" (Hedberg 1976; Salvador 1994). Consequently, a lithostratigraphic unit is defined by physical features, objectively observable and easily recognizable in the field. Fossil content may be important, if it is adequately representative, in the recognition of a lithostratigraphic unit (for example in the case of *coquina* limestone, radiolarites, carbon layers). In this view, Sicilian and generally peri-Tethyan, Ammonitico Rosso limestone, *Megalodon* limestone and *Rudistid* limestone outcropping units are clear examples in which fossils are a useful feature in the recognition and classification of a lithostratigraphic unit on the field.

The conventional hierarchy of formal lithostratigraphic terms is: *Group, Formation, Member, Bed*, *Flow* (Fig. 1.15). Lens and tongue are lithostratigraphic informal units with lens-shaped geometry that can be lithologically differentiated from the lithostratigraphic unit where they are comprised. The Formation, the primary formal unit of lithostratigraphic classification, "is used to map, describe and interpret the geology, including stratigraphic reconstruction, geological history, regional structures and natural resources of a region" (Hedberg1976; Salvador 1994). Thicknesses and areal extent are the most important criteria to establish if a geological rock body recognized in the field can be considered as a Formation and, eventually, formalized; it must be represented graphically on a map, split into two-dimensional (geological cross-sections) or three-dimensional models, to define the geology of the area.

Procedures for establishing a lithostratigraphic unit consist of the definition of its distinctive lithologic properties, which serve to distinguish it from adjacent units. The stratotype section must be complete with the lower and upper stratigraphic boundaries and well-defined and easily accessible to researchers. The description of the proposed formation must be accompanied by representative graphics (stratigraphic sections, location map). Proposals should be published in a recognized international scientific platform.

The idea of codifying stratigraphic nomenclature in a clear, pragmatic and universal manner was developed in the mid-twentieth century in the United States by Hollis D. Hedberg, who came from the field of oil exploration and was a professor of stratigraphy. In 1941, he proposed the constitution of the North American Commission on Stratigraphic Nomenclature (NACSN, already ACSN, Ashley et al. 1933), with the aim of defining a stratigraphic nomenclature code for North America (NACSN 1947, 1961, 1970, 1983). Subsequently, the need for global coordination of research in geological sciences led to the establishment of the IUGS (International Union of Geological Sciences), which aims to promote and encourage international cooperation. In this view, the *International Commission on Stratigraphy* (ICS) was instituted with the aim of establishing standards in stratigraphic methodology and terminology.

Lithostratigraphy became an official method on a global scale when, during the 19th International Geological Congress (IGC held in Algeri in 1952), the ISSC (International Subcommission on Stratigraphic Classification) was proposed and instituted, with the purpose of defining a stratigraphic classification guide, where rules, terminologies and common procedures would be unified throughout the world global scale (Hedberg 1954, 1972 and ISSC *newsletters*).

In the first edition of the *International Stratigraphic Guide* (ISG), edited by Hedberg (1976), the procedures for the classification of rock bodies were defined in detail, and close attention was paid to lithological properties (lithostratigraphy), fossil content (biostratigraphy) and the temporal distribution of rocks (chronostratigraphy and geochronology). In the second edition of the ISG (Salvador 1994) and in its abridged version (Murphy and Salvador 1999), the possible application possibilities of classical methods were examined in greater detail, with more attention dedicated to chronostratigraphic units (Remane et al. 1996). New stratigraphic classification methods, such as seismic stratigraphy, magnetic polarity, geochemical zonation, unconformity-bounded stratigraphic units, eustatic cycles, ocean stratigraphy, analysis of electric logs, soils and volcanogenic layers were also proposed and rendered official (Figs. 1.14 and 1.15).

In the last few years, the work of the ISSC has refined and updated the code by taking in consideration new stratigraphic analysis methodologies. In 2003 and 2008, when M. B. Cita was president of the ISSC, an upgrade of the ISG (New Developments in Stratigraphic Classification project) was implemented by following a new approach to stratigraphic classification based on a *bottom up* procedure different from the previous *top down* approach (Cita 2007 and circulars of the ISSC 2004–2008). In detail, the procedures of cyclostratigraphic classification (Strasser et al. 2007), magnetostratigraphy (Langereis et al. 2010), biostratigraphy (Gladenkov 2010) and chemiostratigraphy (Weissert et al. 2008) were improved and defined. The first results of this work, which is still developing, was summarized in the Proceedings of the workshop chaired by some of the members of the ICS, including M. B. Cita, C. Kendall, A. Strasser and S. Finney, in the frame of the 33rd IGC held in Oslo in 2008, focussing on the issues of Sequence Stratigraphy. Another contribution was offered by the volume *Stratigraphy, Terminology and Practice* (Rey and Galeotti 2008), strongly supported by F. Gradstein (former President of the ISC). It disseminated new knowledge about the terminology, concepts, methods and practical applications of the various stratigraphic approaches, including the methods for the study of igneous and metamorphic rocks, with concrete and well-illustrated examples.

The history of Italian stratigraphic classification is well summarized by Cita (2008a, b, 2009a, b), who gives a historical overview of the development of stratigraphic nomenclature codes in Italy, focusing mainly on lithostratigraphic classification in the frame of National Geological Cartography projects ("legge Sullo" and CARG project). The *Italian Commission on Stratigraphy* (CIS, president Prof. M. B. Cita) produced the "Italian Stratigraphic Classification and Terminology Guide" (Germani and Angiolini 2003 under the supervision of M. B. Cita) with the aim of updating the Italian stratigraphic Nomenclature Code (CINS, Azzaroli and Cita 1968), and it became a very important reference for stratigraphy studies in Italy (see D'Argenio 2008). In this guide, historical Italian and Alpine stratigraphy was tentatively adapted to international rules and codes, as defined by Hedberg (1976) and Salvador (1994) and by recent updates (Cita 2007, 2008c and circular of the ISSC 2002–2008). In this view, the CIS aimed to reorganize the Italian lithostratigraphy nomenclature useful to standardizing the new geological maps of the CARG project (e.g., Basilone et al. 2001, Fig. 2.1). Researchers working on the CARG project developed descriptions of individual formational units using worksheets that followed the rules established on an international scale, and these were examined by regional experts. Their work resulted in the production of the "Italian Formations Catalogue", partly published in "Quaderni del Servizio Geologico Nazionale, III Series" (Delfrati et al. 2000, 2002a, b, 2006a, b; Cita et al. 2007a, b), which describes the validated, the abandoned and the several traditional formational units used in Italian geological literature since the 1800s.

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Chapter 2
Sicilian Lithostratigraphic Units

Abstract This chapter includes the description of the Sicilian lithostratigraphic units (Fig. 2.1). They are grouped in a generally chronological order and the complete list of the worksheets is shown in the Table of contents. In each chronologic group the worksheets of the described formations are organized in alphabetic order. The Permo-Triassic units are the oldest deposits outcropping in Sicily that originated during the early stages of the Southern Tethyan continental rifting. The Meso-Cenozoic carbonate units represent the sedimentary sequences of the various stratigraphic successions differentiated in the field along the Sicilian outcrops. The deposits of the Sicilide Complex (Tethyan units) and the Tertiary clastics (Numidian flysch) are grouped separately. The Miocene and the Plio-Pleistocene units represent the sedimentary cover of the wedge-top basins formed during the construction of the Sicilian FTB. The Quaternary continental and marine deposits are classified as Unconformity-Bounded Stratigraphic Units (UBSUs).

2.1 Permo-Triassic Units

The oldest rock units outcropping in Sicily are characterised by siliciclastic deposits, clastic-carbonate and pelagic limestone, which are comprised in the Permian-Ladinian time interval. These deposits are mainly represented by a succession of mudstones, siltstones, red-greenish micaceous turbiditic sandstones and pelagic limestone with carbonate megabreccia and calciturbidite intercalations. The area from the coastal belt of Termini Imerese (Cerda) to the Roccapalumba-Lercara region and the Sicani Mountains (Palazzo Adriano region) is affected by the presence of rocky bodies of variable thickness—from tens to hundreds of metres—belonging to Permo-Triassic units. In the field, the Permo-Triassic deposits have been found associated with isolated patches of marls and limestone belonging to the Mufara Formation, which in turn represent the lowermost unit of the

*New units

°Amended units

L. Basilone, *Lithostratigraphy of Sicily*, UNIPA Springer Series,
https://doi.org/10.1007/978-3-319-73942-7_2

Mesozoic-Cenozoic deep-water carbonate outcropping Imerese and Sicanian successions (Figs. 2.1, 2.2). These units form a tectonic body, also described as melange (Catalano et al. 1991; Di Stefano and Gullo 1997a, b), superimposed on the Mesozoic carbonate tectonic units and overthrusted by the Numidian and Sicilide nappes (Catalano et al. 1996).

Several Authors have studied the Permo-Triassic deposits, highlighting their stratigraphic and structural problematics (Fabiani and Ruiz 1932a; Trevisan 1937a, b; Cipolla 1951; Di Napoli Alliata 1954; Caflisch and Schmidt di Friedberg 1967; Broquet 1968; Ruggieri and Di Vita 1972; Ruggieri 1973a; Mascle 1979; Montanari 1968; Cirilli et al. 1990; Montanari and Panzanelli Fratoni 1990; Kozur 1993; Robertson 2006). An attempt at reconstruction of the Permo-Triassic stratigraphy units, based on modern conodont and radiolarian biostratigraphy dating the individual lithologies, is reported in Catalano et al. (1988, 1991), Di Stefano and Gullo (1997a, b, 1998), Cirilli et al. (1990). The outcropping sections were studied in the Lercara-Roccapalumba region and along the San Calogero River, near Palazzo Adriano (Figs. 1.1 and 2.3). The occurrence of Permian rocks containing radiolarian of Pacific provenance allowed the paleogeographic evolution and geodynamics of the Southern Tethyan margin during the Permian in Sicily to be reconstructed (Catalano et al. 1988, 1989, 1991, 1992a). The paleogeographic models identify a deep-water basin, named Lercara Basin (Catalano and D'Argenio 1978, 1982a), formed above the North African stretched continental crust during the early stages of the Southern Tethyan rifting.

Previous studies on the Permian-Triassic deposits have recognised and described some lithostratigraphic units (Catalano et al. 1991; Di Stefano and Gullo 1997a). In outcrop, due to the strong Tertiary contractional deformation, the true stratigraphic relationships among the Permian-Middle Triassic deposits are generally hidden. For this reason, the complexity of the surface geology has produced uncertainty about these rock units, their age and their stratigraphic setting (see Carcione et al. 2004 and references thereinafter).

Recently, new data coming from the re-interpretation of the stratigraphic log of some deep exploration boreholes (Agip) have aided lithostratigraphic classification (Basilone et al. 2013a, 2016a). The acceptable stratigraphic continuity of the drilled Permian-Triassic rocks, their comparison with the deposits outcropping in the study adjacent areas and the recognition of new lithostratigraphic units filling the gaps of the previous stratigraphic schemes have enabled the proposal of a new stratigraphic order (Table 2.1; Fig. 2.2).

The new lithostratigraphic units, contributing to reduce the stratigraphic gaps, improve the sedimentary continuity of the deep-water succession for the whole Permian-Triassic time interval (Fig. 2.2). The occurrence of the Upper Triassic Mufara and Scillato Formations, stratigraphically overlying the Permian-Middle Triassic deposits, suggests that the latter were the common substrate for both the Imerese and Sicanian basinal domains (Fig. 1.6).

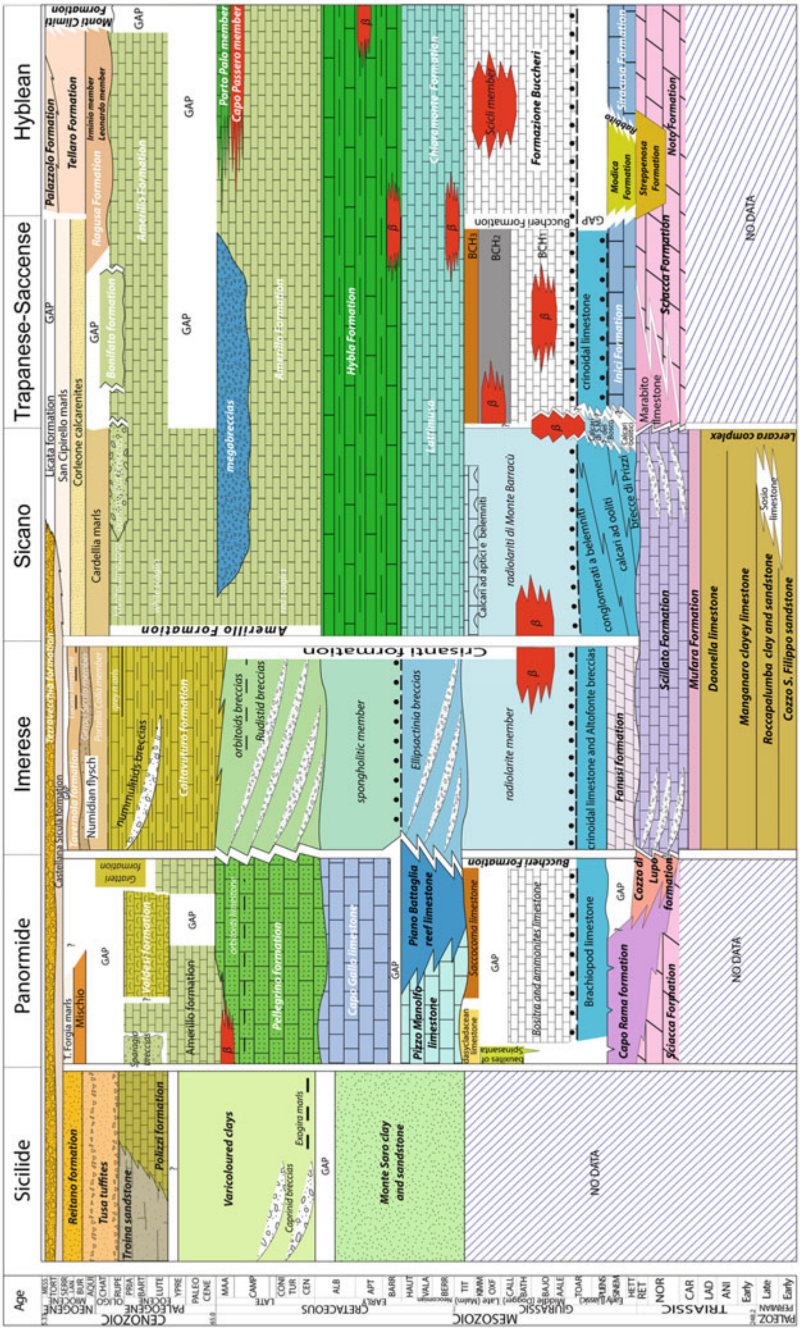


Fig. 2.1 Timetable showing the Permian-Miocene Sicilian lithostratigraphic units pertain the various stratigraphic successions outcropping in Sicily

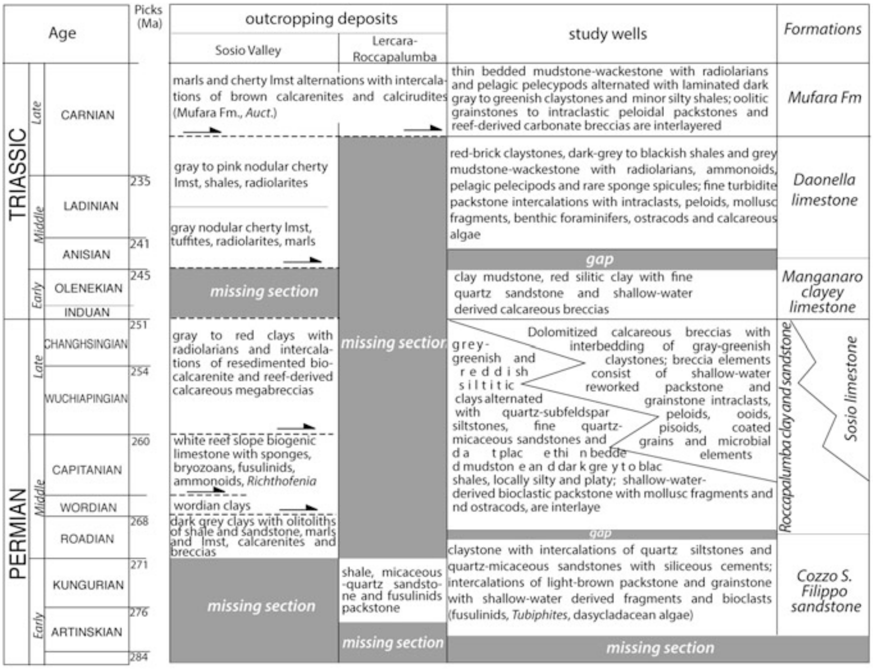


Fig. 2.2 Scheme of comparison among the lithofacies and lithostratigraphic units of the Permian-Upper Triassic deep-water deposits recognized along the drilled successions and outcropping in the Lercara-Roccapalumba region and Sosio Valley (after Basilone et al. 2016a). Time scale according to Gradstein et al. (2004). The outcropping data derive from the integration of previous studies (Catalano et al. 1988–1992; Flügel et al. 1991; Di Stefano and Gullo 1997a, b; Robertson 2006). Dotted lines with arrows indicate tectonic relationships. On the right the new proposed terminology for the Permian-Middle Triassic formations is shown

2.1.1 Lercara Complex

In the past, these deposits were grouped, without detailed subdivision of the lithological units, in the Lercara formation (Schmidt di Friedberg 1964–1965). The latter, following the recommendations of the Italian Commission on Stratigraphy (CIS), is considered as an invalid unit requiring reclassification (Basilone in Delfrati et al. 2006a) as its strongly deformed deposits are in many cases bounded by mechanical contacts. These "*broken formations*" (Salvador 1994) were classified as "Lercara Complex" (Catalano et al. 1991). This unit has been widely used in the new Geological maps of the CARG project (Catalano et al. 2010a, b, 2011b), to describe "a set of strongly deformed deposits of varying age and nature and therefore difficult to distinguish for defining a geological map".

The units, which are part of the "Lercara complex", although not easily distinguishable and separable on the field (Fig. 2.3), are here described following the

Table 2.1 Lithostratigraphic characteristics of the formations pertain to the Permo-Triassic succession

Formations	Carg abb. thick. (m)	Lithology	Depositional environments	Fossil content	Age
Daonella limestone	DAO < 400	Radiolarians, rare sponge spicules and pelagic bivalve-bearing mudstone-wackestone, locally A laminated (Figs. 1–4 in Pl. I) alternated with green marls, grey to blackish shales and red-brick	Deep-water	*Daonella tyrolensis, Diplopora annullatissima,* palynomorphs (*O.pseudoalatus, Rimaesporites potoniei, C. secatus, M. crenulatus*	Ladinian-early
Manganaro clayey limestone	MNG > 200	Radiolarians and pelagic bivalves bearing darkish-red silitic clays alternated to thin bedded clayey mudstone-wackestone, locally dolomitized (Figs. 1 and 2 in Pl. II). Thin intercalations of laminated g fine quartzitic sandstones (Fig. 3 in Pl. II) with carbonate cements frequently occur together with thick calcareous breccias (floatstone) made up of siliceous and calcareous shallow-water subangular elements, welded by red-to-green marly matrix (Fig. 4 in Pl. II)	Deep-water-base of slope	*Posidonia wengensis*. conodonts (*Gladigondolella, Pseudofurnisius*), palynomorphs (*Endosporites papillatus*, *Aratrisporites* sp., *Densoisporites* sp., *Lundbladispora* sp.)	Early Triassic
Roccapalumba clay and sandstone	RCS > 1000	Grey-greenish and reddish siltitic clays, marls and pelites, locally passing to fine grey mudstone, rich in conodonts, radiolarians and palynomorphs alternated with laminated quartz-subfeldspar siltstones (Fig. 1 in Pl. III) and fine sandstones, rich in quartz, micas and feldspars	Slope to deep-water, carbonate apron and turbidites	Conodonts (*Mesogondolella phosphoriensis, Sweetognathus subsymmetricus*), radiolarians (*Albaillellacea*), palynomorphs (*Protohaploxypinus, Striatopodocarpites* and *Vittatina* genus, *Nuskoisporites* sp., *Corisaccites alutas, Playfordiaspora* cf. *crenulata;*	Middle-Late permian

(continued)

Table 2.1 (continued)

Formations	Carg abb. thick. (m)	Lithology	Depositional environments	Fossil content	Age
		(Fig. 2 in Pl. III); at place, thin bedded mudstone and dark grey to black shales. Frequent intercalations of both thin calcareous skeletal packstone-to-grainstone with rare oolites, calcareous algae (dasycladacean), echinoids, ostracods and mollusc fragments (Figs. 5 and 6 in Pl. III), and thick calcareous breccias (*Sosio limestones*) with carbonate platform-derived elements (packstonegrainstone and boundstone) rich in fusulinids, spongid and coral fragments, intraclasts, coated grains, peloids, ooids and microbial elements		*Hamiapollenites* sp., *Lueckisporites virkkiae*, *Potonieisporites* sp. and *Hamiapollenites, Gardenasporites, Strotersporites, Gigantosporites* genus). In the resedimented beds: fusulinids, calcareous algae (dasycladacean), echinoids, mollusc fragments, richtofenids	
Cozzo S. Filippo sandstone	SFS > 500	Claystone with intercalations of quartz-siltstones and quartz-micaceous turbiditic sandstones with prevailing siliceous cements and deep-water *Nereites* ichnofacies; intercalations of light- A brown calciturbiditic packstone and grainstone with shallow-water derived fragments and bioclasts (fusulinids, *Tubiphytes* sp., dasycladacean algae, *Earlandia* sp.)	Slope to deep-water, turbiditic complex	Conodonts (*Mesogondolella intermedia, M. idahoensis, Neotreptognathodus pequopensis, Sweetognathus behnkeni*), radiolarians (*Pseudoalbaillella scalprata scalprata, P.* (*Kitoconus*) *elongata*), palynomorphs (*Hamiapollenites* cf. *karroenss, Crucisaccites* sp., *Rhizomaspora* sp., *Verrucosisporites* sp., *Indotriradites niger, Nuskoisporites* sp., *Striatopodocarpidites* sp., *Potonieisporites* sp., *Plicatipollenites* spp., *Vittatina* sp., *Barakarites rotatus*)	Mid Artinskian-Early Roadian

proposed classification by Basilone et al. (2016a) that studied these units, correlating subsurface and outcrop data (Figs. 1.7 and 2.2).

Carg abbreviation: LER

2.1.2 Cozzo San Filippo Sandstone*

General remarks: The outcropping section for this unit is the composite sequence of Cozzo San Filippo, located at Roccapalumba station (Fig. 2.3), where sedimentological and biostratigraphic characteristics are pointed out by Catalano et al. (1991). Another representative section is the subsurface section drilled by the Casteltermini

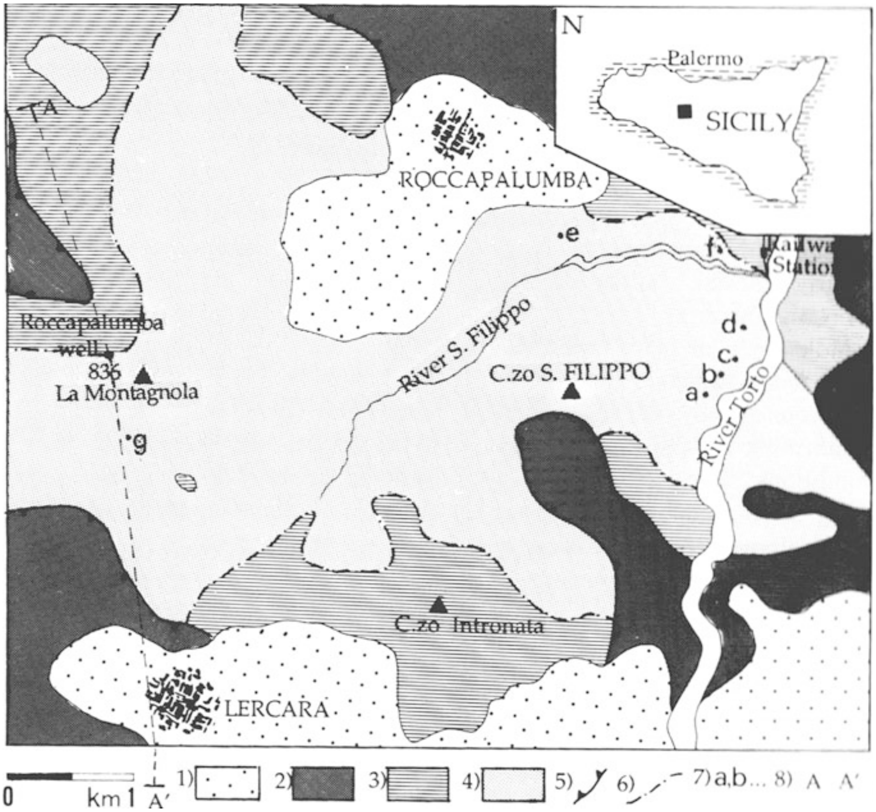


Fig. 2.3 Geological map of the Roccapalumba-Lercara area, considered the type area of the Permo-Triassic successions (after Catalano et al. 1991). *Legend* (1) Molasse (i.e., Terravecchia formation) and evaporites (i.e. Gessoso-solfifero group); (2) Numidian flysch; (3) platy limestone and marls (i.e., Mufara Formation); (4) siliciclastics, clastic carbonates and volcanics (i.e., Lercara complex). (5) main thrust; (6) tectonic boundaries between Triassic and Permian rocks; (7) sampled outcrops

1 well (Fig. 1.7), whose description is supported by lithological, sedimentological and biostratigraphic data (Basilone et al. 2016a).

Synonyms and priority: The unit represents the most representative lithologies of the Lercara formation (now abandoned) described by Schmidt di Friedberg (1964–1965). It has been described as “Permian flysch” (Rocco 1959, 1961; Gemmellaro 1887–1898; Baldacci 1886; Fabiani and Trevisan 1937), “argillaceous-arenaceous flysch” (Castany 1956; Broquet 1968, 1972; Mascle 1979). The Lower-Middle Permian Lercara sandstone could be compared with the well-known “Kungurian flysch” (Catalano et al. 1991) outcropping in the Lercara-Roccapalumba region and to the “San Calogero flysch” (Di Stefano and Gullo 1997a, b) outcropping in the Sosio Valley.

Lithology and thickness: The unit consists of greenish, reddish and locally grey-blackish quartz-micaceous sandstones alternating with reddish and greenish silty clays (Table 2.1). Calcareous breccias and calciturbidites are intercalated. The sandstones are mainly lithic greywackes with abundant plant remains and a variable amount of carbonate bioclasts, quartz, muscovite, minor biotite, feldspar and rare zircon (Broquet 1968). The dm-thick sandstone beds are characterised by gradation, planar to cross lamination (Ta-Tc Bouma levels), flute casts and *Nereites* isp. and *Paleodictyon* isp. ichnofacies. The fine-grained intercalations are laminated pelites and clays with a variable percentage of carbonate silt. The calciturbidites consist of graded and laminated grainstone-packstone with fusulinids, dasycladacean algae (*Mizzia* sp., *Epimastopora* sp.), sponge and crinoid fragments. The coarse calcareous breccias consist of shallow-water elements, up to one m-thick, derived from dismantling and erosion of a Lower Permian carbonate platform (Senowbari-Daryan and Di Stefano 1988). Greenish strongly altered basic magmatic rocks (diabase and lamprophyre, Fabiani and Trevisan 1937; Montanari 1968), small laccolitic bodies (Torrente Margana, Lercara, Vianelli 1970) and tholeiitic magmatites (Censi et al. 2000) occur frequently.

Paleontological content: In the fine-grained lithologies are found conodonts (*Mesogondolella intermedia* (Jgo), *Mesogondolella idahoensis* Youngquist, Hawley & Miller, *Neotreptognathodus pequopensis* (Kozur), *Sweetognathus behntkeni* (Kozur), palynomorphs, benthic foraminifers (*Ammodiscus* sp., *Bathysiphon* sp.), radiolarians (*Pseudoalbaillella scalprata scalprata* (Holdsworth and Jones), *Pseudoalbaillella* (*Kitoconus*) *elongata* Ishiga). In the calcareous beds, algal associations and fusulinids (*Pseudofusulina* (*Lesina*) *kraffti* Schellwien, *Pseudofusulina vulgaris* Schellwien).

Chronostratigraphic attribution: The *Albaillellid* radiolarians (Catalano et al. 1989; Kozur et al. 1996) and fusulinids (Flugel et al. 1991) have suggested Lower Permian age. On the basis of conodont associations, these beds were dated to the upper Artinskian–Kungurian (Lower Permian, Catalano et al. 1991). On the basis of the palynomorphs recovered from the drilled section they have been dated Mid-Artinskian to Early Roadian (Lower-Middle Permian, Basilone et al. 2016a).

Stratigraphic relationships: Lower boundary is unknown. The upper one, as revealed by the well logs (Fig. 1.7), is a transitional contact with the Upper Permian Roccapalumba clay and sandstone.

Depositional environment: On the basis of the sedimentological features, these deposits appear to have formed in a deep-water environment (abyssal plain) affected by frequent turbiditic flows transporting both siliciclastic materials (originally fluitated by a fluvial-deltaic system) and carbonates (from the erosion of a carbonate platform margin). The elevated paleobathymetry (more than 2000 m of water depth, accordingly to Kozur et al. 1996) is also suggested by the presence of margino-abyssal ichnofacies (Seilacher 1967).

Carg abbreviation: SFS

*2.1.3 Daonella Limestone**

General remarks: The Ladinian-Lower Carnian Daonella limestone has been recently proposed as a lithostratigraphic unit of the formational rank by Basilone et al. (2016a) on the basis of the description of the lithologies encountered in the Platani 2, Casteltermini 1 and Valledolmo 1 boreholes (Fig. 1.7).

Synonyms and priority: The unit appears comparable and largely coeval with the few metres-thick "cherty limestone and pinkish nodular limestone" described from Sosio Valley outcropping sections (Fig. 2.2, Catalano et al. 1991; Kozur 1991). It may be correlated with the pelagic "lumachella limestone and resedimented breccias" recently described by Di Stefano et al. (2012b) in the Madonie Mountains and believed of Ladinian age. Based on field and lithostratigraphic observations, the Daonella limestone could include the "Ladinian marls and pelecypods limestone" found in the Madonie Mountains, Caltanissetta and Sosio Valley areas and erroneously related to the Mufara Formation by Carrillat and Martini (2009).

Lithology and thickness: Laminated mudstone-wackestone with radiolarians, rare sponge spicules and pelagic bivalves (Figs. 1–4 of Plate 1), calcareous breccias and fine intra-bioclastic calciturbiditic packstone with ooids, mollusc fragments and calcareous algae (Figs. 5 and 6 of Plate 1) have been drilled for some hundreds of metres in the Platani 2, Casteltermini 1 and Valledolmo 1 boreholes (Figs. 1.7 and 2.2; Table 2.1).

Chronostratigraphic attribution: Based on their palynological content the described rocks unit is assigned to the Late Anisian/Ladinian-Early Carnian time interval (Table 2.1).

Stratigraphic relationships: The unit follows the Lower Triassic Manganaro clayey limestone and upwards leads gradually into the Carnian pelecypods bearing marly limestone (Mufara Formation), as revealed by the Platani 2, Casteltermini 1 and Valledolmo 1 boreholes lithostratigraphy (Figs. 1.7 and 2.2).

Depositional environment: Carbonate pelagic sedimentation in an overall deep-water basin to base of slope where resedimented material deriving from erosion of a carbonate platform margin were placed through the occurrence of turbiditic flows and submarine landslides.

Carg abbreviation: DAO

2.1.4 Manganaro Clayey Limestone

General remarks: The Lower Triassic Manganaro clayey limestone has been encountered only in the boreholes (Figs. 1.7, 2.1 and 2.2). No outcropping coeval rock bodies with equivalent deep-water sedimentary origin is known from previously published researches.

Synonyms and priority: We suggest that they may be age-correlated with the resedimented limestone recognised in small and isolated outcrops in the Sosio Valley and presumed by Kozur (1993) as the equivalent of the "red Hallstatt limestone".

Lithology and thickness: Siltitic clays, thin-bedded radiolarians and pelagic bivalves bearing-clayey mudstone-wackestone (Figs. 1 and 2 of Plate 2) and laminated fine quartz-sandstones (Fig. 3 of Plate 2) are interlayered with calcareous matrix-supported breccias (Fig. 4 of Plate 2). These rocks have been encountered in the Roccapalumba 1 borehole, where thin beds of resedimented intra-bioclastic to oolitic grainstone-packstone and recrystallized fossiliferous reddish mudstone also occur (Figs. 5, 6 of Plate 2 and Fig. 2.2; Table 2.1).

Chronostratigraphic attribution: The unit was dated as Lower Triassic on the basis of palynomorph assemblages (Table 2.1).

Stratigraphic relationships: The unit is comprised between the Roccapalumba clay and sandstone and the Daonella limestone. Data well suggest conformity relationships both for the lower and upper boundary.

Depositional environment: Slope to basin plain interested by sporadic dilute turbiditic flow and grain flow processes.

Carg abbreviation: MNG

2.1.5 Roccapalumba Clay and Sandstone*

General remarks: The unit was defined in the frame of the analysis of the oil exploration boreholes (Table 2.1; Figs. 1.7 and 2.2, Basilone et al. 2016a).

Synonyms and priority: This Middle-Upper Permian Roccapalumba clay and sandstone could be age-correlated with the "Olistrotrome unit", "Wordian clay" and "Red clay unit" of the Sosio Valley, dated on the ground of conodonts and very deep-water radiolarians content (Catalano et al. 1991; Kozur 1993; Di Stefano and Gullo 1997a, b).

Lithology and thickness: Grey-greenish and reddish siltitic clays, marls and pelites rich in conodonts, radiolarians and palynomorphs are alternated with laminated quartz and sub-feldspar fine sandstones (Figs. 1 and 2 of Plate 3). These rocks have been drilled for a few hundred metres in the Casteltermini 1 (Fig. 1.7) and Lercara Friddi 1 boreholes and for more than 1000 m in the Lercara (Agip) 1 and Roccapalumba 1 boreholes. Grey-green fissural basalts (never discovered before) are also encountered in the Roccapalumba 1 borehole, intercalated in these rocks (Fig. 3 of Plate 3).

The arenaceous intercalations, more frequent and thicker in the upper part of the successions drilled by the Lercara Friddi 1 borehole, also display glauconite, phosphate and pyrite in traces (Fig. 4 of Plate 3). In the drilled sections, these lithofacies are interlayered both to thick reef-derived calcareous breccias rich in fusulinids, spongid and coral fragments (more than 150 m in thickness as observed in the Casteltermini 1 borehole, Fig. 1.7) and to thin calcareous skeletal packstone-to-grainstone with rare oolites, calcareous algae (*dasycladacean*), echinoids, ostracods and mollusc fragments (Figs. 5 and 6 of Plate 3; Table 2.1). Comparable calcareous breccias have been sampled in the Lercara-Roccapalumba and Sosio Valley field sections, where they occur as isolated blocks (i.e., the Sosio limestone).

Chronostratigraphic attribution: The microflora assemblage suggests a Middle-Late Permian age (Table 2.1).

Stratigraphic relationships: Lower boundary is a transitional contact with the Permian Cozzo San Filippo sandstone. The upper boundary is a a sharp surface with the Lower Triassic Manganaro clayey limestone.

Depositional environment: Sedimentological data suggest for these deposits a slope to deep-water environment characterised by the occurrence of a large turbiditic fan system and slope apron carbonate breccias.

Carg abbreviation: RCS

2.1.6 Sosio Limestone°

General remarks: This unit comprises the calcareous breccias interlayered in the Upper Permian clastic deposits (i.e., the Roccapalumba clay and sandstone) and outcropping as isolated blocks both in the Lercara-Roccapalumba region and in the Sosio Valley along the San Calogero River (e.g., Pietra di Salomone, Pietra dei Saracini, Rupe del Passo di Burgio outcrops). The thick reef-derived calcareous breccia of the Sosio limestone (Figs. 2.1 and 2.2) are believed to correspond to the contemporary "Sosio megablocks" (Catalano et al. 1991) outcropping both in the Lercara-Roccapalumba region and in the Sosio Valley (for their description see also Flügel et al. 1991; Di Stefano and Gullo 1997a; Robertson 2006).

Synonyms and priority: These deposits were first described as "Fusulinid limestone of the Sosio Valley" by Gemmellaro (1887–1898), "Permian of Sosio" (Fabiani and Ruiz 1932a; Ruggieri 1973a), "Sosio Megablocks" (Catalano et al. 1991) and "Pietra di Salomone limestone" (Di Stefano and Gullo 1997a). Sosio formation, proposed by Schmidt di Friedberg (1964–1965), was officially abandoned (Basilone in Delfrati et al. 2006a). The Sosio limestone is an informal noun that has been largely used in the Sicilian geological literature and it is adopted here based on chronological priority.

Lithology and thickness: White-greyish fossiliferous calcareous breccias, mostly rudstone, whose dm to m-thick elements consist of boundstone with *Tubiphytes* sp. and *Archeolitoporella* sp., bindstone with filloid algae, packstone-grainstone with algae (*Mizzia* sp.), fusulinids, crinoids, brachiopod richtofenids (Figs. 7 and 8 of Plate 3). Outcropping thickness up to 50 m.

Chronostratigraphic attribution: On the basis of the fusulinids they are dated to the Permian (Gemmellaro 1886) and specifically to the Upper Permian (Flügel et al. 1991; Robertson 2006), Gordian the portion outcropping in the Sosio Valley (Di Stefano and Gullo 1997b).

Stratigraphic relationships: They are interlayered in the Upper Permian clastic deposits of the Roccapalumba clay and sandstone.

Depositional environment: Sedimentological data suggest for these deposits a slope to deep-water depositional environment characterised by the occurrence of slope apron carbonate breccias deriving from dismantling and erosion of a carbonate platform margin (Flügel et al. 1991; Robertson 2006).

Carg abbreviation: SOS

2.2 Mesozoic-Cenozoic Carbonate Units

Mesozoic-Cenozoic lithostratigraphic units consist of shallow-water, slope and deep-water carbonate and silico-carbonate deposits developed in different depositional basin along the Southern Tethyan continental margin. These carbonates form various differentiated stratigraphic successions known as Hyblean, Trapanese, Saccense and Panormide carbonate platforms and Imerese and Sicanian basins (Fig. 2.1). The lithostratigraphic characteristics of the formational units forming these successions are summarized in Tables 2.2, 2.3, 2.4 and 2.5.

2.2.1 Amerillo Formation°

General remarks: This unit was classified as a member of the Alcamo formation by Rigo and Barbieri (1959) studying the type section reconstructed from the Amerillo River Valley (Monterosso Almo, Ragusa, SE Sicily). Patacca et al. (1979) amended this unit elevating it to the rank of formation based on the study of the buried successions in the Hyblean plateau. The here-amended unit also includes the chronological and lithological equivalent deposits pertaining to the different successions outcropping in W Sicily and called Trapanese, Saccense, Panormide and Sicano (Catalano et al. 2010a, b, 2011a, b; 2013a, b), where a few facies changes and different stratigraphic relationships occur (Fig. 2.1).

Synonyms and priority: These deposits are known with the informally Italian term of “Scaglia limestone”. In the Sicilian geological literature, this unit was described as “Monte Balatelli formation” (Ceretti and Ciabatti 1965), part of the “allochthonous limestone succession” outcropping in the Madonie Mountains and erroneously included in the Caltavuturo formation by Schmidt di Friedberg et al.

Table 2.2 Lithostratigraphic characteristics of the Mesozoic-Cenozoic formations pertain to the Imerese succession

Formations		Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
Caltavuturo Formation		CAL	Thin-bedded red and white cherty limestone and marly limestone with planktonic foraminifers and nannofossils; intercalations of bioclastic packstone-grainstone with nummulitids, colonial corals fragments, bryozoans and erosional lower boundary (CALa)	200	Onlap	Deep-water to slope	*Rotalipora reicheli, R. cushmani, Globotruncana ventricosa, Morozovella velascoensis, M. subbotinae, M. aragonensis, Turborotalia cerroazulensis*s.l., *Cassigerinella chipolensis-Pseudohastigerina micra* biozones) and calcareous nannofossils (NP10 to NP22 biozones). *Nummulites partschi, N. prelucasi*	Upper Cretaceous Lower Oligocene
Crisanti Formation	Rudistid breccias	CRI_4	Calcareous breccias, graded and laminated rudstone and grainstone-packstone with reef-derived fragments(corals, rudistids, bryozoans and benthic foraminifers)		Erosion and downlap	Slope	Rudistid fragments, *Orbitolina texana, Orbitoides media, Siderolites* cf. *calcitrapoides*	Upper Cretaceous
	Spongholitic (mb)	CRI_3	Thin-bedded marly siliceous limestones with radiolarians and sponge spiculae; intercalations of bioclastic calcarenites with requienids fragments and benthic foraminifers	250–300	Onlap	Deep-water	Benthic (*Dorothia gradata*, *D. filiformis, Marginulina planiscula*) and planktonic foraminifers (*Ticinella primula*); *Orbitolina paronai, O. conoidea* and rudistid fragments in the reworked beds	Barremian-Albian
	Ellipsactinia breccias	CRI_2	Calcareous breccias, oolitic packstone-grainstone, with carbonate platform-derived elements with corals and hydrozoan	30–50	Erosion and downlap	Slope	*Ellipsactinia* sp., *Nerinea* sp., *Bacinella irregularis, Tubiphytes morronensis*, *Clypeina jurassica,* corals, *Protopeneroplis ultrangulata, Globochaete alpina*	Tithonian-Valanginian
	Radiolarite (mb)	CRI_1	Thin-bedded darkish laminated mudstone- wackestone and clays with radiolarians and sponge spiculae, radiolarites and bedded cherts	50–60	Onlap	Deep water	Radiolarians, algae, ammonites, belemnites	Toarcian-Tithonian

(continued)

Table 2.2 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
Crinoidal limestone/ Altofonte breccias	MCD	Bioclastic and oolitic packstone-to-grainstone, with crinoids and benthic forams, red and green crinoidal marls. Calcareous breccias, with Triassic spongid reef-derived elements, display lenticular and channelized geometries with lower erosional surfaces	15–50	Onlap	Slope	Crinoids, brachiopods, nannofossils; corals, algae	Upper Liassic
Fanusi Formation	FUN	White massive dolomites and coarse-grained decametric dolomitized breccias and thin graded and laminated doloarenites	250–300	Unconformity with erosion and downlap	Slope apron	Pervasive dolomitization has obliterated fossils and organic traces	Lower Liassic
Scillato Formation	SCT	Gray thin-bedded cherty limestones with radiolarians, conodonts and pelagic bivalves; locally, few metres of laminated grainstone and pebbly conglomerates, consisting of both deep-water and shallow-water derived-fragments	500	Conformity surface	Deep water	Radiolarians, sponge spicules, conodonts, ostracods and bivalves (*Halobia styriaca, H. norica*); corals, algae and sponges in the reworked beds	Upper Carnian-Rhaetian

(continued)

Table 2.2 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
Mufara Formation	MUF	Alternations of yellow to brown laminated mudstone-wackestone and marls, with radiolarians, conodonts, ammonoids and pelagic pelecypods. Coarse carbonate breccias and laminated grainstone-packstone, with Ladinian-Carnian shallow-water derived fragments	30–250	Not outcropping	Deep water	Bivalves (*Halobia* sp.), ammonoids (*Trachiceras aon*); corals, algae, *Tubiphytes* sp., crinoidal fragments in the reworked carbonate beds	Carnian

Table 2.3 Lithostratigraphic characteristics of the Mesozoic-Cenozoic formations pertain to the Sicanian succession

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/ biostratigraphy	Age
San Cipirello marls	CIP	Grey and sky-blue clays, clayey marls and sandy marls with rich planktonic content	50–150	Sharp conformity	Outer shelf	Plankton forams (MMi 5-7 biozones), calcareous nannofossils (MNN 6a, MNN 7a and *Minilytha convallis* biozones)	U. Langhian L. Tortonian
Corleone calcarenites	CCR	Glauconitic grainstone-packstone with large benthic forams, calcareous and quartzitic sandstones and greenish siltitic marls	80–100	Erosional unconformity surface	Coastal to deltaic influenced by tidal currents	*Operculina complanata, Miogypsina* spp., *Nephrolepidina* spp., plankton forams (*Globoquadrina dehiscens dehiscens-Catapsydrax dissimilis, Gbd. trilobus, Praeorbulina glomerosa* s.l. biozones)	Upper Aquitanian Langhian
Cardellia marls	RDE	Marls and dark-green marly clays with ironized nodules, rich in calcareous plankton; large benthic foraminifers bearing turbidite packstone, 20–100 cm-thick	100–200	Conformity surface	Slope to outer shelf	Plankton forams (*Globoquadrina dehiscens dehiscens-Catapsidrax dissimilis, Globorotalia kugleri* biozones), calcareous nannofossils (NP 24–25 biozones); nummulitids and *Nephrolepidina* spp.	Chattian Lower Aquitanian
Amerillo Formation	AAM	Thin-bedded red and white cherty limestone and marly limestone with ichnofacies, planktonic foraminifers and	Up to 200	Conformity and transitional surface	Deep-water basin interested by gravitational	Plankton forams (*Rotalipora reicheli, Globotruncana elevata, Glt. aegyptiaca, Morozovella subbotinae,*	Cenomanian-Rupelian

(continued)

Table 2.3 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/ biostratigraphy	Age
		nannofossils; calcareous turbidites with large benthic forams, corals fragments, bryozoans and Campanian-Lower Maastrichtian carbonate megabreccias (AMMm), whose elements deriving from the break up of the upper Triassic-Jurassic shallow water deposits			processes (debris and grain flow)	*M. formosa formosa, Turborotalia cerroazulensis* s.l., *Truncorotaloides rorhi, Cassigerinella chipolensis–Pseudohastigerina micra* biozones), nummulitids, algae (*Subterraniphyllum thomasi*)	
Hybla Formation	HYB	Grey-blackish thin-bedded cherty limestones with radiolarians, sponge spiculae and planktonic foraminifers, white marls rich in belemnites and mollusc shells, coarsegrained bioclastic packstone	Up to 50	Conformity and transitional surface	Deep-water	Plankton forams (*Globigerinelloides algeriana, Ticinella primula, Biticinella breggiensis* biozones), belemnites (*Duvalia lata*); *Aptychus* fragments in the reworked beds	Aptian Albian
Lattimusa	LTM	White pelagic limestone with chert nodules and rich in planktonic organisms	10–30	Conformity and transitional surface	Deep-water	Calcareous nannoplankton (*Nannoconus steinmanni*), radiolarians, belemnites, ammonites and calpionellids (*Calpionella, Calpionellopsis, Calpionellites* biozones)	Tithonian Valanginian

(continued)

Table 2.3 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/ biostratigraphy	Age
Barracù Formation	BUU	Thin-bedded darkish and laminated siliceous mudstone-wackestone with radiolarians and sponge spiculae, radiolarites and bedded cherts; upwards fine breccias and packstone	20–50	Onlap	Deep-water	Radiolarians, algae, ammonites, belemnites; pelagic crinoids (*Saccocoma* sp.) and calpionellids in the reworked beds	Toarcian-Tithonian
Oolitic limestones	OOL	Bioclastic and oolitic packstone-tograinstone, with crinoids and benthic forams. Locally, belemnitic conglomerates and green marls and thick calcareous breccias bodies, with both upper Triassic deep-water cherty limestones and reef-derived elements	15–50	Erosional unconformity surface	Slope	Crinoids, brachiopods, belemnites, corals, algae, sponges	Lower Liassic
Scillato Formation	SCT	Radiolarian and pelagic pelecypods bearing thin bedded cherty mudstone-wackestone, locally alternated with varicoloured marls and resedimented bioclastic packstonegrainstone and	400–500	Conformity surface	Deep water	Radiolarians, sponge spicules, conodonts, ostracods and bivalves (*Halobia styriaca, H. norica*); corals, algae and sponges in the reworked beds	Upper Carnian-Rhaetian

(continued)

Table 2.3 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/ biostratigraphy	Age
		reef-derived breccias also with pebbly mudstone					
Mufara Formation	MUF	Light grey to beige, locally dolomitized, cherty mudst-wacks with radiolarians, ammonites and pelagic pelecypods alternated with laminated dark grey to greenish claystones and minor silty shales; reef-derived carbonate breccias with *Thaumatoporella* sp., *Tubiphytes obscurus* Maslov, calcareous sponges, oncooids, thin oolitic grainstone, peloidal and skeletal packstone. Quartz-micaceous to lithic fine sandstones and siltstones, basalts	200–300	Not outcropping	Deep water	Conodonts (*Gladigondolella thethydis* and *Paragondolella polignathiformis noha* biozones), ammonites, *Daonella* spp., *Halobia* spp.	Julian-Tuvalian

Table 2.4 Lithostratigraphic characteristics of the Mesozoic-Cenozoic formations pertain to the Trapanese-Saccense successions

Formations		Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
San Cipirello marls		CIP	Grey and sky-blue clays, clayey marls and sandy marls with rich planktonic content	50–150	Sharp conformity surface	Outer shelf	Plankton forams (MMi 5-7 biozones), calcareous nannofossils (MNN 6a, MNN 7a and *Minilytha convallis* biozones)	U. Langhian L. Tortonian
Corleone calcarenites		CCR	Glauconitic grainstone-packstone with large benthic forams, calcareous and quartzitic sandstones and greenish siltitic marls. Globigerinids packstone-grainstone	40–80	Erosional unconformity with conglomerate layer	Coastal to slope	*Operculina complanata, Miogypsina* spp.,*Nephrolepidina* spp., plankton forams (*Globoquadrina dehiscens dehiscens-Catapsydrax dissimilis, Gbd. trilobus, Praeorbulina glomerosa* s.l. biozones)	Upper Aquitanian Langhian
Ragusa Formation	Irminio member	RAG_2	Thick-bedded fine laminated calcarenites with rodophycean, litothamnium, melobesie, crinoids, alternated with thin-bedded marls and marly limestone with planktonic forams	50–300	Unconformity	Carbonatic ramp	*Lepidocyclina* sp., *Miogypsina* spp., *Miogypsinoides* spp., *Asterigerina* spp., molluscs (*Aturia aturi*), echinoderms, fish thoot (*Carcharodon* sp., *Squalodon* sp.); plankton forams (*Globigerina opima opima, G. ciperoensis ciperoensis, Globorotalia kugleri, Globoquadrina dehiscens dehiscens* biozones)	Upper Oligocene-Aquitanian
	Leonardo member	RAG_1	Thick-bedded white marly limestones and marls, calcarenite intercalations with red algae and large benthic foraminifers		Erosional unconformity surface			
Amerillo Formation		AMM	Thin-bedded red and white cherty limestone and marly limestone with ichnofacies; carbonate megabreccias (AMMm), whose elements deriving from the break up of the upper Triassic-Jurassic shallow water deposits	Up to 200	Conformity and transitional surface	Deep-water	Plankton forams (*Rotalipora reicheli, Globotruncana elevata, Glt. aegyptiaca,Morozovella subbotinae, M. formosa formosa, Turborotalia cerroazulensis* s.l., *Truncorotaloides rorhi* biozones), nummulitids, algae (*Subterraniphyllum thomasi*)	Cenomanian-Maastrichtian and Eocene

(continued)

Table 2.4 (continued)

Formations		Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
Hybla Formation		HYB	Grey-blackish thin-bedded cherty limestones with radiolarians, sponge spiculae and planktonic foraminifers, white marls rich in belemnites and mollusc shells, coarsegrained bioclastic packstone	Up to 50	Conformity and transitional surface	Deep-water	Plankton forams (*Globigerinelloides algeriana, Ticinella primula, Biticinella breggiensis* biozones), belemnites (*Duvalia lata*); *Aptychus* fragments in the reworked beds	Aptian Albian
Lattimusa		LTM	White pelagic limestoneand marls with chert nodules and rich in planktonic organisms	10–30	Conformity and transitional surface	Deep-water	Calcareous nannoplankton (*Nannoconus steinmanni*), radiolarians, belemnites, ammonites and calpionellids (*Calpionella, Calpionellopsis, Calpionellites* biozones)	Tithonian Valanginian
Buccheri Formation	Upper Ammonitico red	BCH_3	Tabular and massive red to grey pelagic crinoids-bearing grainstone/packstone with mollusc fragments, crinoids; thin-bedded nodular cherty limestone with gastropods, ammonites brachiopods, radiolarians and rare calpionellids	10–15	Transitional or in downlap and buttress unconformity with BCH1	Deep-water to slope	*Saccocoma* sp., *Protopeneroplis striata, Globochaete* sp., *Aptychus* sp., *Pygope diphya, Tubiphites obscurus,* calpionellids (*Crassicollaria* sp.), ammonites (*Mesosimoceras cavouri, Hybonoticeras beckeri, H. hybonotum* biozones)	Kimmeridgian Tithonian
	Radiolarite member	BCH_2	Thin-bedded reddish and greenish siliceous limestone, laminated radiolarites and marly clays, bedded cherts	5–15	Para conformity	Deep-water	Radiolarians (UAZ 8, 9–10, 9–11 biozones), ammonites (*trasversarium* and *divisium* biozones), belemnites, nannofossils	Oxfordian-Kimmeridgian
	Lower Ammonitico red	BCH_1	Reddish, brown to grey nodular limestone with ammonites, radiolarians, thin shelled pelagic bivalves (*Bositra buchi*), protoglobigerinids, bioclastic wackestonepackstone with dark dm-sized Fe–Mn nodules, laminitic stromatolites; pillow lavas	0.5–10	Onlap	Deep-water	Ammonites (*Harpoceras serpentinum, Stephanoceras humpresianum, Garantiana garantiana, Parkinsonia parkinsoni, Reneckeia anceps* biozones), belemmites (*Belemnopsis latesulcatus, Rhopalotenthis sauvanansa, R. argoviana*)	Toarcian–Oxfordian

(continued)

Table 2.4 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
Crinoidal limestones	RND	Red to white massive grainstone-packstone, encrusted by Fe–Mn oxides	0.5–15	Onlap	Slope	Crinoid ossicles and plates (*Pentacrinus* sp.), benthic foraminifers and ammonites	Upper Liassic
Inici Formation	INI	Pertidal limestone consisting of calcareous algae and mollusc-bearing wackestonepackstone, alternated with stromatolitic and loferitic packstone and oolitic and bioclastic packstone-grainstone	300–400	Para conformity surface	Tidal flat to back-reef lagoon and sand bar margin	Gastropods, brachiopods, ammonites (*Arietites bucklandi, Echioceras raricostatum*), *Thaumatoporella parvovesiculifera, Paleodasycladus mediterraneous*, *Involutina liassica*	Hettangian-Sinemurian
Sciacca Formation	SIA	White massive dolostone with algae, benthic foraminifers and molluscs, dolomitized stromatolites and marly dolostones	Up to 2000	Not outcropping	Tidal flat to back-reef lagoon	Bivalves (*Megalodon* cf. *gumbeli, M. seccoi, M. paronai, Dicerocardium* cf. *curioni*), gastropods (*Turritella schopeni, Purpuroidea taramellii*), corals, benthic forams (*Triasina* sp., *Galeanella panticae*)	Norian–Rhaetian

Table 2.5 Lithostratigraphic characteristics of the Mesozoic-Cenozoic formations pertain to the Panormide succession

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
Mischio	HIO	Algae and molluscs reef limestones and crossed laminated biocalcarenites with large benthic foraminifers and glauconitic fragments	30–50	Erosional unconformity	Outer shelf	*Pecten burdigalensis*, gastropods, *Clypeaster* sp., corals, bryozoans fish thoot, *Melobesiae*	Burdigalian
Gratteri Formation	GRT	Marls, marly limestones with plankon foraminifers and biocalcarenite intercalations with large benthic foraminifers, bivalve fragments, bryozans, *Lithotamnium* sp.	150–200	Paraconformity with AMM	Slope	*Turborotalia cerroazulensis* s.l., *Globorotalia opima opima* biozones; nummulitids, lepidocyclinids	Upper Eocene-Lower Oligocene
Valdesi Formation	VST	Bioclastic rudstone-to-packstone with large benthic foraminifers, molluscs, corals, bryozoans, algae, echinoids	70–100	Unconformity surface with downlap	Carbonate ramp	*Nummulites crassus, N. munieri, N. molli, Fasciolites oblongus, F. ellipsoidalis, Orbitolites lehmanni, Fabiana cassis; Discocyclina roberti*	Upper Eocene
Amerillo Formation	AAM	Thin-bedded red and white bearing-wackestone and marly cherty limestone and bioclastic packstone-grainstone intercalations	200	Onlap and infilling	Deep-water	*Rotalipora reicheli, R. cushmani, Globotruncana ventricosa, Turborotalia cerroazulensis* s.l. biozones	Upper Cretaceous-Eocene
Pellegrino Formation	LEG	Rudistid massive boundstone and floatsone, alternated to blakish laminated mudstone, stromatolitic and loferitic packstone, bioclastic packstone with orbitolinids, algae and corals and oolite grainstone	150–200	Unconformity surface with downlap	Carbonate ramp with rudistid reef	Rudistids (*Caprina schiosensis, Ichtyosarcolites rotundus*, *Polyconites verneuilli*, *Radiolites sauvagesi, R. nebrodensis*); benthic forams (*Orbitolina* (*Conicorbitolina*) *conica*, *Cuneolina* cf. *pavonia, C.* cf. *conica*, *Trocholina elongata*, *Cornuspira* cf. *cretacea*)	Upper Cretaceous
Capo Gallo limestones	AFU	Well-stratified grey limestones (wackestonepackstone) with requienids, large gastropods (*Nerinea* sp.) and corals, alternated to blakish oolitic grainstone, frequently with abraded and broken ooids and lenticular geometris, and to micritic	120–180	Onlap	Carbonate ramp with sand bar and reef margin	Caprinids (*Offneria* sp.), algae (*Cayeuxia* sp., *Triploporella* cf. *decastroi*) of the *Salpingoporella dinarica* biozone (De Castro 1991), benthic foraminifers (*Cuneolina* ex. gr. *camposauri-laurentii,*	Barremian-Albian

(continued)

Table 2.5 (continued)

Formations	Carg abb.	Lithology	Thick. (m)	Lower boundary	Depositional environments	Fossils content/biostratigraphy	Age
		levels with birdseyes, peloids, algae fragments				*Palorbitolina lenticularis, P. praecursor, Rectodyctioconus giganteus*)	
Piano Battaglia limestone	PNB	Massive grey reef limestones with *Ellipsactinia,* nerineids and corals, calcareous breccias with reef-derived fragments and oolite grainstone with tangentials ooid grains, frequently reworked. Heteropic relationships with CTI	250–300	Onlap	Tidal flat to back-reef lagoon	*Nerinea* sp., algae (*Cayeuxia* sp., *Campbeliella striata, Salpingoporella annulata, Clypeina jurassica, Actinoporella podolica*), *Kunurbia palastiniensis, Montsalevia salevensis*	Tithonian-Valanginian
Buccheri Formation	BCH	Thin-bedded reddish pelagic limestones with ammonites and pelagic bivalves; nodular marly limestone, bioclastic pakstone with pelagic crinoids. Locally, radiolarites and bedded cherts	5–30	Onlap	Deep water	*Bositra buchi, Saccocoma* sp., algae, ammonites, belemnites	Toarcian-Tithonian
Bauxites of Spinasanta	BAX	Brick-red and yellowish bauxite clays with pisoids fragments, oolite and intraclasts with onlap and infilling geometries	0.8	Subaereal erosion unconformity	Continental		Jurassic
Cozzo di Lupo Formation	CZP	Spongid reef limestones with corals, algae and idrozans, alternated to calcareous breccias and calcarenites (grainstone-packstone) with reefderived fragments. Heteropic relationships with FRM	500–700	Paraconformity surface	Reef and forereef	sponges (*Panormida* sp., *Cheilosporites tirolensis*, corals (*Montlivaltia* sp., *Retiophyllia paraclathrata, Thamnastaria* sp.), benthic forams (*Galeanella panticae, Foliotortus spinosus*)	Norian- Rhaetian
Capo Rama Formation	RMF	Peritidal limestones, molluscs and algae wackestone/packstone with oncoids, peloids, corals (patch reefs), alternated with stromatolites and supratidal breccias; vadose pisolite, paleokarst cavities filled by reddish silt and caliche crusts are present	500	Paraconformity surface	Tidal flat to back-reef lagoon	Bivalves (*Megalodon* cf. *gumbeli, M.* cf. *gemmellaroi, Dicerocardium* cf. *curioni*), gastropods, *Thaumotoporella parvovesiculifara*, rare dasycladaceans (*Diplopora tubispora, Heteroporella zankli*), *Involutina liassica*	Norian-Sinemurian
Sciacca Formation	SIA	White massive dolostone with molluscs, dolomitized stromatolite and marly dolostone	150	Unknown	Tidal flat to back-reef lagoon	Bivalves (*Megalodon* cf. *gumbeli, M.* cf. *gemmellaroi, Dicerocardium* spp., *D.* cf. *curioni*), gastropods	Norian-Rhaetian

(1960). It was also described as the “Amerillo unit” of the Monte Bonifato succession (Gianotti and Petrocchi 1960) and “Barracù formation” (Marchetti 1956, 1960).

Lithology and thickness: Thin-bedded calcilutites and calcisiltites (Fig. 1 of Plate 4) with bedded cherts and chert nodules, frequently laminated; white-greyish limestone and red to greenish marls. Microscopically they are mudstone-wackestone rich in planktonic foraminifers (Figs. 5–8 of Plate 4). Laminations consist of aligned planktonic foraminifer shells (i.e., globotruncanites), induced by bottom currents (Fig. 6 of Plate 4). Slumping and cm-thick resedimented normal and inverse graded calcarenites (calciturbidites, Fig. 2 of Plate 4), rich in shallow-water bioclasts

Fig. 2.4 Stratigraphy of the Carbonate Platform Panormide succession, outcropping in the San Vito Lo Capo Mountains (593 Map Sheet “Castellammare del Golfo”, Catalano et al. 2011a)

(rudistids, echinoids, gastropods), frequently occur. Thickness ranges between 30 and 250 m. In the Cretaceous portion of the Panormide succession outcropping in the San Vito lo Capo Mountains (Fig. 2.4), clastic-carbonate bodies become frequent and thicker. These resedimented breccias (AMM_c) consist of shallow-water carbonate elements, eroded from the underlying deposits of the Pellegrino formation. The breccia elements display rudistid fragments, algae, corals, bryozoans, gastropods, crinoids, benthic foraminifers [*Lenticulina* sp., *Spirillina* sp., *Textularia* sp., *Orbitolina lenticularis* (Blumenbach), *Orbitolina trochus* (Fritsch)]. Upwards, *Orbitoides* sp. (uppermost Cretaceous) also occurs. The resedimented breccias, interlayered in the Eocene portion of the pelagic succession (*Sparagio breccias*, AMM_d, Abate et al. 1991a; Catalano et al. 2011a), display a cyclic organization some tens of metres thick (Fig. 2.4). Mainly consisting of shallow-water carbonate elements (Fig. 4 of Plate 4), they are alternated with bioclastic layers (e.g., grain flow) with large benthic foraminifers (Alveolinids, Nummulitids, Lepidocyclinids) and with normal graded and planar-to-cross laminated calcareous turbidites (Ta-Tc Bouma sequence).

The resedimented breccias included in the Amerillo Formation of the Trapanese and Sicanian successions outcropping in W Sicily are interlayered in Campanian-Maastrichtian pelagites (*megabreccias*, AMM_m, Fig. 2.5). Up to

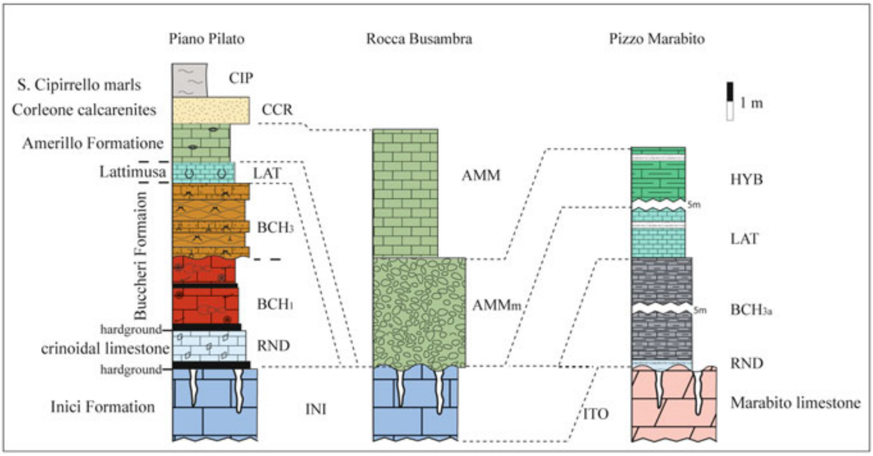


Fig. 2.5 Correlations between different Triassic-Miocene Trapanese successions, outcropping along three natural sections of Rocca Busambra. *Legend* ITO: Upper Triassic Marabito reef limestones INI: Lower Liassic peritidal limestones of the Inici Formation.; RND: Upper Liassic red limestones with crinoids and *Aptychus*; BCH (Rosso Ammonitico deposits of the Buccher Formation): BCH_1 reddish massive limestone with thin shelled pelagic bivalves (*Bositra* sp.); BCH_3 nodular limestones with *Saccocoma* sp. (upper member of the Buccheri formation); BCH_{3a} reddish cherty calcilutites with radiolarians and ammonites; LAT: white calpionellid limestones (Lattimusa); HYB: white and grey calcareous marls and calcilutites (Hybla Formation); AMM: Upper Cretaceous-Eocene red and white pelagic limestone (Amerillo Formation); AMMm: Maastrichtian megabreccias of the Amerillo Formation; CCR: glauconitic Corleone calcarenites; CIP: San Cipirello marls

50–80 m-thick and showing lenticular and massive geometries (Fig. 3 of Plate 4), they consist of calcareous coarse rudstone-floatstone whose elements mostly derive from the dismantling of the Upper Triassic-Lower Jurassic shallow-water carbonates of the Inici and Sciacca Formations (Fig. 3 of Plate 4). The Upper Cretaceous megabreccia deposits outcropping in the northern Hyblean Plateau (Monterosso Almo section, SE Sicily) display 20 m in thickness. The detailed facies analysis of the borehole samples drilled in the Hyblean region suggest their presence in the buried part of the sequence.

The more complete section of the Amerillo Formation is included in the Sicanian succession, where it was subdivided in several lithofacies (Fig. 2.6, Basilone 2011a; Agate et al. 1998). Starting from the bottom, they consist of: (a) alternation of red calcilutites, marls and marly limestone (AMM_a, Upper Cretaceous–Lower Eocene) with calcareous megabreccia intercalations (AMM_m); (b) thick-bedded (20–25 cm) white calcilutites with blackish chert nodules (AMM_b, Middle-Upper Eocene); (c) alternations of grey calcilutites with ichnofacies (*Cancellophycus* isp.) and greenish clays (AMM_e, Lower Oligocene); (d) 5–20 m-thick calcarenites and breccias with nummulitids, lepidocyclinids and *Subterraniphyllum tomasi* Elliot (AMM_f, Lower Oligocene). Locally, thick carbonate breccias are interlayered in Eocene portion of the pelagic succession (*Santo Stefano megabreccias*, Fig. 2.7, Di Stefano et al. 1996).

In the Monte San Calogero section (Sciacca, Saccense succession) and surrounding areas, a several-metres-thick body of celcarenites and breccias with nummulitids, lepidocyclinids (*Lepidocyclina (Nephrolepidina) morgani* Lemoine & Douville, *Operculina* sp., *Heterostegina* sp.), balanids and lithoclasts, occurs (Ruggieri 1959a; Montanari 1961). Similar deposits are present along the succession of the Hyblean region, where calcarenites rich in large benthic foraminifers (*Nummulites distans* Deshayes, *Nummulites perforatus* (de Montfort), *Operculina* cf. *marinellii* Dainelli, *Alveolina schwageri* Checchia-Rispoli, *Alveolina decipiens* Schwager) are followed by tuffitic marls and calcareous megabreccias (Montanari 1982).

This pelagic limestone, in which several resedimented packstone-grainstone levels are intercalated, occurs along the north-western margin of the Hyblean Plateau and displays a thickness ranging between 600 and a few tens of metres (Rigo and Cortesini 1961). The best and most complete Upper Cretaceous pelagic sequence outcrops in the Monterosso Almo section where almost 300 m can be measured. The mafic volcanites outcropping and drilled in the Hyblean region are included in the Capo Passero member (Rigo and Barbieri 1959; Patacca et al. 1979). Consisting of many basalts and pyroclastics, they have been found at the base of the pelagic deposits (Albian) and at the top (Campanian-Maastrichtian). The pillow lavas, displaying tabular geometry, were age-dated to 66.5/65.3 Ma (Grasso et al. 1983); the volcanic dykes were dated to 81.1/78.5 Ma (Barberi et al. 1974). A massive geological body of rudistid limestone 40 m thick, known as the Porto Palo member, overlies and is intercalated with the volcanics of the Capo Passero member (Colacicchi 1963; Allison 1955; Montanari 1982). This reef limestone is interpreted as an atoll that developed on a guyot (Patacca et al. 1979). More

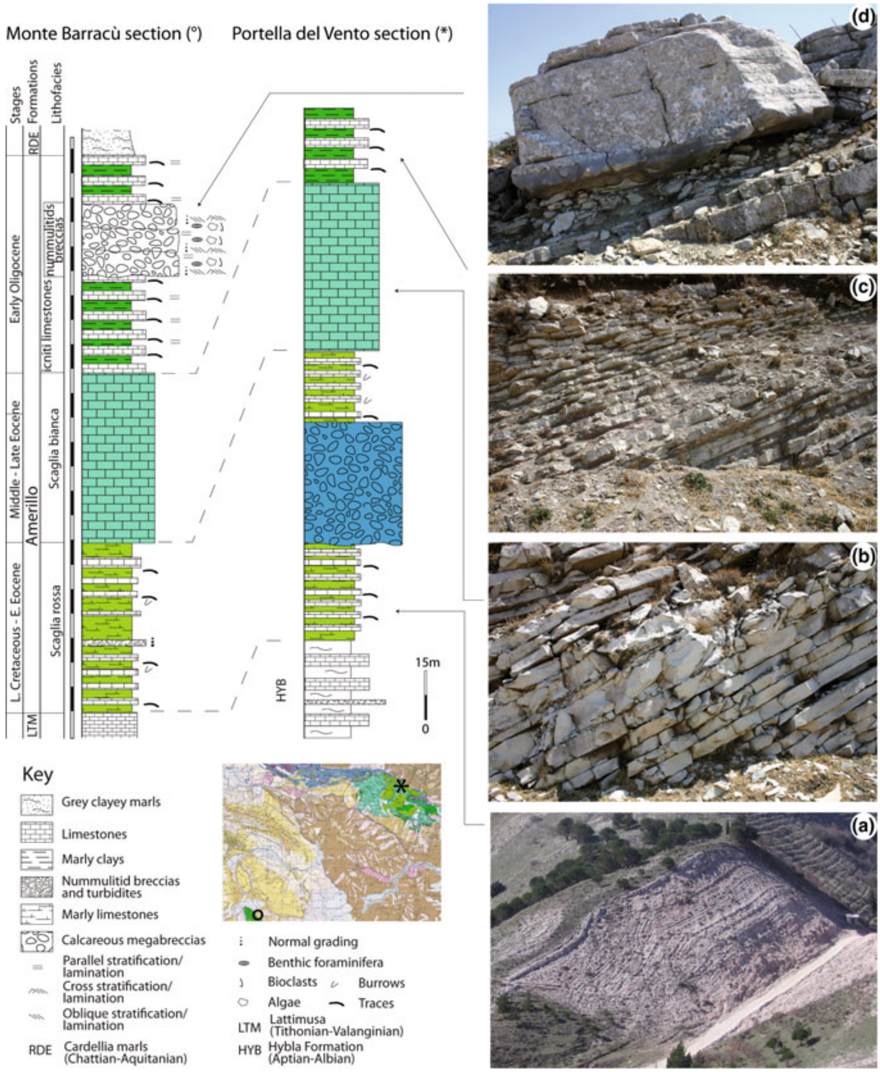


Fig. 2.6 Comparison between the Sicanian Amerillo Formation outcropping at Monte Barracù and at Piano della Tramontana (eastern side of the Rocca Busambra ridge, after Basilone 2011a). Impressive characters of the main lithofacies are shown: **a** Strongly deformed reddish limestones and marls; **b** thin white cherty limestones; **c** rhythmic alternations of thin grey limestones with ichnofacies (*Cancellophycus* isp.) and greenish marly clays; **d** calcarenites and breccias with nummulitids; the m-thick resedimented bodies show erosional lower boundary, parallel and oblique lamination and gradational structures

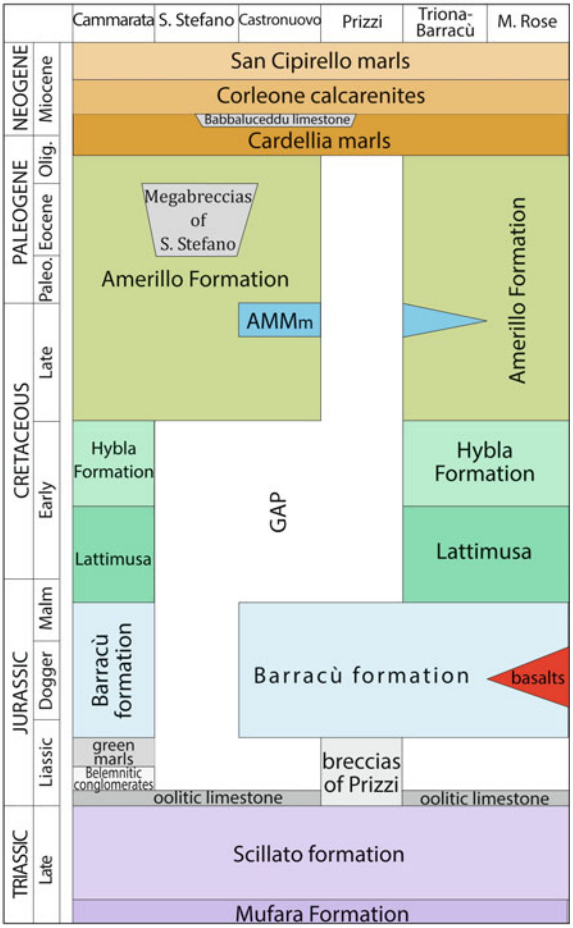


Fig. 2.7 Mesozoic-Cenozoic lithostratigraphic units of the Sicanian basinal domain from the different outcropping sections studied in the Sicanian Mountains (central-western Sicily)

specifically, *Hyppuritid* boundstone has been identified, developed directly on the top and on the edges of the volcanic seamounts (Pachino area), as well as reworked rudistid packstone-grainstone deposited along the distal flank of the volcanoes (Priolo and Augusta areas).

Paleontological content: Mostly planktonic foraminifers and calcareous nannofossils. In the resedimented biocalcarenites large benthic foraminifers (*Orbitoides* sp., *Alveolina schwageri* Checchia-Rispoli, *Alveolina rugosa* Hottinger, *Operculina* sp., *Nummulites* sp.), algal, coral, gastropod and bivalve fragments.

Chronostratigraphic attribution: The unit comprised in the Sicanian succession shows a continuity of sedimentation and, on the basis of microfossils distribution, is referred to the Upper Cretaceous-Early Oligocene time interval. Among the planktonic foraminifers, the markers of the *Rotalipora reicheli* and *Rotalipora cushmani* biozones (Caron 1985) reveal they belong to the Cenomanian; the globotruncanids [including *Globotruncana ventricosa* (White), *Globotruncanita* *stuartiformis* (Dalliez), *Globotruncana lapparenti* (Brotzen), *Globotruncana arca* (Cushman), *Contusotruncana fornicata* (Plummer)] reveal the Santonian-Maastrichtian time interval. Among the calcareous nannofossils, although poor preserved, *Praediscosphaera cretacea* (Arkhngelsky), *Micula decussata* Vekshina, *Lithraphidithes quadratus* Bramlette & Martini and *Eiffellithus* spp., comprising the *Calculites obscurus/Nephrolithus frequens* (CC 17-26) biozones (Sissingh 1977), identify the Campanian-Maastrichtian. The markers of the *Morozovella velascoensis*, *Morozovella formosa formosa*, *Morozovella aragonensis* and *Turborotalia cerroazulensis* s.l. biozones (Martini 1971; Okada and Bukry 1980; Perch-Nielsen 1985a, b) and *Cassigerinella chipolensis/Pseudohastigerina micra* (Toumarkine and Luterbacher 1985) reveal the Paleocene-Eocene and the Early Oligocene time intervals, respectively. The equivalent lithologies recognised in the Trapanese, Saccense and Panormide successions record large hiatuses, which include the Paleocene, Early Eocene and Early Oligocene intervals.

Stratigraphic relationships: The lower boundary is a paraconformity with the marl and limestone of the Hybla Formation (Sicanian and Trapanese-Hyblean successions) or an unconformity, characterised by onlap stratal terminations and infilling geometries, with the Upper Tithonian-Valanginian Piano Battaglia reef limestone and the Cenomanian shallow-water limestone of the Pellegrino formation (Panormide succession). The upper boundary is a transitional conformity surface with the Cardellia marls (Sicanian succession), an erosional surface, where the Corleone glauconitic calcarenites (Cammarata section, Sicanian succession), the shallow-water limestone of the Bonifato formation (Trapanese succession) and the bioclastic calcarenites of the Ragusa Formation (Saccense and Hyblean successions) rest with downlap geometry. In the Panormide succession, it can be a submarine erosional unconformity with the Valdesi formation, marked by long hiatus and downlap relationships (Gallo section, Palermo Mountains) or a paraconformity surface, locally with erosional contact, with the Gratteri formation (Madonie Mountains).

Depositional environment: The pelagic and hemipelagic deposits of the unit were deposited in deep-water environment and on pelagic structural highs (e.g. seamounts). The resedimented materials eroded from adjacent shallow-water areas were deposited in a slope and base-of-slope depositional setting by means of gravitational processes, including bebris flows, turbiditic currents and slump movements.

Regional aspects: The unit outcrops extensively in western Sicily, maintaining homogeneous lithology with local minor facies variations. The most complete sections outcrop in the Palermo Mountains (e.g., Cala Rossa section, Fig. 2.8, Catalano et al. 1973; Basilone et al. 2016b; Bellolampo section, Catalano et al. 2013a) in the San Vito Lo Capo Mountains (Monte Acci section, Giunta and Liguori 1970, 1972; Abate et al. 1991a, b), in the Sicanian Mountains (Monte Barracù section, Agate et al. 1998; Basilone 2011a) and other incomplete sections studied by Montanari (1967a, b) from Western and South-Eastern Sicily. The resedimented carbonates that can be considered as "marker bed" for the Late

Fig. 2.8 Overview of the Meso-Cenozoic Cala Rossa succession. The limestones, outcropping in the small island, consist of Jurassic radiolarian limestones and bedded cherts of the Buccheri Fformation. The Cretaceous-Paleogene Amerillo formation consists of thin-bedded reddish limestone, outcropping along the cliff

Cretaceous interval of the succession are well exposed in Genuardo and Pizzo Telegrafo Mountains (Catalano and D'Argenio 1982a; Catalano et al. 1982; Di Stefano and Gullo 1987) and at Rocca Busambra (Giunta and Liguori 1975; Gullo and Vitale 1986; Basilone 2009a, 2011a). The unit is comprised in the Panormide, Trapanese, Saccense and Hyblean carbonate platform successions and in the deep-water Sicanian carbonate succession.

Carg abbreviation: AMM

2.2.2 *Barracù Formation**

General remarks: This new proposal aimed to formalize the siliceous Jurassic deposits (radiolarites and bedded cherts) characterising the Sicanian succession. These deposits informally described as "siliceous schists" or "siliceous limestone" are well exposed along the western slope of Monte Barracù (Fig. 2.9a, b), where we measured and sampled the possible type-section. This section was previously studied by Daina (1965a, 1967), Mascle (1979) and Agate et al. (1998). Other support sections, studied in the Sicani Mountains region, have been described by Mascle (1979), Broquet (1968) and Broquet et al. (1967).

Lithology and thickness: Red, black green and locally purple thin bedded (10–20 cm) radiolarites (Fig. 2.10a–c), bedded cherts and siliceous limestone (radiolarian-bearing wackestone with belemntites, Fig. 2.10d) regularly alternated with thin-bedded (1–5 cm) shales (Fig. 2.10a, c). At the top, some metres of reddish medium to thin-bedded (10–30 cm) packstone with *Aptichus*, benthic foraminifers, *Saccocoma* sp., algae and shallow-water carbonates (*Aptichus limestone*

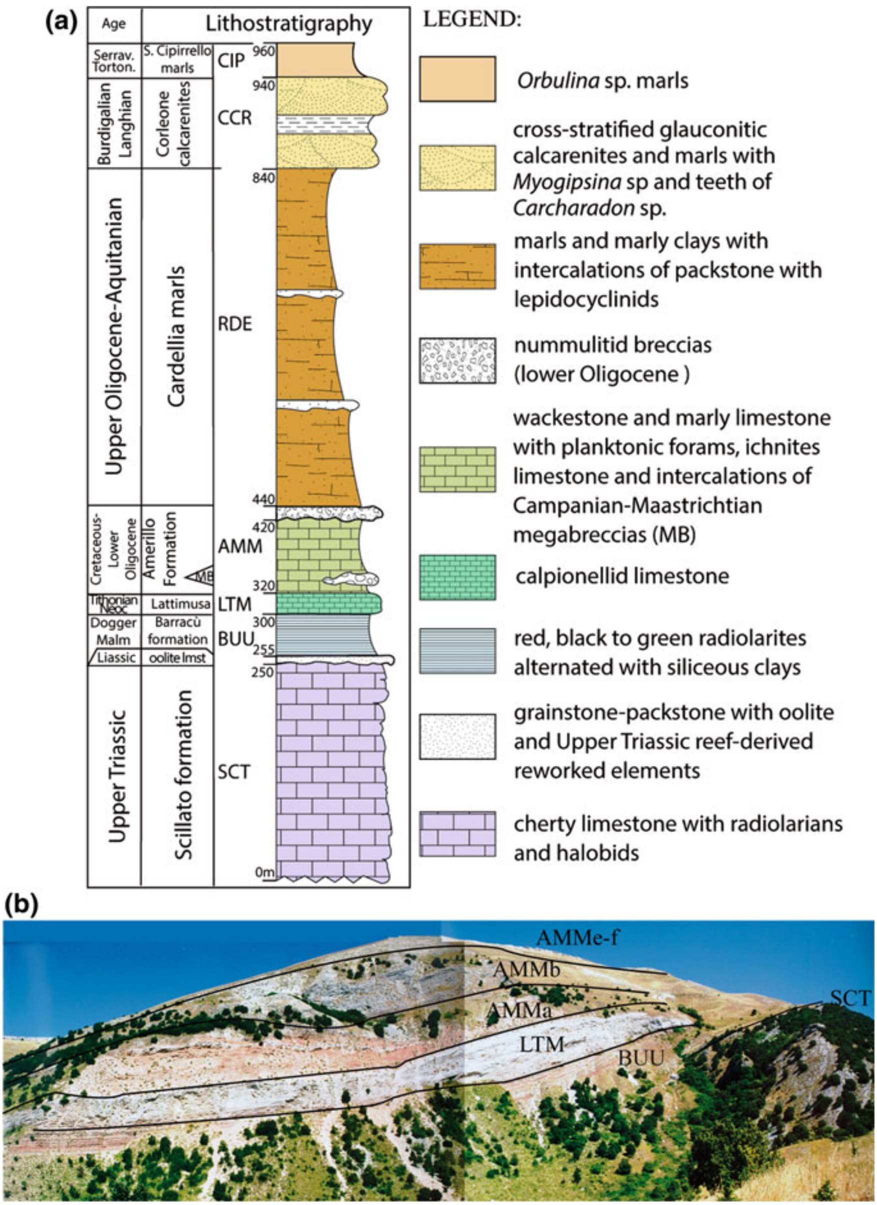


Fig. 2.9 **a** Upper Triassic-Miocene columnar section of Monte Barracù (Sicani Mountains); **b** View of the Triassic-Oligocene Sicanian pelagic succession, western side of Monte Barracù. SCT: cherty limestones of the Scillato Formation (Upper Triassic), passing upwards to crinoidal limestones (Lower Jurassic); BUU: reddish radiolarites (Barracù formation), passing upwards to calcarenites with *Apthycus* sp. and *Saccocoma* sp. (Middle-Upper Jurassic). LTM: cherty limestones with calpionellids (Tithonian-Neocomian, Lattimusa); Amerillo Formation: red marly limestones (Late Cretaceous-Early Eocene, AMMa); white calcilutites (Eocene, AMMb); calcarenites and clays with ichnites and nummulitid breccias (Early Oligocene, AMMe-f)

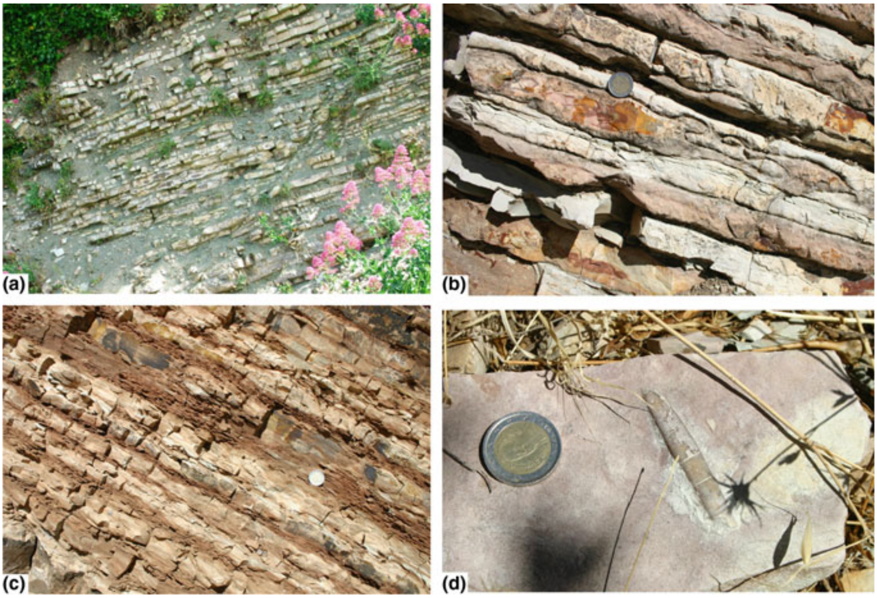


Fig. 2.10 Outcropping photos showing the various lithologies pertaining to the Barracù formation: **a** Regular alternations of blackish claystone and radiolarite (Monte Barracù section); **b** alternations of radiolarites and bedded chert and thin marly levels (Monte Cammarata section); **c** alternations of reddish claystone and siliceous limestone (Monte Cammarata section); **d** pinkish siliceous limestone with *Belemnites* sp. (Monte Cammarata section)

lithofacies). Locally, powerful (up to 60 m in the Giuliana section, Trevisan 1935) tuffitic and basalts with lens geometry (Fabiani 1926, 1929; Scherillo 1935; Lucido et al. 1978) occur. They show pillow lava structures, frequently altered by hydrothermal vents (Vianelli 1968). Thickness of the type section is 56 m (Fig. 2.9a).

Paleontological content: Radiolarians, sponge spicules, calcareous nannofossils (*Watznaueria barnesae* Bukry), *Belemnites semisulcatus* Quenstadt, *Lamellaptychus beyrichi* Opp, *Saccocoma* sp., *Protopeneroplis striata* Weynschenk.

Chronostratigraphic attribution: Toarcian-lower Tithonian. The markers pertaining to the UAZ 3-6, UAZ 9-11 of the unitary association biozonations of Baumgartner (1995) date the radiolarites to the Bajocian–lower Kimmeridgian (Campofiorito section, Chiari et al. 2008). On the basis of the fossil fauna, pertaining to the *Kurnubia palaestinensis* and *Clypeina jurassica* biozones (Chiocchini et al. 1994), the reworked limestone beds of the uppermost Barracù section are dated to the Kimmeridgian-lower Tithonian time interval (Basilone 2011a).

Stratigraphic relationships: The lower boundary is a sharp unconformity surface—often marked by onlap stratal terminations—with the Lower Jurassic resedimented limestone (oolite limestone and/or Prizzi breccias), or directly with the Upper Triassic cherty limestone of the Scillato Formation (Barracù section, Fig. 2.9a, b) and with the S. Maria del Bosco limestone (Mount Genuardo section, Di Stefano et al. 2013). Upwards, they lead—along a sharp or transitional boundary marked by colour changing towards white-greenish tints—to the calpionellid limestone of the Lattimusa.

Depositional environment: The Jurassic radiolarites of the Tethys are generally related to deep-water environment below the CCD (Bosellini and Broglio Loriga 1971; Bosellini and Winterer 1975). Another hypothesis that explains the spread of these lithologies during the Jurassic is based on the occurrence of marine waters highly concentrated in silica coming from the oceanic ridges that during this time were highly active (Jenkyns and Hsü 1974; Jenkyns 1978, 1980, 1986).

Regional aspects: The unit outcrops extensively in the Sicani Mountains and at Judica and Scalpello Mountains (Eastern Sicily). The interbedded basalts are well exposed in the Giuliana and Monte Genuardo outcropping sections (Fig. 1.1, W Sicanian Mountains), in the Palazzo Adriano Mountains and in the Santo Stefano di Quisquina section (Fig. 1.1, E Sicanian Mountains). These radiolarites are very similar to those of the radiolarite member of the Crisanti Formation that characterised the Imerese succession and with those representing the intermediate member of the Buccheri Formation (Fig. 2.1, Trapanese, Saccense and Hyblean successions).

Carg abbreviation: BUU

2.2.3 Bauxites of Spinasanta*

General remarks: These Jurassic continental deposits outcrop exclusively in the Monte Gallo (Mondello, Palermo), where they are intercalated between the Upper Triassic-Lower Jurassic shallow-water limestone of the Capo Rama formation and the Upper Jurassic-Lower Cretaceous Pizzo Manolfo shallow-water limestone. Their stratigraphical and sedimentological characteristics have been studied by Catalano et al. (1979); Bommarito (1982); Di Stefano et al. (2002c) and their petrographic and geochemical characteristics have been studied by Ferla and Bommarito (1988), Censi and Ferla (1989), Ferla et al. (2002a). The type section is located in an abandoned quarry at Contrada Spinasanta, at the foot of the southern slope of Pizzo Impiso (Monte Gallo). These deposits cannot be classified in the rank of formations due to their reduced outcropping extension and thicknesses. They are here described for their stratigraphic and paleoenvironmental interest, useful in reconstructing the geological history of the Mesozoic Panormide shallow-water succession.

Lithology and thickness: Brick-red and yellowish bauxite clays with pisoids fragments, ooids and intraclasts merged in a fine sandstone matrix (Fig. 2.11). These deposits are preserved in neptunian dykes or in little troughs and karren displaying onlap and infilling geometries. Locally, they are associated with blackish speleothems. Maximum thickness 80 cm. XRD analysis reveals the presence of

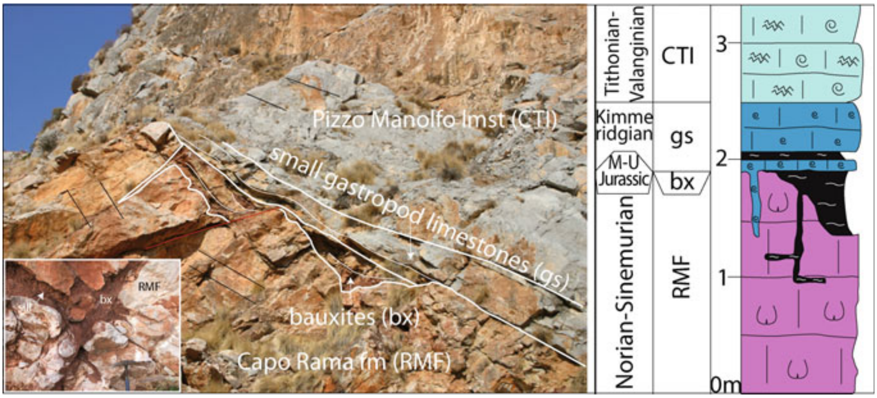


Fig. 2.11 Triassic-Jurassic carbonate succession at Spinasanta quarry (after Basilone and Di Maggio 2016). The Upper Triassic-Lower Jurassic peritidal limestones of the Capo Rama formation (RMF) are dislocated by synsedimentary faults. The Jurassic red bauxite clays (bx) fill erosional ponds at the top of the RMF and a dense network of neptunian dykes (inset). Kimmeridgian dasycladacean and gasteropods limestone (gs) and Upper Tithonian-Valanginian Pizzo Manolfo limestone (CTI), onlap the older strata

boehmite, hematite, anatase, kaolinite and illite (Ferla et al. 2002a). Goethite characterises mostly the yellowish bauxites and is considered as the product of the alteration of iron minerals. Geochemical results show the presence of basaltic-type volcanic components and a clay fraction consisting mostly of illite, interpreted as the result of erosion of laterite-bauxite soils and "terre rosse" that in turn are believed to be the product of the alteration of the underlying limestone.

Chronostratigraphic attribution: On the basis of the stratigraphic positions, the bauxites are ascribed to the Toarcian (?)-Kimmeridgian time interval.

Stratigraphic relationships: The lower boundary is an uneven subaerial erosion surface affecting the shallow-water limestone of the Capo Rama and Sciacca formations, where the bauxitic clays rest with onlap stratal terminations of about 10° and infilling geometries (inset in Fig. 2.11). The upper boundary is a sharp unconformity surface with the Pizzo Manolfo limestone, which rests with onlap stratal terminations (Fig. 2.11); it is also a transitional contact, which is represented by an alternation of centimetre-decimetre layers of red bauxitic clays and thin-bedded grey limestone, which become gradually thicker upwards, with the Kimmeridgian "small gastropods and algae limestone" (Figs. 1–4 of Plate 5 and Fig. 2.11).

Depositional environment: These deposits are interpreted as paleosoils of karst origin formed in a tropical and humid climate (Di Stefano et al. 2002c; Ferla et al. 2002a). Their sedimentation follows a tectonic uplift with tilted blocks that occurred during the last stage of the Southern Tethyan continental rifting (Catalano and D'Argenio 1982b).

Carg abbreviation: BAX

2.2.4 Bonifato Formation

General remarks: The unit was formalized by Schmidt of Friedberg (1962) based on the description of Ruggieri (1959b) carried out on the Carrubazzi quarry section (eastern side of Mount Bonifato, Alcamo).

Synonyms and priority: These deposits have been described by Baldacci (1886) as "Trapani and Alcamo limestone".

Lithology and thickness: Whitish-grey thick-bedded packstone-grainstone rich in large benthic foraminifers (*nummulitids, heterosteginids, lepidocyclinids, discocyclinids*), pectinids and *Melobesia* nodules. Upwards, dm-m thick grey-greenish marl with fine rounded quartz and glauconite grains are interlayered. Locally, thin layers of white mudstone-wackestone with planktonic fauna. 22 m thick in the type section (incomplete); 152 m in the Segesta1 well (Gianotti and Petrocchi 1960).

Paleontological content: The fossil content described by Ruggieri (1959b) mainly regards the abundant large benthic foraminifers (*Discocyclina* sp., *Lepidocyclina* (*Nephrolepidina*) *tournoueri* Lemoine and Douville, *Nummulites fichteli* Michelotti, *N. vascus* Joly and Leymerie, *N. incrassatus* De La Harpe, *Operculina* sp., *Heterostegina* sp.), echinoids, (*Clypeaster pyramidalis* Michelin, *Clypeaster intermedius* Desmoulins), corals, small ostreyds, balanids, pectinids (*Pecten latissimus* Brog). In the uppermost marls, abundant planktonic foraminifers [*Crysalogonium longicostatum* Cushman and Jarvis, *Globigerina dissimilis* Cushman and Bermudez, *Cibicides perlucidus* Nuttall, *Cibicides mexicanus* Nuttall, *Marginulina longiforma* (Plummer), *Siphonodosaria paucistriata* (Galloway and Morrey), *Cyclammina acutidorsata* (Hantken)].

Chronostratigraphic attribution: On the basis of the fossil content the unit is referred to the Upper Oligocene.

Stratigraphic relationships: The lower boundary is an unconformity sharp surface with downlap relationships and large hiatus with the Eocene limestone and marl of the Amerillo Formation. The upper one is an unconformity with the Calcareniti di Corleone, marked by the occurrence of a thin calcareous breccias rich in glauconite of Langhian age (Ruggieri 1957).

Depositional environment: Open shelf.

Regional aspects: The unit, forming part of the Trapanese succession, outcrops in limited extensions and with highly variable thicknesses mostly in western Sicily (Trapani Mountains).

Carg abbreviation: BON

2.2.5 Brachiopods Limestone

General remarks: This unit refers to the calcarenites and calcilutites rich in brachiopod shells that characterised with variable thickness the lower portion of the Jurassic (middle-upper Liassic) Panormide succession (Fig. 2.12). The reduced

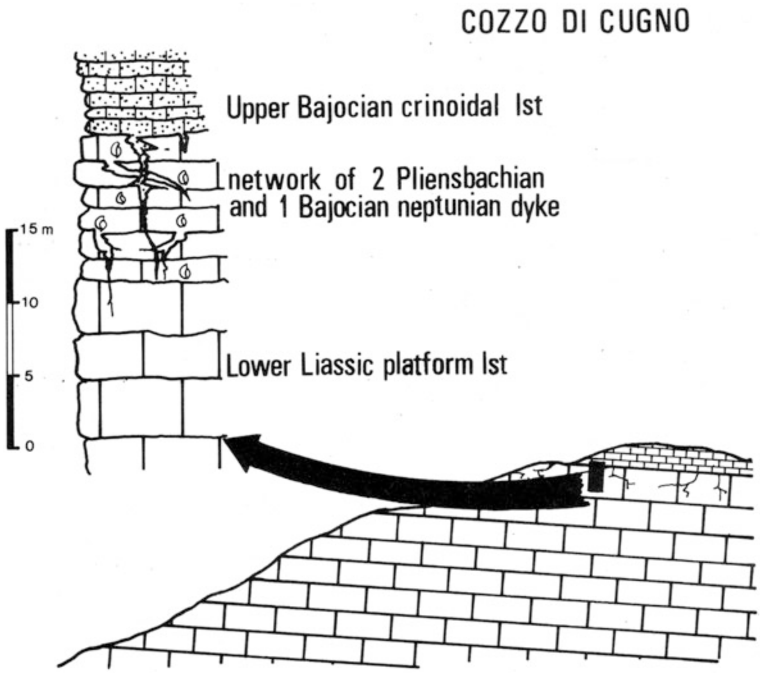


Fig. 2.12 Interpretative section of the lower and Middle Jurassic carbonates at Cozzo Cugno (after Vorös et al. 1986)

thicknesses and lateral discontinuity of the unit not allow its classification in the rank of formations, but it can be considered as a "marker bed" of the succession. Historically, they have been recognised in the Palermo Mountains by Baldacci (1886) and Gemmellaro (1886). Tricomi (1939) described several brachiopod taxa, dated in detail by Vorös et al. (1986).

Lithology and thickness: The unit is represented by two main lithofacies: (i) thin-bedded (cm- to dm-thick) red to yellowish wackestone with brachiopods, radiolarians, algae, *Aptychus*, mollusc fragments, echinoid spines and extraclasts deriving from the erosion and dismantling of the underlying shallow-water limestone (Fig. 5 of Plate 5); this lithofacies shows tabular geometry with lateral thinning, appearing as a single bed up to 35 cm-thick associated with a dm-thick Fe–Mn crust (Fig. 6 of Plate 5, Pecoraro section, Palermo Mountains) or as a succession of thin-bedded calcarenites, up to 15–20 m thick (Bellolampo section, Palermo Mountains); (ii) thick-bedded red-greyish coarse packstone-grainstone with abundant crinoidal plates and articles and brachiopod shells generally follow, upwards. Locally, this unit, up to 25 m thick, displays thick-bedded calcareous breccias with shallow-water darkish angular fragments interlayered with thin levels of reddish wackestone, followed upwards by graded and laminated crinoidal calcarenites (Piano delle Tavole section, Palermo Mountains).

Paleontological content: Brachiopods (*Rynchonellina*? *renevieri* (Haas), *Phimatothyris carasulum* (Zitteli), *Rynchonella furcillata* Gemmellaro, *Rynchonella zitteli* Gemmellaro, *Pygope aspasia* Meneghini), crinoids, algae, molluscs.

Chronostratigraphic attribution: Pliensbachian–Toarcian.

Stratigraphic relationships: The lower boundary is an erosional unconformity with the Upper Triassic shallow-water limestone of the Capo Rama and Cozzo di Lupo formations The surface is marked by subaerial erosion, as highlighted by the associated paleokarst features including in situ breccias, dissolution cavities, truncated beds and erosional long hiatus and by synsedimentary tectonic features, including extensional and transtensional paleofaults and neptunian dykes (Basilone 2009a; Basilone et al. 2016b). The Brachiopods limestone lies on this surface with onlap stratal terminations. The upper boundary of the unit is a sharp paraconformity surface with the *Bositra* limestone (lower member of the Buccheri Formation). Locally, a 15–20 cm-thick blackish Fe–Mn oxides crust with pinnacles morphology caps the top of the unit outcropping in the western side of Monte Sparagio (San Vito Lo Capo Mountains), similarly to those recognised in the coeval deposits of the Trapanese succession (e.g., Busambra and Kumeta sections, Di Stefano P et al. 2002a; Basilone 2009a).

Regional aspects: These deposits, characterising the Lower Jurassic Panormide successions, outcrop discontinuously in the Palermo, Madonie and San Vito Lo Capo Mountains.

Carg abbreviation: CDR

2.2.6 Breccias of Prizzi

General remarks: This informal unit consists of a resedimented carbonate body of considerable thickness that is comprised between the Upper Triassic cherty limestone of the Scillato Formation and the Jurassic radiolarites of the Barracù formation, pertaining to the Sicanian deep-water carbonate succession. These deposits outcrop from the hill on which the town of Prizzi (Corleone) is situated; their lithological and sedimentological characteristics have been described by Gaffurini and Ascoli (1956), Mascle (1979) and Di Stefano et al. (1996).

Lithology and thickness: This unit consists of thick-bedded carbonate megabreccias alternating with bioclastic calcarenites, calciturbidites and calcilutites with radiolarians (Figs. 7 and 8 of Plate 5). The breccia elements are mostly reef-derived fragments of an Upper Triassic carbonate platform, including codiacean and dasycladacean limestone with oncoids and benthic foraminifers, peloidal packstone with algae and molluscs, fenestral limestone, spongid boundstone and dolomitized clasts, fine-grained siliceous mudstone and limestone with radiolarians deriving from the erosion of the underlying Upper Triassic cherty limestone of the Scillato Formation. Outcropping thicknesses up to 70–80 m.

Paleontological content and *Chronostratigraphic attribution*: Benthic foraminifers [*Galeanella panticae* Zaninetti and Bronnimann, *Foliotortus spinosus* (Piller & Senowbari-Daryan), *Involutina liassica* (Jones)] date these deposits to Lower Jurassic (Lower Liassic, Di Stefano et al. 1996). The integrated palynomorphs analysis (*Ovalipollis* sp., *Granuloperculatipollis rudis* Venkatachala & Góczán) of the equivalent deposits drilled in central Sicily allow us to date them to the Rhaetian-Hettangian (Basilone et al. 2016a).

Stratigraphic relationships: The lower boundary is an erosional unconformity that affects the cherty limestone of the Scillato formation. The upper boundary is an unconformity surface where the radiolarites of the Barracù formation rest with onlap stratal terminations.

Depositional environment: These deposits are the product of gravity flows, including debris flow and turbidites that, by reworking the shallow-water materials eroded from an adjacent carbonate platform and its margin, deposited them along the slope and base of slope depositional environments.

Regional aspects: These lithologies are discontinuous laterally and outcrop with various characteristics in the Sicani Mountains and have been recognised in the subsurface, where a recent revision of the deep boreholes for oil exploration drilled in Central Sicily by Agip have revealed the occurrence of several tens of metres of these carbonate breccias (Basilone et al. 2016a).

Carg abbreviation: PRI

2.2.7 Buccheri Formation°

General remarks: This formation represents the deposits historically comprised in the well-known Jurassic Rosso Ammonitico unit. They consist of reddish calcilutites, frequently with nodular texture and the widespread occurrence of ammonitic fauna. The Buccheri formation was proposed by Patacca et al. (1979) on the basis of subsurface data coming from the Hyblean region (Buccheri 2 well, Gulf Italia). The unit, originally subdivided in three different lithologies, was recently amended in three members well recognisable in the field (Di Stefano P et al. 2002a, b; Catalano et al. 2010a). In this view, the Monte Kumeta ridge (Marineo) can be considered as the type area for these outcropping units (Figs. 2.13 and 2.14). These deposits are characterised by strong lithofacies variability (Figs. 2.5 and 2.15), as well illustrated by several studied outcropping sites (Wendt 1963–1964, 1965, 1969; Mascle 1964b; Jenkyns 1970a, c, d, 1974; Catalano and D'Argenio 1982a, 1990; Abate et al. 1990; Di Stefano and Mindstzenty 2000; Martire et al. 2000; Martire and Pavia 2002; Santantonio 2002; Basilone 2009a, 2011a). Basalts (pillow lava) and pyroclastic intercalations, comprised in the Scicli member of the formation drilled in the Hyblean subsurface, are largely diffused also in the Western Sicily outcrops (Fig. 2 of Plate 6, Balatelle, Vicari and Roccapalumba sections, Trevisan 1937a, b; Caflisch and Crescenti 1969; Gasparo Morticelli and Lena 2008; Basilone et al. 2010). The formation in the Hyblean region display up to 50 m in thickness. It

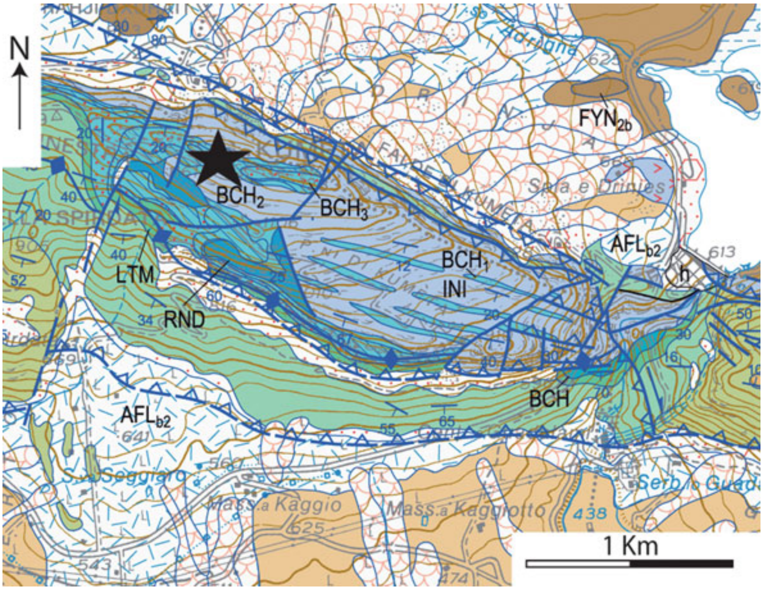


Fig. 2.13 Location of the proposed outcropping type section of the Buccheri Formation (BCH). The map was extracted from the geological Sheet n. 607 "Corleone" (1:50,000 scale, Catalano et al. 2010a)

Fig. 2.14 Upper portion of the type section of the Buccheri Formation, at 'High quarry', Pian di Kumeta (see Fig. 2.13 for location), where the several lithotypes forming the upper Rosso Ammonitico member outcrop

is generally represented by condensed deposits in the Western Sicily outcrops and displays few metres in thickness.

Synonyms and priority: The unit was defined also as "Giardini formation", in a study of the outcropping rocks of Eastern Sicily (Rigo and Barbieri 1959).

Lithology and thickness: The three differentiated members from the bottom are the lower Rosso Ammonitico (BCH_1), the radiolarite member (BCH_2) and the upper Rosso Ammonitico (BCH_3).

Lower rosso ammonitico: Thin- to thick-bedded reddish and whitish calcilutites, marly calcilutites and calcarenites (Fig. 1 of Plate 6) with pelagic pelecypods (*Bositra* sp.), gastropods, ammonites (Figs. 6 and 7 of Plate 6) and, frequently, with intercalations of mm-thick blackish Fe–Mn crusts. The *Bositra* limestone, the lowermost lithofacies of the member, consists of massive dark-reddish wackestone with disarticulated *Bositra* shells and ammonites and is characterised by black Fe–Mn crusts and nodules (Figs. 3–5 of Plate 6), stromatolitic packstone with undulate laminae. Further upwards, thin reddish to pink marly limestone with nodular fabric where the nodules are frequently due to the large occurrence ammonite shells (nodular lithofacies), bioclastic wackestone-packstone with *Bositra* sp., protoglobigerinids, *aptychus* and crinoidal grainstone. The thick basaltic rocks drilled in the Hyblean subsurface and defined as Scicli member (Patacca et al. 1979) outcrop with discontinuity also in Western Sicily, where they appear as pillow lava in the Vicari (Fig. 2 of Plate 6) and Balatelle sections (Fig. 1.13, Basilone et al. 2010) or as pyroclastites (Roccapalumba section) where the rich content in pelagic pelecypods have allowed scholars to date this volcanic event to the Bajocian (Fabiani and Trevisan 1937; Trevisan 1937a, b).

Paleontological content: Abundant thin-shelled bivalves (*Bositra buchii* Roemer), *Globuligerina* sp., *Lenticulina* sp., ammonites, belemnites, radiolarians, calcisphaere, brachiopods, crinoidal articles, echinoids (*Disaster* sp.).

Chronostratigraphic attribution: These deposits are dated using ammonites biozonation schemes (Warmann and Arkell 1954; Wendt 1969; Hantzpergue et al. 1991; Geyssant and Enay 1991). The *Harpoceras serpentinum* biozone refer the lowermost beds to the Toarcian. The *Bositra* limestone is dated, using the *Stephanoceras humpresianum, Garantiana garantiana, Parkinsonia parkinsoni* biozones, to the Bajocian. The nodular lithofacies, characterised by the markers of the *Zig-zag* biozone, is dated to the Bathonian. The ammonites of the *Hecticoceras* (*Phroecticoceras*) *retrocostatum* and *Reneckeia anceps* biozones permit us to date the red calcilutites to the Upper Bathonian–Callovian time interval. The belemnite associations (*Belemnopsis latesulcatus*, *Rhopalotenthis sauvanansa, R. argoviana*) dated the uppermost beds of the condensed deposits outcropping in the Kumeta section to the middle Oxfordian (Mariotti 2002).

Carg abbreviation: BCH_1

Radiolarite member: Thin-bedded red to greenish siliceous mudstone with chert nodules, red laminated radiolarites and bedded cherts alternate with thin white-reddish marls with radiolarians, 0–15 m-thick (Fig. 2.7).

Paleontological content: Abundant radiolarians with variable preservation and frequency, ammonites, belemnites, *Aptychus*, crinoid articles.

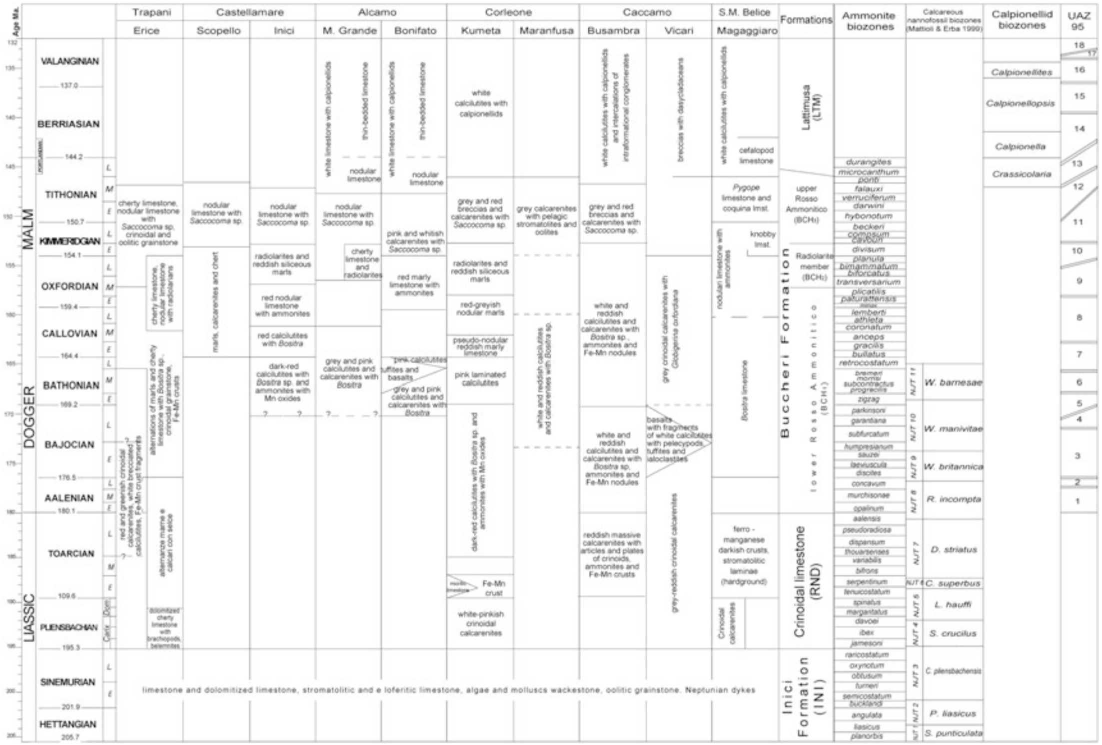


Fig. 2.15 Synoptic diagram showing the several lithofacies of the Jurassic deposits of the Trapanese succession, and their geographic distribution in Western Sicily outcrops. The columns on the right refer to modern lithostratigraphic terminology and to ammonite, calcareous nannofossil, calpionellid and radiolarian biozonal schemes. The data (lithologic and biostratigraphic) were taken by various Authors (Warmann and Arkell 1954; Christ 1960; Tamajo 1960; Wendt 1963–1964, 1965, 1969, 1971, 2017; Jenkyns 1970a, b, 1971a, b; Mascle 1979; Catalano and D'Argenio 1982a; Cecca and Pochettino 2000; Martire et al. 2000, 2002; Martire and Bertok 2002; Basilone 2007, 2009a; Baumgartner 1995; Allemann et al. 1971; Baldanza et al. 2002; Di Stefano P et al. 2002a, b; Pavia et al. 2002)

Chronostratigraphic attribution: Ammonitic fauna reveal the occurrence of the *trasversarium* and *divisium* biozones that date these beds to the Upper Oxfordian–Lower Kimmeridgian time interval (Inici section, Wendt 1969). Radiolarian markers of the UAZ 8, 9–10, 9–11 of the biozonational scheme of Baumgartner (1995) justify dating the radiolarite member of the Kumeta section to the middle Callovian–Tithonian (Beccaro in Martire et al. 2002; Baldanza et al. 2002). Calcareous nannoplankton markers (*Lotharingius crucicentralis* Grün & Zweili, *L. hauffii* Grün & Zweili, *Retecapsa incompta* Bown, *Cyclagelosphaera margerelii* Noël) of the *Lotharingius crucicentralis* and *Lotharingius hauffi* biozones (scheme of Bown and Cooper 1998) constrain the radiolarites of the Kumeta section to the Oxfordian–Lower Kimmeridgian (Baldanza et al. 2002).

Carg abbreviation: BCH_2

Upper rosso ammonitico: Red-greyish to whitish packstone-wackestone with thin-shelled bivalve fragments, echinoids, gastropods, ammonites, brachiopods, calcitized radiolarians and primitive calpionellids. They occur in massive strata or thin-bedded with nodular-to-pseudonodular fabric and with chert nodules and bedded cherts particularly in their lower portion along the transitional contact with the underlying radiolarite member. Outcropping thicknesses range between 10 and 15 m. Calcilutites and grey-brown calcarenites (grainstone-packstone) with pelagic ooids and deep-water stromatolites, alternate with peloidal wackestone-packstone (lithofacies of the pelagic oolites) with a total thickness of 20–25 m and paraconformably follow the *Bositra* limestone at the Maranfusa section (Roccamena, Fig. 2.16, Jenkyns 1972). A few metres of massive packstone-grainstone with benthic foraminifers, pelagic crinoids and calpionellids in the topmost beds (*Saccocoma* limestone, Figs. 8 and 9 of Plate 6) outcrop at Rocca Busambra. Bioclastic resedimented packstone-grainstone regularly alternate with grey-brown siliceous mudstone with chert nodules and bedded chert and greenish marls with pelagic crinoids (*Saccocoma* sp.), radiolarians and tintinnids, characterise the upper member of the Buccheri Formation inserted in the Panormide succession and outcropping both in the Palermo and San Vito Lo Capo Mountains with thicknesses ranging between 30 and 50 m (Basilone 2000; Catalano et al. 2010b, 2013b).

Paleontological content: Ammonites, radiolarians, rare *Apthycus*, brachiopods, belemnites and, upwards, *Pygope diphya* (Verona) and calpionellids (*Crassicollaria* sp.). The bioclastic content of the reworked limestone beds consists of *Saccocoma* sp., *Protopeneroplis striata* Weynschenk, *Globochaete* sp., *Textularia* sp., *Trocholina* sp., *Cayuexia* sp., *Tubiphites obscurus* Maslov and coral fragments.

Chronostratigraphic attribution: On the basis of the ammonitic fauna markers of the *Mesosimoceras cavouri, Hybonoticeras beckeri, Hybonoticeras hybonotum* biozones recognised in the Inici section (Castellammare del Golfo Mountains), these beds have been dated to the Upper Kimmeridgian–Lower Tithonian (Wendt 1969; Pavia et al. 2002). The calcareous nannofossil content (*Lotharingius crucicentralis* Grun and Zweili, *Lotharingius hauffi* Grun and Zweili) of the Inici section dates these beds to the Callovian–Kimmeridgian (Caracuel et al. 2002) and to the Lower Tithonian, when the markers of the *Conusphaera mexicana* biozone (the

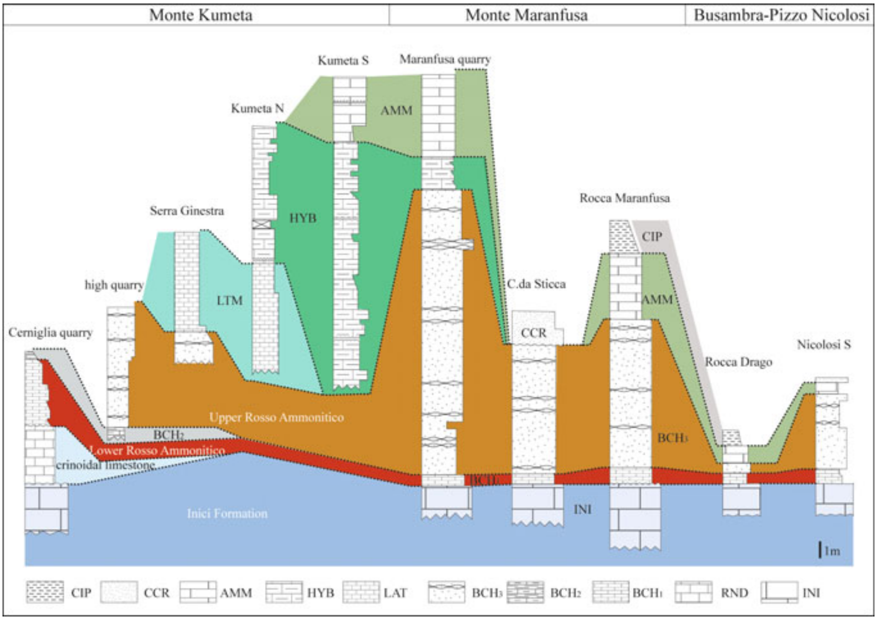


Fig. 2.16 Lithostratigraphic correlation of some sections of the Trapanese succession, sampled in different outcrop section in Western Sicily. INI Lower Liassic peritidal carbonates of the Inici Formation., RND Upper Liassic crinoidal limestones, Jurassic pelagic and condensed deposits of the Buccheri Formation: BCH_1 Lower Rosso Ammonitico member, BCH_2 intermediate radiolarite member, BCH_3 Upper Rosso Ammonitico member, LTM Tithonian-Neocomian cherty limestones of Lattimusa, HYB Lower Cretaceous cherty limestones and marls of Hybla Formation, AMM Upper Cretaceous-Eocene pelagic deposits of Amerillo Formation, CCR Lower Miocene Corleone glauconitic calcarenites, CIP Middle-Upper Miocene San Cipirello marls

NJ20 biozone of the biozonational scheme of Bralower et al. 1989) occur. The *Cyrtocrinid thetyan* crinoidal association, corresponding to the B2 biozone of Manni and Nicosia (1994), dates to the Kimmeridgian the *Saccocoma* limestone outcropping in the Kumeta section (Santantonio 2002).

Carg abbreviation: BCH_3

Chronostratigraphic attribution: On the basis of the rich fossil content, mostly ammonites described by Floridia (1931), Gugenberger (1936a, b), Warmann and Arkell (1954), Christ (1960), Mascle (1964b), Forzy (1995), Cecca et al. (2001), Santantonio (2002), the deposits of the Buccheri Formation are dated to the Middle-Late Jurassic. Fabiani and Ruiz (1932b) dated the calcilutites with brachiopods to the Dogger. Wendt (1965, 1969) reconstructs a detailed ammonite biozonation on the basis of the recognition of more than 50 taxa of ammonites from the Monte Inici outcropping section, dating the whole succession to the Toarcian-Lower Tithonian.

Stratigraphic relationships: The lower boundary is an unconformity, marked by onlap stratal termination, with the Lower Jurassic Crinoidal limestone and/or the shallow-water limestone of the Inici Formation (Trapanese succession). This boundary is marked by the occurrence of a thick blackish Fe–Mn crust, frequently characterised by pinnacle morphology, evidencing bio-erosion (Di Stefano and Mindstzenty 2000) that covers both the “Crinoidal limestone” and, regionally, the Inici Formation. This contact is easily recognisable in the field due to the morphologic discontinuity, different bedding structure (i.e., thin-bedded pelagic limestone of the Buccheri Formation versus thick-bedded shallow-water limestone of the Inici Formation) and the colour changes (reddish ammonitic limestone versus whitish shallow-water limestone of the Inici Formation). Locally, this boundary is characterised by synsedimentary tectonics where the ammonitic limestone rests in buttress unconformity (sensu Davis and Reynolds 1996) above the small fault escarpments cutting the top of the Inici Formation (Inici and Rocca Busambra sections, Basilone 2009a). In the Panormide succession, it is an unconformity surface with onlap with the Upper Triassic-Lower Jurassic shallow-water limestone of the Capo Rama and Cozzo di Lupo formations, frequently marked by karstic features. The upper boundary can be a transitional contact or a paraconformity with the calpionellid limestone of Lattimusa (Trapanese succession). It is marked by morphological discontinuity (marly nodular limestone of the Buccheri Formation versus thin-bedded limestone of the Lattimusa), the disappearance of nodular texture, colour changes towards whitish tints and the increasing of chert nodule content. This boundary can be a transitional contact marked by a lithological interval some decimetres-thick characterised by alternations of white and reddish limestone and marls, where the reddish colour of the rocks and the marly content gradually disappear upwards (e.g., Piano Pilato, Rocca Busambra, Fig. 2.5). This boundary in the Panormide succession is a submarine erosional unconformity with the Piano Battaglia reef limestone.

Depositional environment: The overall pelagic sedimentation associated with the occurrence of iron-manganese crusts, condensed deposits and nodular fabric characterising these deposits has been related to a deep-water environment to slope setting and pelagic structural highs (e.g., seamount, Jenkyns 1970a, 1971b; Di Stefano P et al. 2002a, b; Santantonio 1993, 1994, 2002; Basilone 2009a; Basilone et al. 2010). The lithofacies of the upper member, particularly those outcropping along the Panormide succession, characterised mostly by fine-grained clastic-carbonates, hemipelagites and pelagites, reveals a slope to base of slope depositional environments where the pelagic sedimentation was accompanied by gravity flows (e.g., grain flow, Basilone 2000, 2009b; Basilone et al. 2016b).

Regional aspects: This formation, largely outcropping in Western Sicily (e.g., Kumeta and Busambra ridges, Trapani, Castellammare del Golfo, Sciacca Mountains) and in the subsurface of the Hyblean region, displays strong lateral discontinuity, facies and thicknesses variability and different stratigraphic relationships. The three members, widely occurring along the Hyblean and Saccense successions, are frequently absent (e.g., Busambra, Maranfusa, Roccapalumba, Vicari sections) or occurr as a complete sequence with reduced thicknesses and condensed deposits (e.g., Kumeta, Balatelle, Inici sections) along the Trapanese succession (Fig. 2.16). Generally, the intermediate radiolarite member (BCH_2) is absent in the outcropping area (Palermo, Madonie and San Vito Lo Capo Mountains) of the Panormide succession or occur with strong lateral discontinuity (Sparagio section, San Vito Lo Capo Mountains). The similar deposits known as Ammonitico Rosso outcrop frequently in the Apennines and Alps Mesozoic successions (Farinacci and Sirna 1960; Santantonio 2002 and references therein).

Carg abbreviation: BCH

*2.2.8 Calcarenites and Marls of Sauci**

General remarks: This informal unit was defined to describe the deposits recognised in the Monte Acci Panormide succession (Fig. 2.4, San Vito Lo Capo Mountains), where a recent study has highlighted several new lithological and textural features that justify the proposal of a new unit (Catalano et al. 2010b). These deposits were previously considered as pertaining to the Lattimusa formation (Giunta and Liguori 1970, 1972; Abate et al. 1991a, b, 1993).

Lithology and thickness: Grey thick-bedded graded calcarenites and laminated calcilutites with chert nodules (Fig. 3 of Plate 7), followed by yellowish to greenish marly limestone and marly clays with rare and thin lenticular intercalations of radiolarites and marls with radiolarians. The calcarenites, consisting mainly of packstone-grainstone, display tabular to lenticular geometry, normal gradational structures, planar and cross laminations, aligned clasts and oriented shells indicating the direction of bottom paleocurrents and bioturbations (Fig. 4 of Plate 7). Locally slumping structures also occur.

Paleontological content: Ammonites, *Aptychus*, belemnites, gastropods, pelecypods, diceratids, coral fragments, sponge spiculae, echinoid spines, pelagic crinoids (*Saccocoma* sp.), *Globochaete alpina*, Lombard, benthic foraminifers [*Conicospirillina basiliensis*, Mohler, *Protopeneroplis trochoangulata* Sepfontaine, *Pseudocyclammina lituus* (Yokoyama)], rare tintinnids [*Crassicollaria* sp., *Calpionella alpina* Lorenz; *Calpionella elliptica* Cadisch, *Remaniella cadischiana* (Colom), *Tintinnopsella carpathica* (Murgeanu and Filipescu)], *Charophyta*, ostracods and radiolarians.

Chronostratigraphic attribution: On the basis of the benthic and planktonic fossil content, the unit is dated to the Upper Tithonian–Neocomian time interval.

Stratigraphic relationships: The lower boundary is a paraconformity with the Buccheri Formation; the upper boundary is characterised by transitional relationships with the marl and limestone of the Hybla Formation.

Depositional environment: Slope to basin, where the pelagic and hemipelagic sedimentation was interrupted by gravity flows (e.g., calciturbidites) reworking shallow-water materials.

Carg abbreviation: SUI

2.2.9 *Caltavuturo Formation°*

General remarks: The unit was proposed by Schmidt di Friedberg et al. (1960) in their study of the Contrada Vera Luce outcropping section (Fig. 2.17, Caltavuturo, Madonie Mountains). The formation was originally referred to the Middle-Upper Eocene time interval although Ogniben (1960, 1963a) and Wezel (1966) indicated the occurrence of Oligocene fauna in the Portella Colla section (Fig. 1.1, Madonie Mountains). The unit is here amended to include some lithologies and lithofacies such as the "Nummulitid breccias" (Basilone 2000) and the "grey marls" (Montanari 1966) used in the geological maps of the CARG project (Fig. 2.18). The whole succession is comprised in the Upper Cretaceous-Lower Oligocene time interval (see also Sottocomitato Reg. Sic., 1995).

Synonyms and priority: The unit corresponds to the upper portion of the "Cuminello formation" of Ceretti and Ciabatti (1965), and to the "formazone calcescistosa di Caltavuturo" of Ogniben (1960). Schmidt di Friedberg and Trovò (1962) compared the Caltavuturo formation to the Barracù formation of Marchetti (1956), which in the new classification proposed here is referred to the Amerillo formation (see Synonyms).

Lithology and thickness: Thin-bedded calcilutites and calcisiltites with conchoidal fracture, bedded cherts and whitish to blackish chert nodules, planar lamination and abundant ichnites regularly alternated with reddish marls and

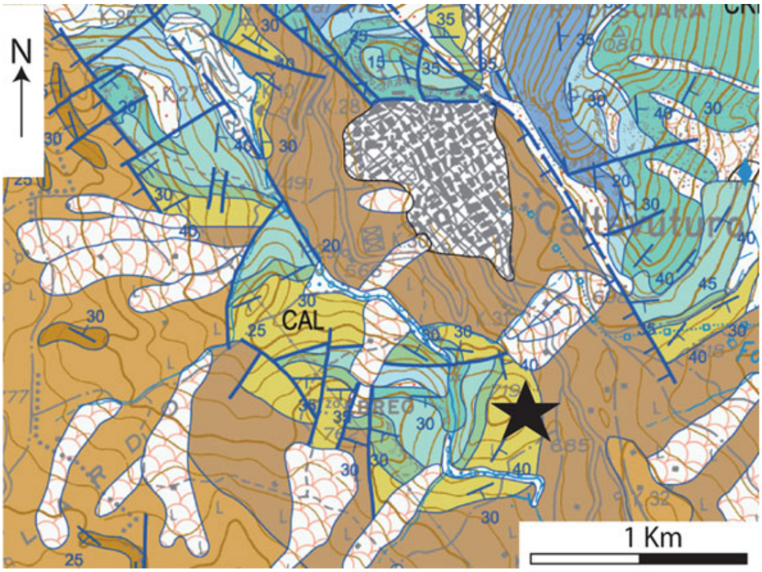


Fig. 2.17 Location of the type section of the Caltavuturo formation (CAL). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map, Catalano et al. 2011b)

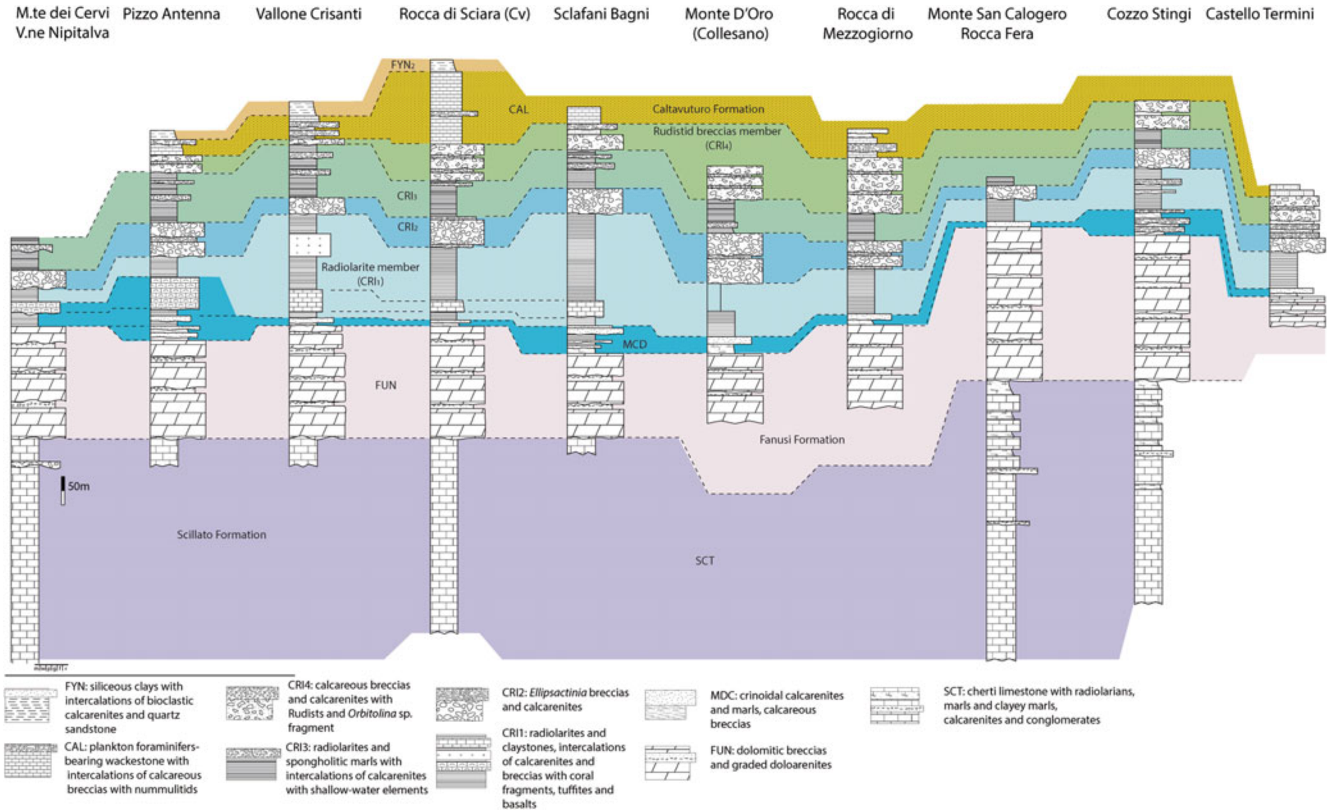


Fig. 2.18 Correlation between the formations of the several stratigraphic sections of the Imerese succession outcropping in the Termini Imerese and Madonie Mountains

varicoloured marly limestone (Figs. 1–2 of Plate 8). Microscopically, they are mudstone-wackestone with planktonic foraminifers (Fig. 3 of Plate 8). Grey graded and laminated thin-bedded biocalcarenites (packstone-grainstone) with large benthic foraminifers (alveolinids, nummulitids) are interlayered. Upwards, resedimented calcareous breccias and calcarenites with shallow-water derived fragments and large benthic foraminifers, displaying thick-bedded stratification (between one metre to several metres) characterised by turbiditic sedimentary structures (mostly Ta-d, Ta-e Bouma sequences) and internal discordance (Nummulitid breccias, CAL_a). They are rudstone and fossiliferous grainstone-packstone (Figs. 4–8 of Plate 8). Measured thicknesses are between 15 and 20 m. The lower boundary of this lithofacies is an erosional submarine surface with downlap stratal termination and truncation of the underlying pelagite beds (Basilone 2000). About 10 m-thick greyish marls and calcareous clays alternated with thin-bedded packstone-grainstone rich in *Nephrolepidina* sp. and small nummulitids (grey marls, CAL_b) locally characterised the top of the formation. The whole unit displays a variable thickness between 50 and 150 m (Fig. 2.18).

Paleontological content: Fossil associations not are always preserved. Calcareous nannofossils and planktonic foraminifers of the genus *Globotruncana, Globorotalia, Globigerina*, *Hantkenina, Morozovella, Globigerinatheka, Turborotalia* are abundant; radiolarians and sponge spicules also occur. Reworked fauna comprises *Nummulites partschi* De La Harpe, *Nummulites praelucasi* Douvillé, algae fragments, corals, bryozoans, bivalves and gastropods.

Chronostratigraphic attribution: These deposits are referred to the Upper Cretaceous-Lower Oligocene time interval. In detail, the markers of the *Globotruncana ventricosa* (Upper Cretaceous), *Morozovella velascoensis* (Upper Paleocene), *Morozovella subbotinae* and *Morozovella aragonensis* (Lower Eocene), *Turborotalia cerroazulensis* s.l. and *Globigerinatheka semiinvoluta* (Upper Eocene) planktonic foraminifer biozones can be recognised. The occurrence of *Acarinina bullbrooki* (Bolli) and *Globigerinatheka index* (Finlay) indicates the Middle Eocene. The markers of the *Discoaster multiradiatus* (NP9), *Discoaster sublodoensis* (NP14), *Nannotetrina fulgens* (NP15), *Discoaster saipanensis* (NP17) and *Sphenolithus pseudoradians* (NP20) calcareous nannofossils biozones dated the unit to the Upper Palaeocene–Upper Eocene. The fossil content (planktonic and reworked benthic fauna) of the Nummulitid breccias lithofacies dates these beds to the Middle-Upper Eocene. The markers of the *Cassigerinella chipolensis*-*Pseudohastigerina micra* and *Globigerina ampliapertura* planktonic foraminifer biozones and the *Sphenolithus predistentus* (NP23) calcareous nannofossils biozone date the grey marls lithofacies to the Lower Oligocene. An integrated biostratigraphic analysis of large benthic foraminifers, recognised along the Portella Colla section (Benedetti 2010), reveal the occurrence of *Heterostegina reticulata italiaca* Herb, *Borelis vonderschmittii* (Schweighauser), *Halkyardia minima* Liebus, *Dyscocyclina dispansa dispansa* Sowerby, *Orbitoclypeus varians* Kaufmann, *Nummulites* ex. gr. *incrassatus.* These elements, pertaining to the SBZ19 (shallow benthic zones of the biozonation scheme of Serra-Kiel et al. 1998), along with the occurrence of *Nummulites vascus* Joly & Leymerie, *Nephrolepidina* sp., *Nummulites fichteli* Michelotti*, Halkyardia maxima* Cimerman*, Operculina complanata* Defrance*, Heterostegina* sp., pertaining to the SBZ 21-22A (biozonation scheme of Cahuzac and Poignant 1997), date these beds to the Priabonian.

Stratigraphic relationships: The lower boundary is an unconformity surface with the underlying rudistid breccias member of the Crisanti formation, where the marly limestone of the Caltavuturo formation rests in onlap. It can also be a paraconformity, marked by long hiatus, with the Lower Cretaceous spongolithic member of the Crisanti formation. The upper boundary is a sharp, conformity surface—locally with transitional contact—with the brown claystone of the Portella Colla member of the Numidian flysch, as well observable at Portella Colla section (Madonie Mountains).

Depositional environment: Lithofacies characteristics, environmental and paleo-bathymetric data (fossils, ichnites) suggest a slope to deep-water depositional environment, where the pelagic and hemipelagic sedimentation was interrupted by the occurrence of gravity flows, including slumping phenomena and grain flow and turbidites originating from the margin of an adjacent carbonate platform margin. The several species of agglutinated foraminifers (DWAF) suggest well-oxygenated paleoenvironments and mesotrophic conditions in the lower portion of the succession. Upwards, oligotrophic conditions with poor oxygenated waters change in the uppermost section to a deepening of the water column with an increase in nutrients (Benedetti and Pignatti 2008). These reconstructions are consistent with the subsequent terrigenous sedimentation, represented by the lithology of the Numidian flysch.

Regional aspects: This formation, a part of the Mesozoic-Paleogene Imerese deep-water carbonate succession, largely outcrops in NW Sicily from the Madonie Mountains to the southern Palermo Mountains, through Termini Imerese and the Trabia Mountains

Carg abbreviation: CAL

*2.2.10 Capo Gallo Limestone**

General remarks: This unit was proposed in the frame of the geological maps of the Carg project (Basilone et al. 2001; Catalano et al. 2013a, b) to describe the Lower Cretaceous shallow-water carbonates with small rudistid shells (requienids) comprised in the Panormide succession. The following description is based on the proposed Pizzo Sella type section reconstructed by Basilone and Lena (2009) from the outcropping succession of Monte Gallo (Fig. 2.19, Mondello-Palermo). It is supported by the detailed biostratigraphic studies of Montanari (1965) and Camoin (1983), in their study of the S. Rosalia section (Monte Pellegrino, Palermo).

Synonyms and priority: This unit was described and comprised in the "Cefalù formation" by Schmidt di Friedberg (1964–1965) on the basis of the studied section outcropping along the western side of the Rocca di Cefalù (Madonie Mountains). In this unit were comprised the Cretaceous shallow-water deposits outcropping in Western Sicily, including the Upper Tithonian-Valanginian Piano Battaglia reef limestone and the Cenomanian Pellegrino formation differentiated here. These

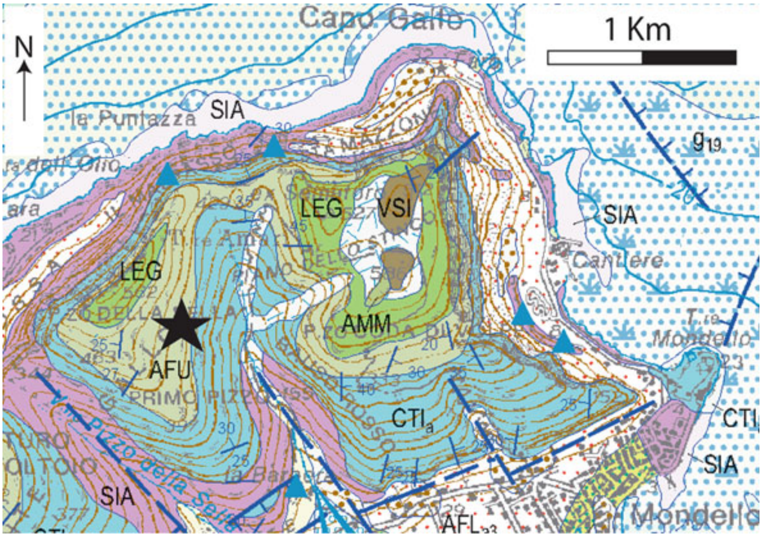


Fig. 2.19 Location of the proposed type section of the Capo Gallo limestone (AFU). The map was extracted from the geological Sheet n. 585–594 "Partinico-Mondello" (1:50,000 scale), performed by Catalano et al. (2013a)

rocks were also called "detritic-organogen limestone of the Rocca di Cefalù" (Baldacci 1886), "rudistid limestone" (Caflisch 1966) and "Cefalù limestone" (Grasso et al. 1978).

Lithology and thickness: Grey bioclastic micritic limestone with requienids, algae, large gastropods (*Nerinea* sp.) and benthic foraminifers (*Palorbitolina* sp.), coated grains by *Bacinella* sp. (Figs. 4–9 of Plate 9) alternating cyclically with blackish oolitic and bioclastic grainstone (Fig. 3 of Plate 9) and locally with dm-thick fenestral limestone with peloids and benthic foraminifers (Fig. 2 of Plate 9). Locally, thin greenish to yellowish marls are interbedded or filling paleokarst and microkarst cavities, where the dissolution features related to a vadose and phreatic meteoric processes are recognisable. The mudstone-wackestone and rarely-occurring packstone display abundant mollusc shells that are frequently broken or aligned and parallel to the bedding, highlighting the occurrence of bottom currents (Fig. 1 of Plate 9). Locally, lenses of microbreccias and fine-to-coarse calcarenites with rudistid, gastropod and coral fragments are intercalated. Laterally thin-bedded (dm- to m-thick tabular beds) darkish-grey micritic limestone with peloids and bioclasts and features have been recognised, indicating restricted circulations as described in reference to the Raffo Rosso section (Palermo Mountains, Catalano et al. 2013a) and to the Cozzo Carcarello section (Madonie Mountains, Catalano et al. 1974a). Outcropping thickness ranges between 120 and 180 m.

Paleontological content: Caprotinids, Caprinids (*Offneria* sp., *Precaprina* sp.), frequently in life position, aligned requienid shells evidencing bottom currents, gastropods (*Nerinea* sp.), algae (*Cayeuxia* sp.), dasycladacean (*Triploporella* cf.

decastroi BARATTOLO, *Salpingoporella* spp., *Macroporella* spp.), benthic foraminifers (*Palorbitolina lenticularis praecursor* (MONTANARI), *Rectodictioconus giganteus* SCHROEDER, *Trocholina* spp., *Cuneolina* ex. gr. *camposauri-laurentii* SARTONI & CRESCENTI and Textularids, Miliolids, Ophtalmidids), microproblematics (*Bacinella irregularis* RADOICIC, *Lithocodium* sp.), corals.

Chronostratigraphic attribution: On the basis of the occurrence of benthic foraminifers and algae of the *Salpingoporella dinarica* biozone (De Castro 1991), these deposits have been dated to the Upper Barremian–Lower Albian (Camoin 1983; Montanari 1965; Catalano et al. 1974a).

Stratigraphic relationships: The lower boundary is an unconformity—marked by onlap stratal terminations (3°–5°)—with the Pizzo Manolfo limestone. The upper boundary is an unconformity—marked by submarine erosion and downlap stratal terminations—with the Cenomanian shallow-water limestone of the Pellegrino formation. Locally, it is characterised by the occurrence of continental pelites (Costa Mazzone clays, Basilone and Di Maggio 2016; Basilone et al. 2017) or by Fe-Mn crust (hardground, Basilone and Sulli 2018).

Depositional environment: Back-barrier lagoon and tidal flat affected by storm events, changing seawards to an oolitic sand bar.

Regional aspects: The unit outcrops in the Palermo (Pellegrino, Castellaccio and Gallo sections), Madonie (Cefalù section) and San Vito Lo Capo Mountains.

Carg abbreviation: AFU

*2.2.11 Capo Rama Formation**

General remarks: This unit was proposed in the context of the Geological Maps of the CARG project (Basilone et al. 2001; Catalano et al. 2013a) to describe the Upper Triassic-Lower Jurassic shallow-water carbonates of the Panormide succession (Table 2.5). The description is based on the lithological and sedimentological features of the Capo Rama type section (Fig. 2.20, Palermo Mountains). Having a thickness of about 250–300 m (Fig. 2.21a and Fig. 1 of Plate 10), it was studied in detail by Catalano et al. (1974b, c, 2013a). The sedimentological and lithological analysis of the deposits outcropping in the Palermo, San Vito Lo Capo and Madonie Mountains, made it possible to identify several lithofacies and facies associations (Di Stefano 1981; Di Stefano et al. 1997a; Basilone 1996, 2000). They comprise the loferitic cyclothems facies association, well exposed along the cliff of Capo Rama and related to inner carbonate platform depositional environments, and the Costa Ginestra limestone (Figs. 2.21b and 2.22), consisting of cyclic sequence of algal limestone with rich dasycladacean associations, megalodontids limestone and coralgal biolitites, considered as belonging to the most marginal sectors of the carbonate platform, near the reef margin (Abate et al. 1977; Di Stefano 1981). It is well exposed along the northern side of the Cozzo di Lupo (Torretta, Palermo Mountains), where the lateral (heteropic) transition with the reef margin facies is clearly visible (Figs. 2.21b and 2.23).

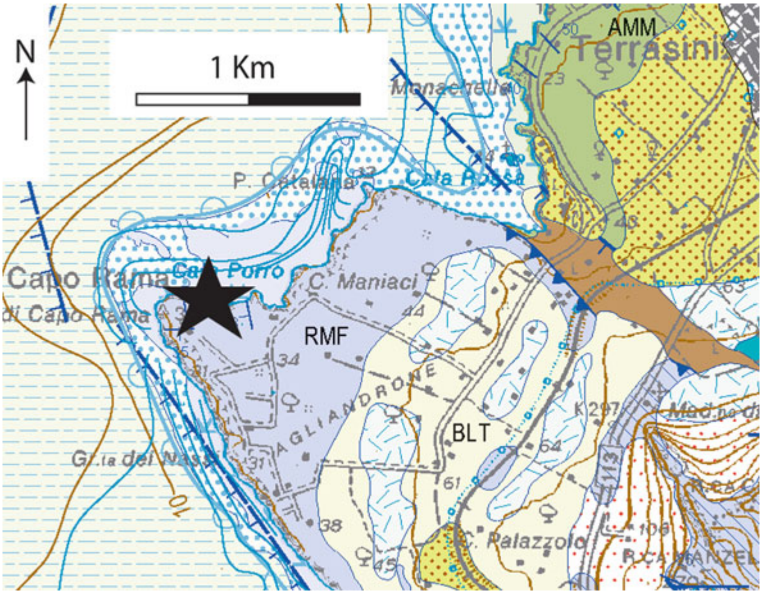
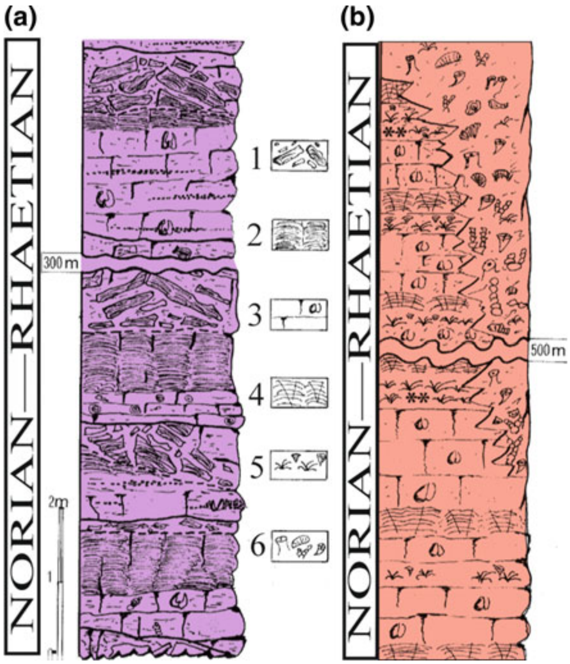


Fig. 2.20 Location of the proposed type section of the Capo Rama formation (RMF). The map was extracted from the geological Sheet n. 585–594 "Partinico-Mondello" (1:50,000 scale), performed by Catalano et al. (2013a)

Fig. 2.21 Stratigraphic columns representative of the upper Triassic Panormide carbonate platform facies, outcropping in the Palermo Mountains (after Catalano et al. 1974b; Di Stefano 1981). **a** Succession of the Capo Rama formation, **b** succession of the Cozzo di Lupo formation that change, downward and laterally to the Costa Ginestra lithofacies of the Capo Rama formation *Legend* (1) Loferitic breccias, (2) stromatolitic dolostones, (3) megalodontid dolomitic limestones, (4) algal boundstone, (5) corals boundstone, (6) spongid boundstone



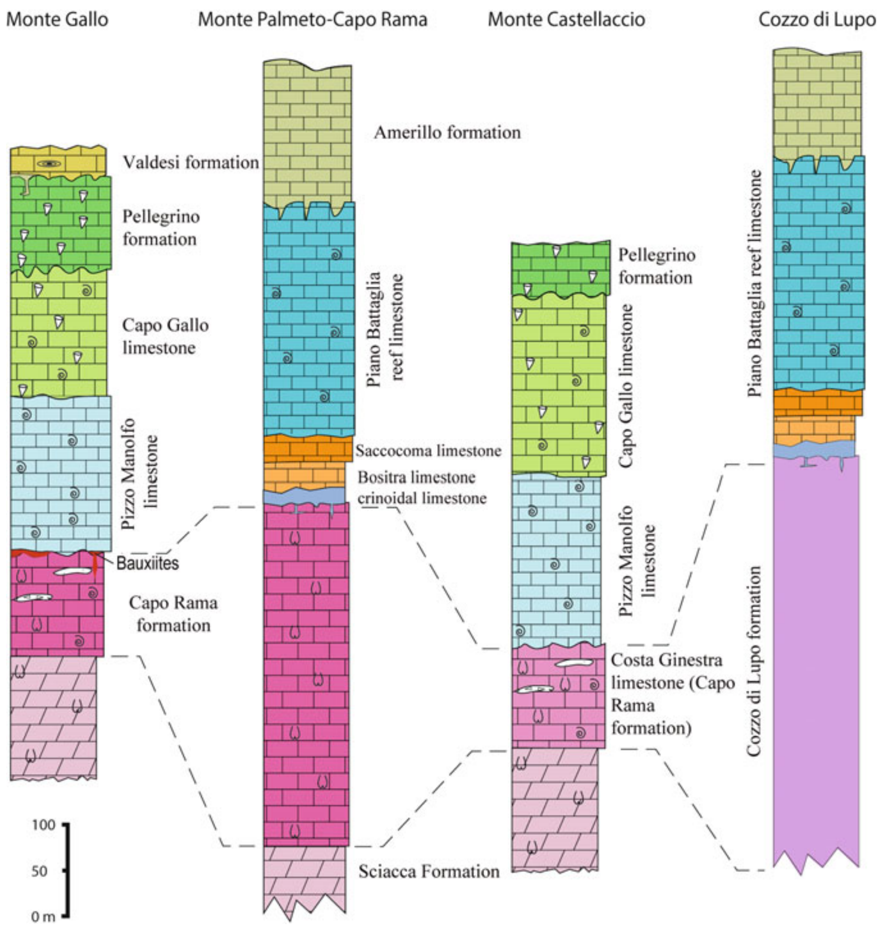


Fig. 2.22 Columnar stratigraphic sections of the Panormide Carbonate Platform, reconstructed from various outcropping sites of the Palermo Mountains

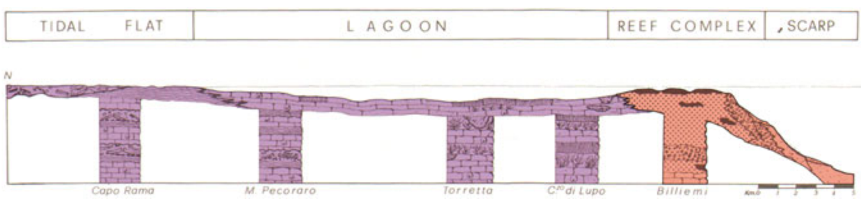


Fig. 2.23 Facies distribution of the deposits outcropping in the Palermo Mountains on the hypothetical depositional profile of the Upper Triassic Panormide carbonate platform (after Abate et al. 1977). For the legend see Fig. 2.21

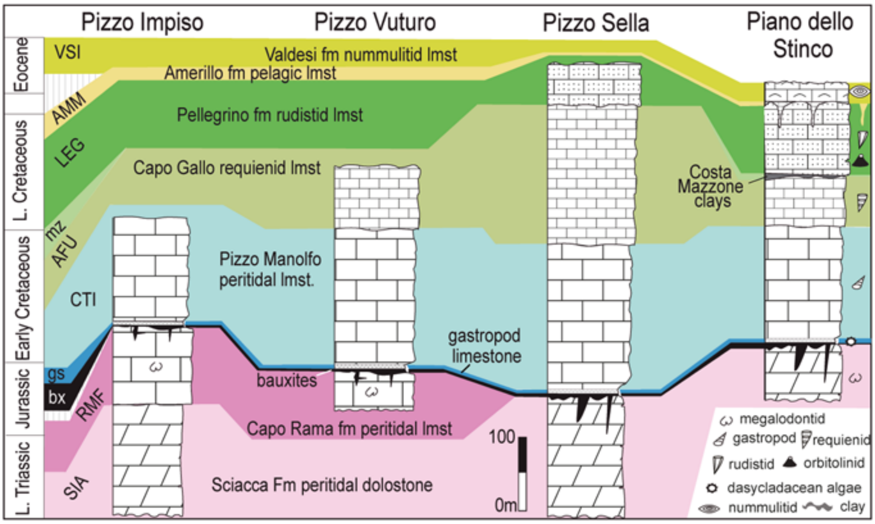


Fig. 2.24 Stratigraphic correlation of Upper Triassic-Eocene sections logged in the Monte Gallo area (after Basilone and Di Maggio 2016). The Capo Rama formation, peritidal limestones change in their thickness towards east, due to the more incisive subaerial erosional caused by the Jurassic uplift. Thicknesse of bx, gs, mz and AMM is slightly exaggerated

Lithology and thickness: The unit includes several lithofacies arranged in shallowing upwards cycles of grey to white limestone and dolomitized limestone with algae and megalodontids, oncolites, gastropods and corals with intercalations of coralgal boundstone (patch reef Fig. 6 of Plate 10), laminated stromatolitic dolostone and loferitic limestone, loferitic breccias (Figs. 7 and 9 of Plate 10). Locally, there are intercalations of calcirudites and calcarenites with algae, coral, benthic foraminifers and mollusc fragments. Outcropping thickness reaches 500 m (Fig. 2.22). The greatest thickness variations are observed along the Gallo section (Mondello, Palermo) where thickness ranges from 0 and 250 m (Fig. 2.24, Basilone and Di Maggio 2016). In the peritidal succession of the Capo Rama section the following lithofacies, from the bottom of each peritidal cycle, are recognised:

(i) algae and megalodontids limestone (subtidal lithofacies) consisting of thick-bedded (50–150 cm in thickness) wackestone-packstone with large bivalves (*Megalodus* spp.), generally in life position, algae (mostly dasycladacean), gastropods, corals, ammonites, peloids (mostly fecal pellets), large oncoid nodules (where sand-sized particles consisting of bioclasts or intraclasts are coated by encrusting algae), benthic foraminifers and several paleokarst cavities filled by red and yellowish internal silt (Figs. 2, 3, 4 and 8 of Plate 10). The oncoid nodules and the large bivalve shells are diagnostic elements used to recognise this lithofacies (Fig. 5 of Plate 10). The mineralogical analysis detects the presence of calcite with a low content of magnesium, dolomite with scarce clay mineral content and few or the absence of quartz grains (Lo Cicero 1987). Among the diagenetic features, vadose pisoids larger than 2 mm are abundant (Fig. 3 of Plate 10), consisting of concentric siltitic laminae alternated with microsparite growing around intraclasts and bioclasts nucleus; also present are paleokarst dissolution cavities and caliche crusts produced by precipitation of calcite by meteoric waters. This lithofacies was deposited in a lagoon with moderate energy, where isolated patch reef developed. The tempestitic layers suggest that the back-reef lagoon was affected by occasional storm events, highlighting exchanges with the open sea.

(ii) Stromatolitic dolostone (infratidal lithofacies) consisting of 10–40 cm-thick stromatolitic laminated packstone (Fig. 9 of Plate 10, LLH type in Logan et al. 1964) alternated with thin rudstone-coarse grainstone with bioclasts and intraclasts (tempestites). Fenestral limestone with cavities (birds eyes) filled by sparry calcite and vadose silt. There was a tidal flat depositional environment, where sporadic storm events occurred.

(iii) Loferitic breccias (supratidal lithofacies) consisting of tabular beds (max 60 cm-thick) of coarse dolomitized breccias (rudstone-floatstone), whose elements, chaotically arranged and merged in a sand-sized calcareous matrix, are the product of the in situ erosion of the underlying lithofacies. The typical “tepee” antiform structures, due to fragmentations of the underlying partially lithified laminated stromatolites, are diagnostic characters (Fig. 9 of Plate 10). Intra-bioclastic grainstone with algal fragments, ammonites and hydrozoans represents the product of storm events. This lithofacies is the product of subaerial erosion of the partly lithified sediments forming in the tidal flat.

(iv) Black breccias consisting of dm-thick floatstone with blackish pebbly mudstone and angular elements merged in a fine-grained whitish matrix, showing nodular to brecciated fabric (Fig. 7 of Plate 10). This lithofacies is the product of the in situ erosion of the micritic mud formed in restricted lagoon or marsh areas populated by tropical vegetation (mangrove, see Bosellini 1991).

The Costa Ginestra limestone consists of magalodontid wackestone, algal bafflestone and coralgal boundstone organized in shallowing upwards cycles (Di Stefano et al. 1997a). Locally, grainstone with bioclasts and sub-rounded intraclasts and oolitic packstone-grainstone are interlayered (Carini section, Palermo Mountains). Total thicknesses are about 500 m. They outcrop along the northern side of Cozzo di Lupo (Torretta), at Monte Palmeto (Basilone 2000), in the eastern side of Monte Castellaccio (Tommaso Natale) and with a measured thickness of 40 m, along the sub-vertical bedded Addaura section (Pellegrino Mount, Palermo). In the Calampiso region (San Vito Lo Capo Mountains), the shallow-water limestone of the Capo Rama formation is crossed by several dykes, ENE-WSW oriented, filled by magmatic filonian rocks (diabase, Fig. 2.4, Catalano et al. 2011a). In adjacent sectors, ialoclastites and altered pillow lava also occur. Unpublished petrographic data allow us to classify these magmatic rocks as alkaline basalts rich in olivine (Ferla and Di Maggio, unpublished data). They are considered intraplate basalts related to the extensional phases that occurred during the Jurassic Southern

Tethyan rifting (Bellia et al. 1981), which formed during the Lower Jurassic (middle-upper Liassic), as suggested by the stratigraphic relationships with the Middle-Upper Jurassic ammonite limestone of the Buccheri Formation that drapes them

Paleontological content: The fossiliferous content of the formation consists of benthic foraminifers (*Alpinophragmium* sp., *Aeolisaccus* sp., *Aulotortus* sp., *Glomospira* sp., *Triasina* sp., *Galeanella* sp.), microproblematics (*Bacinella irregularis* Radoicic, *Lithocodium* sp., *Tubiphytes* sp.), corals [*Retiophillia paraclatrata* Roniewicz, *Astreomorpha confusa* (Winkler)], gastropods, bivalves (*Megalodus* cf. *gumbeli* Stoppani, *Megalodus* cf. *gemmellaroi* Di Stefano, *Dicerocardium* cf. *curioni* Stoppani), ammonites (*Rhabdoceras suessi* (Hauer), *Pinacoceras* sp., *Gladiscites cornatus* (Bronn), *Stenarcestes subumbilicatus* (Bronn), *Megaphyllites insectus* (Mojsisovic), *Placites* cf. *polydactylus* (Mojsisovic), *Aulacoceratides* sp.), echinoids (*Theelia seniradiata* Zankl), hydrozoans [*Heterastridium conglobatum* (Reuss)]. Algal content comprises Cyanoficean (*Cayuexia* sp., *Orthonella* sp., *Zonotrichites* sp.), Solenoporacean (*Solenopora styriaca* Flügel, *Parachetetes maslovi* Flügel) and rare dasycladacean (*Gyroporella vesiculifera* Gümbel, *Thaumotoporella parvovesiculifara* Raineri). In the Costa Ginestra limestone, dasycladacean algae (*Diplopora tubispora* Ott, *D. borzai* Bystricky, *D. adnetensis* Flügel, *Heteroporella macropora*, *H. micropora*, *H. zankli* Ott, *Teutloporella* cf. *T. echinata* Ott., *Aciculella* sp.) are abundant.

Chronostratigraphic attribution: On the basis of the paleontological content, the unit is comprised in the Norian-Sinemurian time interval. The occurrence of *Rhabdoceras suessi* (Upper Norian biozone) and *Heterastridium conglobatum* (Reuss) have permitted the dating of these deposits to the Norian-Rhaetian (Catalano et al. 1974a). Dasycladacean algae associations (*Diplopora tubispora* Ott, *Diplopora adnetensis* Flügel) can be compared with those recognised in the Upper Triassic shallow-water carbonates outcropping in the Alpine-Mediterranean region (Flügel 1981; Barattolo et al. 1993). The holothurian sclerites of *Theelia seniradiata* Zankl were recognised in the Upper Norian pelagites and in the Norian-Rhaetian backreef lagoon deposits of the *Dachstein* (Zankl 1966). The occurrence of *Involutina liassica* (Jones) and *Thaumatoporella parvovesiculifera* (Raineri) in the topmost beds, warrant us to refer the top of the unit to the lowermost Jurassic (Hettangian-Sinemurian).

Stratigraphic relationships: The lower boundary is a paraconformity with the dolostone of the Sciacca Formation. The upper boundary is a drowning unconformity where the Lower Jurassic crinoidal and brachiopods limestone and the Jurassic *Bositra* limestone (Buccheri Formation) rest with onlap stratal terminations. It may be, as observed in the Monte Gallo section, a subaerial erosional angular unconformity with both the Spinasanta bauxites—that rest with infilling geometries—and with the Upper Jurassic-Lower Cretaceous Pizzo Manolfo shallow-water limestone—that rests with onlap stratal terminations. A common characteristic of the topmost beds of the Capo Rama formation is the occurrence of a dense network of neptunian dykes filled by Pliensbachian and Bajocian pelagites (Vorös et al. 1986).

Depositional environment: Facies analysis of these shallow-water deposits suggests a protected lagoon depositional environment bordered by a large tidal flat that was cyclically emerged and eroded by subaerial processes in an overall warm tropical climate. The Costa Ginestra limestone is referred to the outer sector of the protected lagoon adjacent to the reef margin.

Regional aspects: The Capo Rama formation, a part of the Panormide Carbonate Platform succession, is widely outcropping in areas of northern Palermo Mountains, San Vito lo Capo Mountains (Monaco, Sparagio and Cofano sections) and in the eastern sector of the Madonie Mountains (Pizzo Carbonara section).

Carg abbreviation: RMF; Costa Ginestra limestone: RMF_a

*2.2.12 Cardellia Marls**

General remarks: This new lithostratigraphic unit was proposed by Catalano et al. (2010a) on the basis of the Monte Cardellia type section (Fig. 2.25, Basilone 2011a), located near the town of Corleone, whose biostratigraphic features were studied in detail by Biolzi (1985).

Synonyms and priority: These deposits were informally named "Oligocene clays" by Mascle (1979). Checchia Rispoli (1911a, b, c) has studied the paleontological content of the bioclastic limestone intercalations in various outcrops of western Sicily (Campofiorito, Corleone, Burgio, Palazzo Adriano sections), where these rocks are locally named "pietra frumentina" (Motta 1958).

Lithology and thickness: Brown to darkish-green clays, marls and sandy marls with abundant planktonic fossils (foraminifers and nannofossils), ferruginous nodules and glauconite (Fig. 1 of Plate 11). Upward, in the type section, quartz-glauconitic sandstone intercalations a few metres thick are present (Fig. 2.25 and Fig. 1 of Plate 11). Graded and laminated calcirudites and calcarenites (calciturbidites) with large benthic foraminifers (mostly *Lepidocyclina* sp.) and calcareous breccias with shallow-water derived elements, up to 1 m thick, are intercalated (RDE_a, Fig. 2 of Plate 11). Intercalations of volcanic rocks and alkaline basalts outcrop frequently in Western (Lago del Leone, Monte Rose sections) and Eastern (Judica and Scalpello sections, Fig. 1.1) Sicily. They were erroneously dated to the Eocene by Mascle (1964a) and Lucido et al. (1978) and then attributed to the Chattian by Montanari (1987). Total thickness ranges between 60 and 200 m. In the Bivona outcropping area (E Sicani Mountains), the marls are more calcareous and display a whitish colour (Bivona marls).

Paleontological content: Planktonic foraminifers [*Globorotalia opima opima* (Bolli), *Globorotalia ampliapertura* (Bolli), *Globorotalia ciperoensis* (Bolli), *Globorotalia angulisuturalis* (Bolli), *Globoquadrina praedehiscens* (Blow and Banner), *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia kugleri* (Bolli)], calcareous nannofossils [*Sphenolithus ciperoensis* (Bramlette and Wilcoxon), *Cyclicargolithus floridanus* (Bukry), *Zygrhablithus bijugatus* (Deflandre)]. Large benthic foraminifers (*Lepidocyclina* spp., *Nephrolepidina*

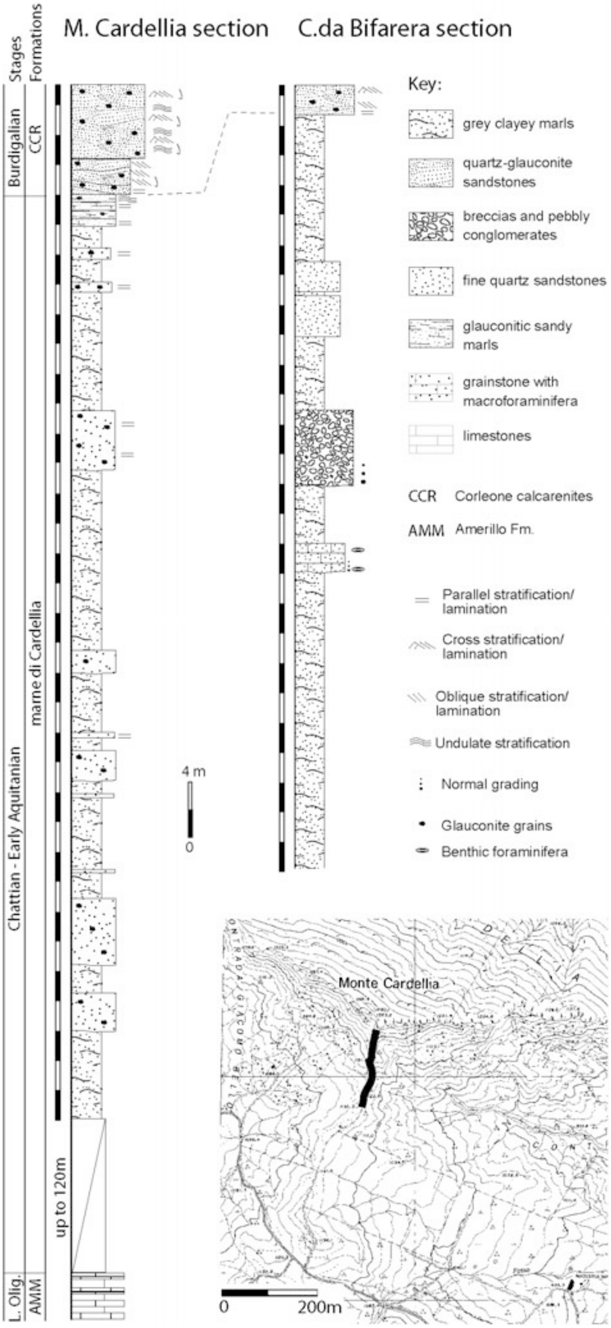


Fig. 2.25 Proposed type section of the Cardellia marls, measured and sampled along the Monte Cardellia type area (Corleone). On the right a support section, reconstructed along the Case Bifarera outcrop, north to Rocca Busambra (after Basilone 2011a)

spp.), algal nodules and shallow-water bioclasts are the main fossil content of the resedimented limestone.

Chronostratigraphic attribution: On the basis of the markers of calcareous nannofossils (*Sphenolithus distentus* and *Sphenolithus ciperoensis,* NP 24-25) and planktonic foraminifers (*Globorotalia opima opima, Globigerina ciperoensis* and *Globorotalia kugleri* that indicates the Oligocene-Miocene boundary) biozones, the unit is dated to the Chattian–Lower Aquitanian.

Stratigraphic relationships: The lower boundary is a paraconformity with the pelagic limestone of the Amerillo Formation. The upper boundary is a submarine erosional unconformity or a transitional contact with the Corleone glauconitic calcarenites.

Depositional environment: The lithological features and paleontological content suggest continental platform-to-slope depositional environments, where the hemipelagic marls sedimentation was intercalated by gravity processes (grain and debris flows) that reworked clastic (glauconitic-quartz sandstone) and carbonate (calcarenites with large benthic foraminifers) materials deriving from the dismantling and erosion both of the adjacent carbonate platform and the fluvial to deltaic system transporting siliceous materials.

Regional aspects: These deposits outcropping exclusively in the Sicani Mountains (W Sicily) and in the Judica and Scalpello Mountains (E Sicily) pertain to the Sicanian deep-water succession (Table 2.3).

Carg abbreviation: RDE

2.2.13 Carlentini Formation

General remarks: The unit comprises the volcanoclastic deposits in the Palagonia, Mineo and Vizzini villages (Hyblean Plateau, Fig. 1.1), first reported by Cristofolini (1969) and stratigraphically described by Di Grande (1969, 1972). The type section located around the Carlentini village was studied in depth by Grasso et al. (1979). Carbone and Lentini (1981) and Carbone et al. (2011) have detailed the facies characteristics and recognised the original emission craters.

Lithology and thickness: The unit is predominantly a thick volcanoclastic sequence, represented by polygenic breccias, cross-laminated fine-grained volcanoclastic and ash layers and subordinate basaltic lava flows. These flows, up to 20 m in thickness and with lenses geometry, are variously distributed along the section and display intercalations of ialoclastitic breccias locally. Two intervening carbonate horizons, consisting of coral and red algae (*Lithotamnium* sp.) boundstone (patch reefs) alternating with cross- to planar-laminated calcarenites with *Halimeda* sp., are present; lacustrine deposits represented by marly limestone and diatomites occur locally. Total outcropping thickness is 100 m. In the subsurface, they have been drilled up to 250 m.

Paleontological content: In the limestone beds, corals (*Porites* sp., *Tarbellastraea* sp., *Montastraea* sp. *Favites* sp.), algae and molluscs can be recognised.

Chronostratigraphic attribution: Tortonian

Stratigraphic relationships: The lower boundary is an unconformity surface with the Siracusa limestone member of the Monti Climiti Formation. The upper boundary is a sharp contact with the shallow-water limestone of the Monte Carrubba Formation.

Depositional environment: These deposits are believed to be the product of freato-magmatic eruptions in continental or in shallow-water conditions (Grasso et al. 1979).

Regional aspects: The paleoenvironmental reconstruction suggests that the formation was deposited around the SW margins of a low island or landmass lying to the north of the Hyblean region (Grasso et al. 1982) According to Grasso et al. (1983), lavas are normally magnetised and correlated with magnetic interval 7 (i.e., older than 7.27 Ma).

Carg abbreviation: FLT

2.2.14 Corleone Calcarenites°

General remarks: This unit was proposed by Ruggieri (1966) on the basis of the outcropping succession of the type area of the town of Corleone (Palermo). The Rocca dei Maschi type section (Figs. 2.26 and 2.27) was proposed by Basilone (2011a) on the basis of a detailed sedimentological and physical-stratigraphical study and on the biostratigraphic results obtained by Mascle (1979).

Lithology and thickness: cm- to dm-thick tabular greenish glauconitic calcarenites and calcirudites (rudstone to packstone-grainstone) alternate regularly with dark-greenish glauconitic clays, marls and silty-sands rich in large benthic foraminifers (mostly *Miogypsina* sp.), algae, echinoid spines and molluscs fragments (Figs. 5–7 of Plate 12). Bioturbation and planar to cross stratification and lamination (Figs. 1 and 2 of Plate 12) are the main sedimentary structures. Yellowish quartz-glauconitic sandstone intercalations and phosphate nodules occur locally (Ruggieri 1957). Measured thicknesses range between 30 and 80 m. Facies analysis has allowed two lithofacies associations to be identified (Lo Cicero and Pratini 1981): (i) sequences with erosive channels filled by calcarenites with wave and current sedimentary structures, including planar, concave-oblique and cross laminations (Figs. 1 and 3 of Plate 12); (ii) marl sequences rich in microcrystalline aggregates of glauconite. The unit outcropping in the Rocca Busambra, Maganoce and Cammarata sections consists of thin-bedded planktonic foraminifera-bearing limestone (Basilone 2009a, c, 2011a). This lithofacies is a grainstone with globigerinids, frequently abraded, with angular glauconite grains, some sand-sized quartz grains and a small quantity of bioclasts of shallow-water organisms (Figs. 4 and 8 of Plate 12).

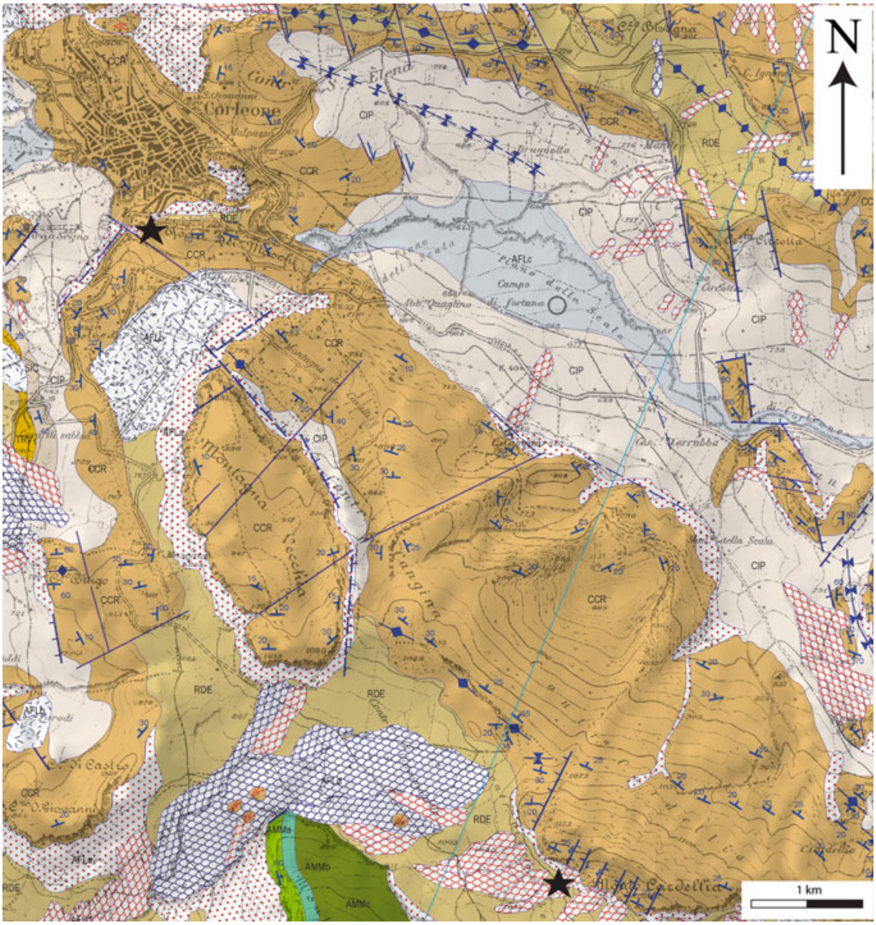


Fig. 2.26 Location of the proposed Rocca dei Maschi type section (black star immediately S of the town of Corleone) of the Corleone calcarenites (CCR, see Fig. 2.27), extracted from the Geological Map of Corleone-Rocca Busambra, performed by Basilone (2011a). The smaller black star at the bottom edge of the map indicate the location of the type section of the Cardellia marls

Paleontological content: A long list of fossils recovered from the clastic-carbonate lithologies is provided by Checchia Rispoli (1911a, b), Gemmellaro (1912), Lorenz and Mascle (1972). It comprises large benthic foraminifers [*Operculina complanata* (Deflandre), *Miogypsina* cf. *irregularis* (Michelotti), *M.* gr. *tani* (Drooger), *Nephrolepidina* cf. *burdigalensis* (Güembel), *N. tournoueri* (Lemoine and Douvillé)], *N. morgani* (Lemoine and Douvillé), fish tooth [*Carcharadon megalodon* (Agassiz), *C. auriculatus* (Blainville), *Odontapsis contortidens* (Agassiz), *Oxyrhina desori* Agassiz, *O. hastalis* Agassiz, *Chrysophrys cincta* (Agassiz)], bryozoans, echinoids, crinoids, pectinids, oysters, brachiopods (*Terebratula* sp.), balanids and algae. The pelitic intercalations are rich in

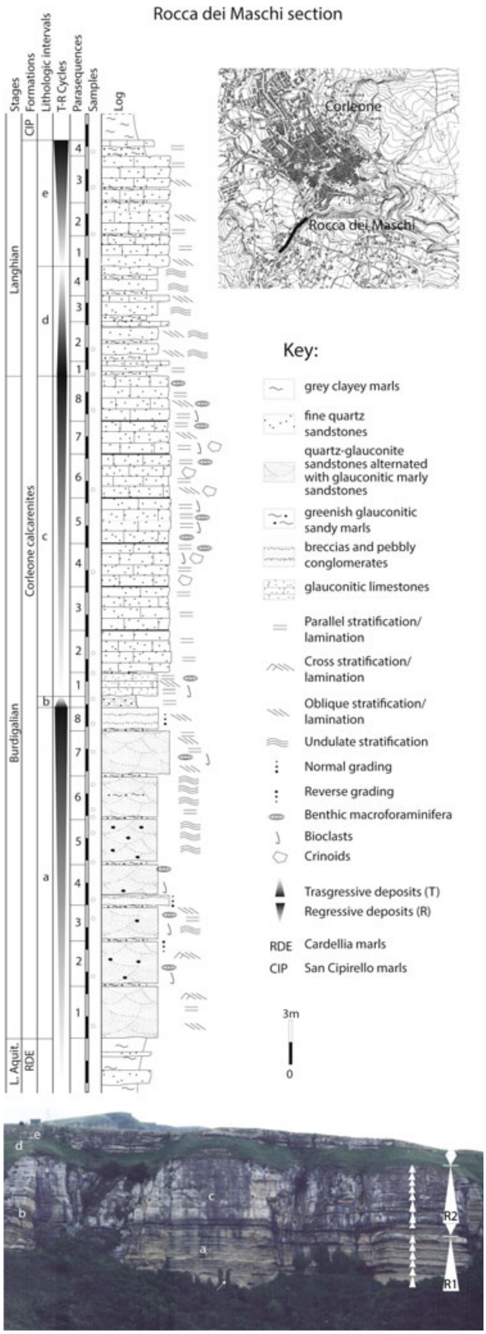


Fig. 2.27 The proposed type section of the Corleone calcarenites at Rocca dei Maschi, in the town of Corleone (PA); see Basilone (2011a) for details

planktonic foraminifers (*Praeorbulina glomerosa glomerosa* Blow, *Globoquadrina dehiscens* Chapman, *Catapsydrax dissimilis* Cushman and Bermudez, *Orbulina suturalis* Brönnimann, *Paragloborotalia siakensis* Roy, *Globigerina praebulloides* Blow) and calcareous nannofossils (*Helicophaera ampliaperta* Bramlette and Wilcoxon and *Sphenolithus heteromorphus* Deflandré).

Chronostratigraphic attribution: The large benthic foraminifers date these deposits to the Aquitanian–Burdigalian time interval. *Myogipsina* spp. allow the beds to be attributed to the Burdigalian. The markers of the *Globigerinoides trilobus, Praeorbulina glomerosa* s.l. and *Orbulina suturalis-Paragloborotalia peripheroronda* planktonic foraminifer biozones (Iaccarino 1985; Foresi et al. 2001) date these deposits to the Burdigalian–Langhian time interval and to the upper Aquitanian.

Stratigraphic relationships: The lower boundary is a sharp surface with submarine erosion and downlap relationships, with local transitional contact with the Cardellia marls (Sicanian succession). In the Trapanese successions, it is an unconformity—marked by discordance and long hiatus—with the pelagic limestone of the Amerillo Formation. The unconformity is frequently associated with breccias (Ruggieri 1957); these breccias, no more than 50 cm thick, consist of angular elements, deriving from the erosion of the underlying beds, welded in a yellowish sand with glauconitic and phosphate nodules and Fe–Mn crusts. Locally, this boundary is marked by buttress unconformity relationships with the faulted Lower Jurassic shallow-water limestone of the Inici Formation or with downlap terminations on the Jurassic and Cretaceous beds in the footwall faulted block (Basilone 2009a). The upper boundary is a sharp conformity surface with the San Cipirello marls.

Depositional environment: Coastal to shallow-water depositional environments are suggested by the abundant sedimentary structures. These have been interpreted as having formed in deltaic and beach paleoenvironments (Catalano and D'Argenio 1978; Lo Cicero and Pratini 1981). These deposits have been associated with a high-energy sand bar paleoenvironment, at depths from littoral up to 50–100 m due to the presence of phosphates and glauconite (Mascle 1979).

Regional aspects: The glauconitic calcarenites that pertain to both the Trapanese-Saccense and Sicanian successions (Tables 2.3 and 2.4), outcrop throughout Western Sicily, especially in the Sicani Mountains, in the Trapani and Castellamare del Golfo Mountains, along the Kumeta and Rocca Busambra ridges, where they outcrop with reduced thicknesses, from just a few to 40 m.

Carg abbreviation: CCR

*2.2.15 Cozzo di Lupo Formation**

General remarks: The formational unit was proposed in the frame of the geological maps of the Carg project by Catalano et al. (2013a), on the basis of the Cozzo di Lupo type section (Torretta, Palermo, Fig. 2.28) whose sedimentological and

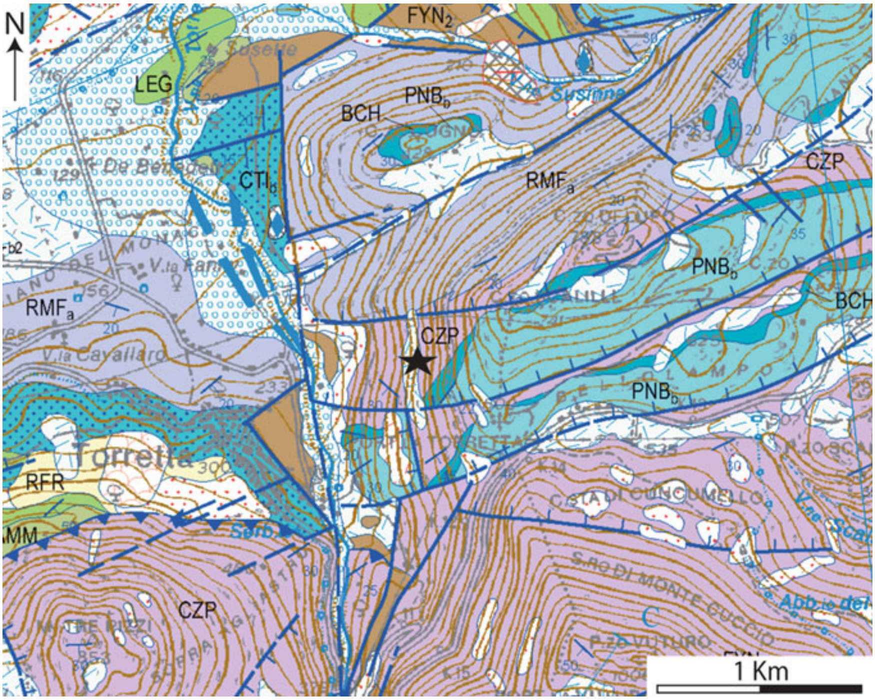


Fig. 2.28 Location of the type section of the Cozzo di Lupo formation (CZP). The map was extracted from the geological Sheet n. 585–594 "Partinico-Mondello" (1:50,000 scale map), performed by Catalano et al. (2013a)

paleontological features were described by Catalano and Abate (1974), Abate et al. (1977) and Di Stefano (1981). Supported sections are those outcropping at Cozzo Belliemi quarry (Bellolampo, Palermo), from which the ornamental "Belliemi limestone" is extracted, and at Cozzo Trigna (Piano Battaglia, Madonie Mountains).

Lithology and thickness: Grey massive spongid boundstone with algae, hydrozoans, benthic foraminifers, microproblematics, corals (Figs. 2, 3, 5–8 of Plate 13 and 2.29b) and intrareef cavities bordered by rim cements and filled by biocalcarenites and internal silt (Figs. 1, 2 and 4 of Plate 13, reef lithofacies) regularly alternated with bioclastic grainstone-packstone and reef-derived breccias (forereef lithofacies, Figs. 2.21b and 2.23). Outcropping thickness is 400–500 m in the type section, increasing to 700 m at Cozzo Trigna (Madonie Mountains). Frequently, the topmost portion of the unit is affected by paleokarst and a dense network of neptunian dykes that are filled by red pelagites with ammonites pertaining to the Buccheri Formation and by crinoidal calcarenites (Fig. 2.12).

Paleontological content: The rich fossil content, described by Abate et al. (1977), Di Stefano (1981), Senowbari-Daryan et al. (1982), Di Stefano and Senowbari-Daryan (1985), Senowbari-Daryan (1980), comprises calcareous sponges (*Amblysiphonella* sp., *Paravesicocaulis* sp., *Cryptocoelia* sp., *Panormida* sp.,

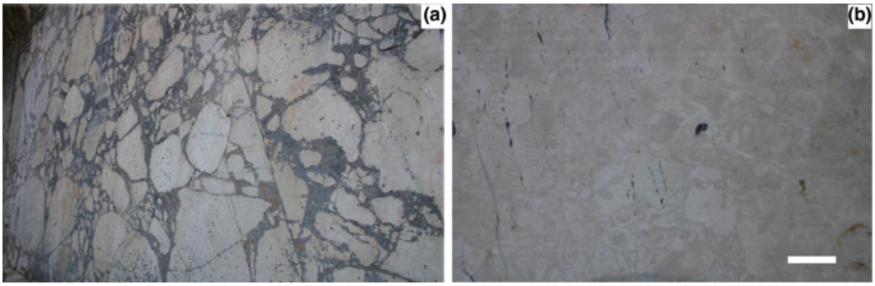


Fig. 2.29 **a** Quarry front, showing the brecciated structure of the Marabito limestones (Cave di Pietra, Pizzo Marabito, easternmost side of Rocca Busambra ridge); **b** close-up of picture **a**, showing the texture of the breccia elements, consisting of algae and spongid boundstone with intrareef cavities filled by calcitic cements (scale bar 1 cm)

Cheilosporites tirolensis Wähner) associated with "*Tabulozoans*", bryozoans, isolated (*Montlivaltia* sp.) and colonial (*Retiophyllia paraclathrata* Roniewicz, *Thamnastaria* sp.) corals, hydrozoans (*Disjectoporids* sp.), benthic foraminifers (*Pseudocucurbita* sp., *Galeanella panticae* Zaninetti and Brönnimann, *Siculocosta battagliensis* Senowbari-Daryan, *Foliotortus spinosus* Senowbari-Daryan, *Aeolisaccus* sp.), microproblematics (*Microtubus communis* Flügel, *Radiomura cautica* Schäfer and Senowbari-Daryan, *Baccanella floriformis* Pantic, *Lamellitubus cauticus* Ott, *Tubiphytes obscurus* Maslov), cyanoficean and rare dasycladacean algae [*Diplopora adnetensis* Flügel, *D. decastroi* Di Stefano and Senowbari-Daryan, *D. tubispora* Ott, *Heteroporella zankli* (Ott)].

Chronostratigraphic attribution: On the basis of the fossil content (mostly calcareous sponges and algae), the unit is dated to the Norian-Rhaetian time interval.

Stratigraphic relationships: The lower boundary is a paraconformity with the shallow-water dolomitized limestone of the Sciacca Formation and, more frequently, a tectonic contact (thrust) with the Cenozoic clays of the Numidian flysch. The upper boundary is an unconformity with both the Pliensbachian brachiopods limestone and the Jurassic red ammonite limestone of the Buccheri Formation. This boundary—marked by a sharp surface and onlap geometry—is morphologically recognised due to the different degree of erosion and textural features (massive versus thin-bedded stratification). The reef limestone of the Cozzo di Lupo formation displays lateral (heteropic) relationships with the back-reef lagoon deposits (Costa Ginestra limestone of the Capo Rama formation), as can be well observed along the northern side of the Cozzo di Lupo hill (Figs. 2.21b, 2.22, 2.23 and 2.28, see also Di Stefano et al. 1997a).

Depositional environment: Reef to fore-reef (Fig. 2.23).

Regional aspects: These deposits are included in the Panormide Carbonate Platform successions outcropping in the Palermo and Madonie Mountains (Table 2.5). Similar deposits have been mapped at Rocca Busambra (*Marabito limestone*, ITO, Basilone 2007, 2009a, 2011a), pertaining to the Trapanese succession, where the unit displays an overall brecciated texture in the topmost beds (in situ breccias, Fig. 2.29a). These deposits have been also mapped in the Pizzo Telegrafo region (Sciacca Mountains), where they are followed by the shallow-water limestone of the Inici Formation (Saccense succession, Di Stefano et al. 2013), and in Monte Genuardo (Contessa Entellina), where lateral (heteropic)-vertical relationships with the shallow-water dolomitized limestone of the Sciacca Formation are observable (Catalano and D'Argenio 1982a; Di Stefano et al. 1990).

Carg abbreviation: CZP

2.2.16 Crinoidal Limestone

General remarks: This unit refers to the calcarenites rich in crinoid fragments that characterise with variable thickness the lower portion of the Jurassic (middle-upper Liassic) Trapanese succession. The reduced thicknesses and lateral discontinuity of the unit does not justify its classification in the rank of formations, but it can be considered as a "marker bed" of the succession. The following description is based on the most representative section located at Kumeta ridge (Fig. 1.1) that was studied in its lithological, biostratigraphic and paleoenvironmental features by various Authors (Jenkyns and Torrens 1969; Abate et al. 1982a; Di Stefano P et al. 2002a; Santantonio 2002).

Lithology and thickness: Pinkish-white bioclastic calcarenites, mostly grainstone and more rarely packstone, with over 80% of crinoid plates and minor benthic foraminifers, *Thaumatoporella* sp. fragments, peloids and micritized grains (Figs. 5–8 of Plate 14). They display massive or lenticular stratification and low-angle cross-bedding. A diagnostic character is the presence of iron-manganese crusts both interlayered and capping the unit (Figs. 1–4 of Plate 14). Locally, these deposits fill erosive pockets and neptunian dykes affecting the fractured and faulted underlying shallow-water limestone of the Inici Formation (Figs. 9 and 10 of Plate 21). An interesting site to observe this dense network of neptunian dykes is that of Rocca Argenteria (Rocca Busambra), extensively studied by Wendt (1965, 1969, 2017). Maximum Outcropping thickness ranges between about 20 m (Kumeta section) and few metres to some decimetres (Busambra, Maranfusa, Montagna Grande and Inici sections, Fig. 1.1).

Paleontological content: Crinoids, ammonites, tooth shark, pelecipods, brachiopods [*Liospiriferina angolata* (Oppel), *Liospiriferina* cf. *darwin* (Gemmellaro), *Securina* cfr. *securiformis* (Gemmellaro), *Lignitiris esposta zitteli* (Gemmellaro)]. The fossil fauna and in particular the recognised various ammonite taxa are reported in Wendt (1963, 1964) and Santantonio (2002).

Chronostratigraphic attribution: Brachiopod fauna and stratigraphic relationships have permitted to date these deposits to the middle-upper Liassic (Gemmellaro 1886). On the basis of the mollusc fauna recognised in the Kumeta section, the unit is dated to the Upper Pliensbachian (Jenkyns and Torrens 1969);

ammonite faunal associations, collected in the neptunian dykes of Rocca Busambra, reveal an age extended up to the Lower Toarcian (Wendt 1963–1964).

Stratigraphic relationships: Lower boundary is a sharp, submarine erosive unconformity surface with the shallow-water limestone of the Inici Formation, where the crinoidal limestone lies with downlap stratal terminations (Kumeta section). Onlap stratal terminations occur above the Fe–Mn crust capping the top beds of the Inici Formation (Busambra section). The upper boundary is an unconformity surface with the lower member of the Buccheri Formation, generally marked by dm-thick Fe–Mn crust with pinnacle morphology and by onlap stratal terminations of the *Bositra* limestone.

Depositional environment: The deposits of the Kumeta section have been interpreted as mobile submarine dunes formed on carbonate seamounts (Jenkyns and Torrens 1969). An alternative model considers these limestone as deposits that take place on the uneven surface of a slope controlled both by tectonics and gravity (Di Stefano and Mindszenty 2000; Di Stefano P et al. 2002a). The erosive nature of the unconformity appears to be related to mechanical abrasion exerted by the movement of the crinoidal sands. Paleo-bathymetric data, based on the fluid inclusions analysis, suggests that the early cementation began at a depth between −20 and −100 m below sea level (Mallarino et al. 2002).

Regional aspects: These deposits, pertaining to the Trapanese and Saccense carbonate pelagic-platform succession, are well outcropping in the Kumeta and Rocca Busambra ridges (NW Sicily) and in the Trapani and Sciacca Mountains.

Carg abbreviation: RND

*2.2.17 Crinoidal Limestone and Altofonte Breccias**

General remarks: This unit includes calcarenites rich in crinoid articles and plates that characterise with variable thickness the lower portion of the Jurassic (middle-upper Liassic) Imerese succession. The reduced thicknesses and lateral discontinuity of the unit do not warrant its classification in the rank of formations, but it can be considered as a "marker bed" of the succession. The unit consists of two main subunits: the crinoidal limestone, defined on the basis of the Termini Imerese type section (Basilone 2000, Fig. 1 of Plate 15), and the Altofonte breccias described from the proposed Cozzo di Castro-Altofonte type section (Fig. 2.30, Catalano et al. 2013a, b).

Synonyms and priority: These beds have been described as "Entrochi limestone" (Baldacci 1886), "*Leptaena* beds" (Gemmellaro 1886) and were considered part of the Crisanti Formation (Schmidt di Friedberg 1964–1965).

Lithology and thickness: The crinoidal limestone consists of thick-bedded (dm to m) grey bioclastic and pseudo-oolitic planar laminated grainstone with tabular geometry alternating regularly with thin encrinitic marls (Fig. 1 of Plate 15). The fine and well-rounded arenaceous grains are, mainly, recrystallized bioclasts, micritized grains, crinoid articles and plates, algal fragments (Figs. 3–8 of Plate 15);

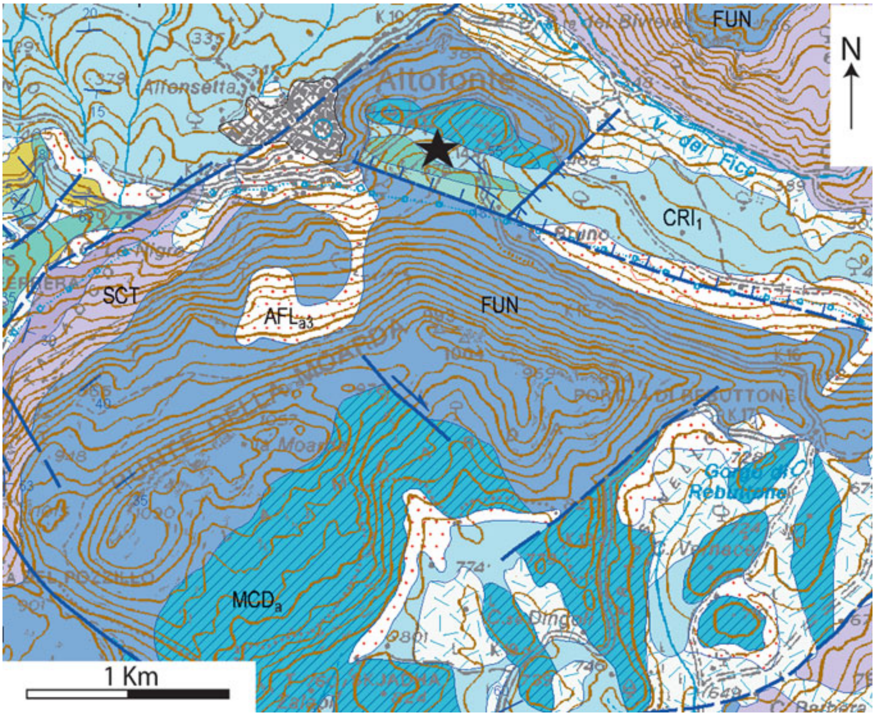


Fig. 2.30 Location of the proposed type section of the Altofonte breccias (MCDa). The map was extracted from the geological Sheet n. 585–594 “Partinico-Mondello” (1:50,000 map scale), performed by Catalano et al. (2013a)

the yellow, green and reddish marls, 10–15 cm-thick, contain bioclasts and reworked quartz grains. Red and blackish marls 80–150 cm thick followed by coarse calcarenites rich in crinoid fragment and fine breccias in metre-thick beds characterise the Cozzo Famo section (Termini Imerese Mountains, Basilone 2009b). Outcropping thickness of the crinoidal limestone subunit ranges between 5 and 15 m. 20–30 m of white calcilutites with chert nodules and bedded cherts alternating with thin greenish marls with *Lenticulina varians* (Bornemann), *Nodosaria fontinensis* (Berthelin), *Dentalina mucronata* Neugeboren characterise the upper portion of the unit outcropping in the Monte dei Cervi and Sclafani Bagni sections (Madonie Mountains, Broquet 1968). The Altofonte breccias (MCD_a) are calcareous grain-supported massive breccias whose elements consist of shallow-water carbonate fragments with sponges, algae and corals derived from the dismantling and erosion of the Upper Triassic carbonate platform reef margin (Fig. 2 of Plate 15). Upwards, biocalcarenites with chert nodules, graded and planar to cross laminated calcarenites (calciturbidites) and thin calcilutites and marls alternate with thick calcareous breccias showing channelized geometries (Fig. 2.31). The thickness of this subunit ranges between 35 and 80 m and has a

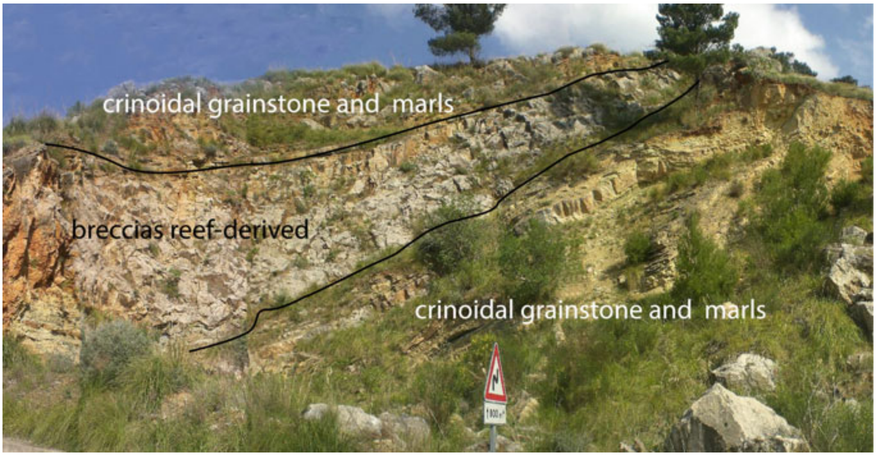


Fig. 2.31 Channallized geometry of the Lower Jurassic Altofonte calcareous breccias, consisting of shallow-water and reef derived fragments and bioclasts, interlayered within the thin-bedded crinoidal calcarenites and marls (Gibilrossa, Palermo Mountains)

lateral extension of several kilometres (Santa Cristina Gela and Piana degli Albanesi sections, Palermo Mountains).

Paleontological content: Crinoids (*Pentacrinus* sp.), benthic foraminifers (*Lingulina tenera* Bornemann), bivalve fragments, brachiopods (*Leptaena* spp.), cyanoficean algae (*Cayeuxia* sp.), radiolarians, *Aptychus* and echinoid spines.

Chronostratigraphic attribution: On the basis of the brachiopods and crinoids content, Gemmellaro (1886) and Di Stefano (1900b) have dated the first metres of the "scisti silicei" (i.e., the radiolarite member of the Crisanti formation) to the Lower Jurassic (middle-upper Liassic). The calcareous nannofossils of the NJT4a and NJT5a subzone and the dinoflagellates (*Nannoceratopsis* and *Mendicodinium* genus) justify dating the Altofonte breccias to the Upper Sinemurian–Lower Toarcian (Bartolini et al. 2002).

Stratigraphic relationships: The lower boundary is a sharp unconformity surface —marked by onlap (4°–6°)—with the dolostone of the Fanusi Formation (Termini Imerese section). It can be considered an erosional surface with angular discordance (Gibilrossa section, Palermo Mountains), where the crinoidal grainstone rests in downlap with channelized geometry. The upper boundary is an unconformity surface showing onlap geometry or a paraconformity with the radiolarites member of the Crisanti formation.

Depositional environment: These deposits are the product of the resedimentation of materials dismantled from a carbonate platform margin (e.g., Panormide carbonate platform) that were reworked along the slope and deposited at the base of slope (Imerese domain) by gravity flows, including grain flows (crinoidal limestone), turbiditic currents and debris flows (Altofonte breccias).

Regional aspects: This unit is a guide level useful for large-scale correlations. It outcrops in the Termini Imerese (Termini Imerese, Cozzo Famo, Rocca di Mezzogiorno-Monte San Calogero sections), Madonie (Sclafani Bagni, Monte dei Cervi sections) and Trabia (Monte S. Onofrio-Pizzo Cane, Angelia sections) Mountains, from which the several supported sections derived (Montanari 1966; Basilone 2009b; Basilone and Lo Cicero 2002). The Altofonte breccias commonly outcrop in the Palermo Mountains, and they have been mapped in the Belmonte Mezzagno-Gibilrossa and Piana degli Albanesi-Santa Cristina regions (Catalano et al. 2013a, b).

Carg abbreviation: MCD

2.2.18 Crisanti Formation°

General remarks: The unit was described by Schmidt di Friedberg et al. (1960) on the basis of the proposed type section, located in the southern side of Monte Cervi (Fig. 2.32, Madonie Mountains). The unit is here amended on the basis of the study of the Rocca di Mezzogiorno (Basilone 2000, Figs. 2.33, 2.34 and 2.35) and

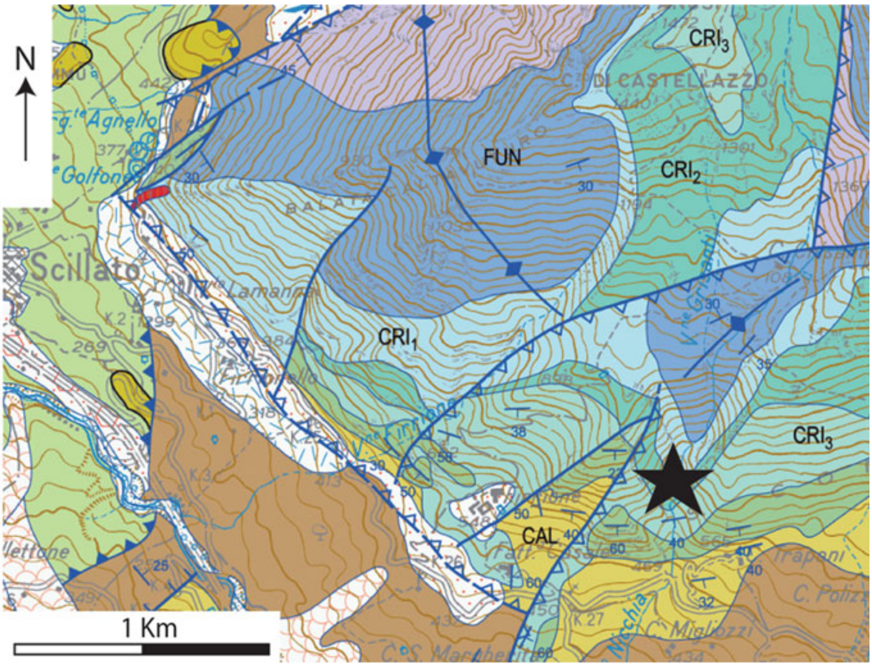


Fig. 2.32 Location of the original type section of the Crisanti formation (CRI) at Vallone Crisanti, Monte dei Cervi (Madonie Mountains). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

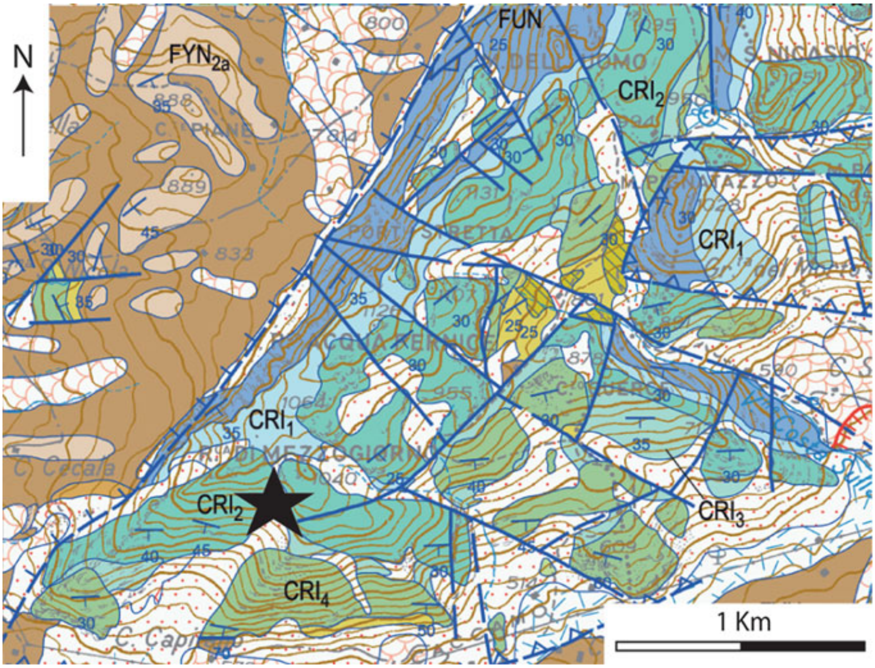


Fig. 2.33 Location of the amended paratype section (see Figs. 2.34, 2.35) of the Crisanti formation (CRI) at Rocca di Mezzogiorno, Monte San Calogero (Termini Imerese Mountains). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

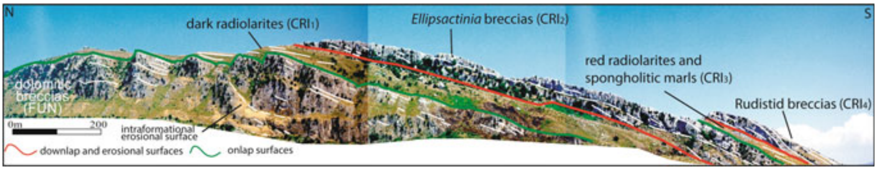


Fig. 2.34 Physical-stratigraphic relationships of the Jurassic-Cretaceous Imerese succession (western flank of Rocca di Mezzogiorno, Termini Imerese Mountains, after Basilone 2009b)

Sclafani Bagni (Fig. 2.36) paratype sections, where the formation has been subdivided in four members, distinguishing the pelagic siliceous limestone with radiolarians, radiolarites and bedded cherts, clays and siliceous clayey marls (radiolarites and spongolithic marl members) from the intercalated levels of resedimented clastic-carbonates (*Ellipsactinia* breccia and rudistid breccia members) deriving from the dismantling and erosion of shallow-water limestone (Figs. 2.37, 2.34 and 2.35). The large outcropping thickness of the members and their correlation at regional scale support their formalization (Fig. 2.18).

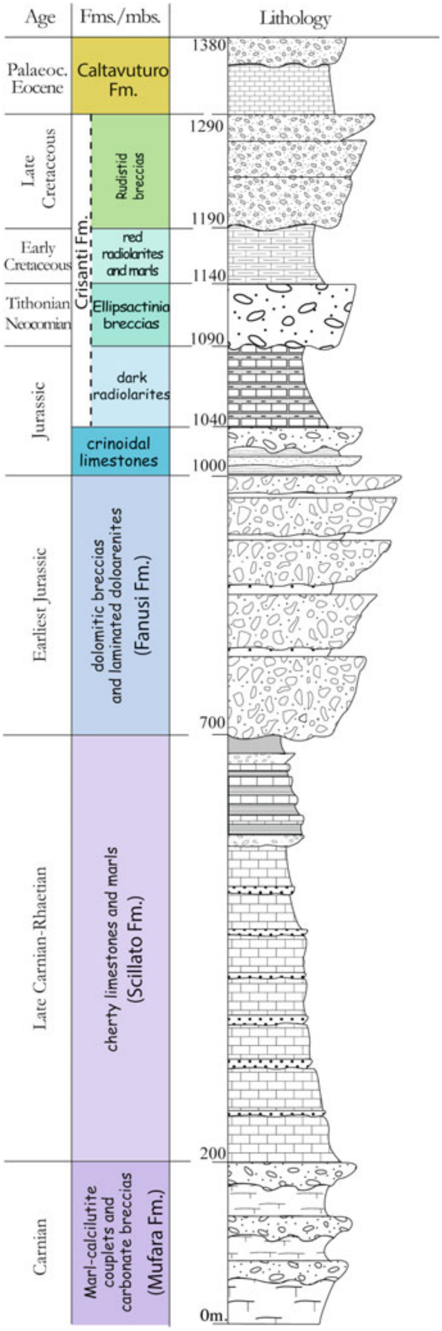


Fig. 2.35 Stratigraphic column of the Monte San Calogero-Rocca di Mezzogiorno composite section (after Basilone 2009b)

Synonyms and priority: The deposits of the lower portion of the succession are historically known as "scisti silicei" (Gemmellaro 1882; Baldacci 1886; Di Stefano 1900b). The formation was referred to as "Monte dei Cervi and Mandria del Conte formations" by Ceretti and Ciabatti (1965) who used these terms to identify the pelagic lithologies and the interbedded carbonate levels, respectively. Previous subdivisions of the formation into different subunits (Fig. 2.37) were attempted by Broquet (1968), who differentiated only the "Cenomanian" level (i.e., here called Rudistid breccias). The Author, in agreement with Ogniben (1960), believed it to be formed in shallow-water environment and resting above the underlying rocks through a transgression surface. Lentini and Vezzani (1974) and Abate et al. (1988a) mapped these deposits and distinguished two main lithologies—the radiolarites and the resedimented carbonates—without suggesting any subdivision or detailing the age of the differentiated deposits. In the geological map of the Madonie Mountains by Grasso et al. (1978), the Jurassic "radiolarite" and the Cretaceous "spongolithes" (see also Montanari 1966) are separated by the "Calcirudites with *Ellipsactinia*".

Lithology and thickness: On the basis of the new classification (Table 2.2), the unit consists of:

Radiolarites member: Thin-bedded black and locally reddish to whitish planar laminated and bioturbated radiolarites with iron-manganese oxides and bedded cherts, siliceous mudstone rich in radiolarians and sponge spiculae, regularly alternated with brownish mudshales and siliceous claystones (Figs. 1 and 2 of Plate 16). Thickness, 50 m in average, ranging between 30 and 140 m. Laminations are the product of planar alignment of radiolarian shells (Figs. 3 and 4 of Plate 16) caused by bottom currents (e.g., dilute turbidites). Several vertical burrows, occurring at the top of the beds, have caused the destruction of the laminae. Grey-greenish vacuolar basalts (pillow lava) are frequently interlayered, as is observable along the Vallone Crisanti type section and Sorgente Golfone (Madonie Mountains). These volcanic rocks have been compared and correlated by Fabiani and Ruiz (1932b) with the Bajocian tuffaceous levels outcropping at Roccapalumba (Trapanese succession).

Paleontological content: Sponge spiculae, radiolarians, benthic foraminifers (*Aeolisaccus* sp., *Trocholina* sp.), algae (*Thaumatoporella* sp.), crinoid fragments, pelagic pelecypods (*Bositra* sp.).

Chronostratigraphic attribution: Fossils here are generally poorly preserved and the lack of specific biostratigraphic studies based on radiolarian distribution do not permit the precise dating of the unit, which is therefore dated primarily on the basis of its stratigraphic position. It is dated to the Toarcian-Upper Jurassic (lower Tithonian?) time interval (see also Jacobacci 1954).

Stratigraphic relationships: The radiolarites member is easily recognisable in the field, as it displays flattened morphologies comprised between hardened rocks, corresponding to the Lower Jurassic dolostone of the Fanusi formation and the Upper Jurassic *Ellipsactinia* breccias member (Figs. 2.34 and 2.36). The lower boundary is an unconformity surface with the crinoidal limestone or directly with the Fanusi formation, where the radiolarites rest with onlap stratal terminations. The

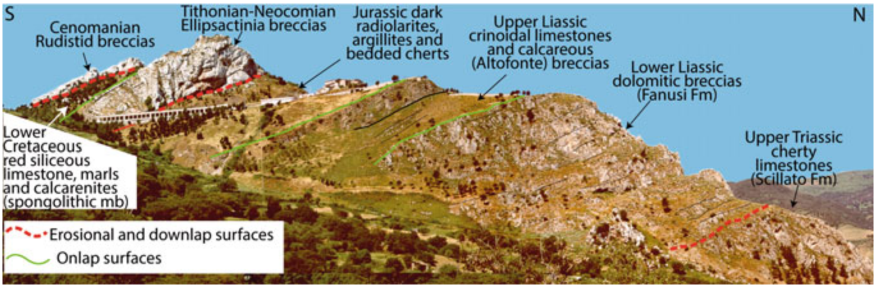


Fig. 2.36 Rocca di Sclafani Bagni natural section showing the Mesozoic formational units of the Imerese deep-water carbonate succession and their stratigraphic relationships

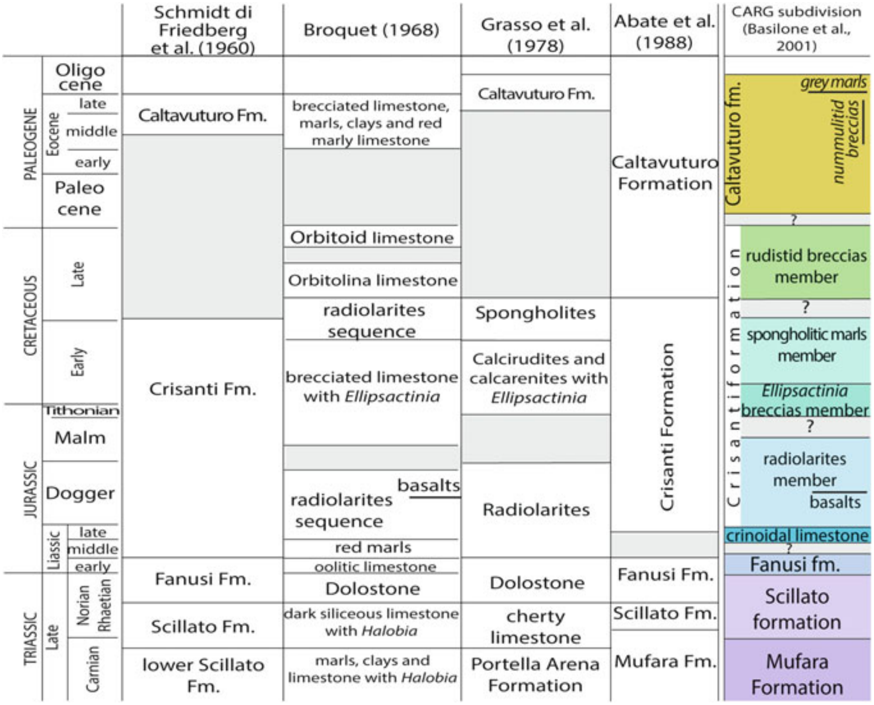


Fig. 2.37 Comparative scheme of the terminology used for the lithostratigraphic classification of the Mesozoic-Paleogene Imerese deep-water carbonate succession

stratigraphic contact is highlighted by morphological and colour changes (black radiolarites versus white dolostone). This boundary is, locally, represented by an unconformity—marked by a dm-thick Fe–Mn blackish crust (hardground) high-lighting sediment starvation and long hiatus with the cherty limestone of the Scillato Formation. On this surface, the radiolarite member rests with onlap stratal terminations (Chiarastella section, Trabia Mountains). The upper boundary of the unit is a sharp uneven submarine erosional surface marked by erosional truncations, where the *Ellipsactinia* breccias rest with channelized geometry and downlap stratal terminations.

Depositional environment: Deep-water environment with paleobathymetry over 400 m, where the pelagic sedimentation was influenced by gravity-induced flows producing both large slumping phenomena (Fig. 2 of Plate 16) and diluted turbidite currents (planar laminations of the radiolarite beds). McBride and Folk (1979) also speculated that the radiolarites could have been deposited in an tidal flat environment.

Carg abbreviation: CRI_1

Ellipsactinia breccias member: Conglomerate calcareous breccias and calcarenites with carbonate platform margin-derived elements and with a small percentage of reworked angular elements of radiolarites and chert deriving from erosion of the underlying lithologies of the radiolarites member. Thickness 50 m on average. Two main facies associations are recognisable: (i) massive mud-supported coarse conglomerates 25–30 m thick, followed by one or two tabular beds 50–80 cm-thick of oolitic calcarenites (Cozzo Famo, Termini Imerese and Sclafani Bagni sections, Fig. 2 of Plate 17). In the middle portion of the conglomerates' body, laminated green marls a few metres thick with lenticular geometry are intercalated; (ii) decametric thick-bedded calcirudites regularly alternated with decimetric thin-bedded coarse to fine well-sorted calcarenites rich in crinoid articles characterised locally by the occurrence of cherty nodules (Rocca di Mezzogiorno section, Termini Imerese Mountains, Fig. 2.34 and Fig. 5 of Plate 17).

Paleontological content: The breccia elements mainly consist of shallow-water-derived fragments with several reef fossils (Figs. 3, 4, 6–9 of Plate 17) including *Ellipsactinia* sp., colonial and isolated corals, molluscs, cyanoficean (*Clypeina jurassica* Favre) and dasycladacean (*Pseudocymopolia* sp., *Cylindroporella* sp., *Neomeris* sp.) algae, benthic foraminifers (*Charentia* sp., *Protopeneroplis* sp., *Trocholina alpina* Leupold, *Trocholina elongata* Leupold), microproblematics (*Lithocodium aggregatum* Elliott, *Bacinella irregularis* Radoicic, *Shamovella obscura* (Maslov), *Tubiphytes morronensis* (Crescenti), *Stomiosphaera moluccana* Warner). Locally, calpionellids are found in the pelagic matrix of the breccias.

Chronostratigraphic attribution: On the basis of the stratigraphic position and the fossil content, this member is dated to the Upper Tithonian-Neocomian time interval (Montanari 1966; Broquet 1968; Catalano et al. 2011b).

Stratigraphic relationships: The lower boundary is a submarine erosional unconformity—marked by downlap stratal terminations—with the underlying truncated beds of the radiolarites member (Fig. 1 of Plate 17 and Figs. 2.44 and 2.36). The upper boundary is an unconformity surface that frequently displays thin iron-manganese crusts (hardground) indicating sediment starvation and marked by onlap stratal terminations of the overlying pelagic deposits of the spongolithic marls member.

Depositional environment: The *Ellipsactinia* breccias are considered as reworked material resedimented in the marginal sector of a deep-water basin (Scandone et al. 1972; Abate et al. 1982b). Sedimentological study has suggested that the resedimented materials were transported along an erosional channel and deposited at the base of slope through debris flow (i.e., the conglomerate lithofacies), turbidite currents (i.e., the breccias and calcarenites lithofacies) and grain flow (i.e., the oolite calcarenites lithofacies) processes (Basilone 2000; Basilone and Lo Cicero 2002).

Carg abbreviation: CRI_2

Spongolithic marls member: Reddish, pinkish and greenish thin-bedded radiolarites and siliceous mudstone with radiolarians, planktonic foraminifers and sponge spiculae regularly alternated with planar laminated calcareous marls, siliceous claystone with sponge spicules and quartz grains (Figs. 5 and 7 of Plate 16). Thin- to thick-bedded (10–25 cm) laminated calcarenites and graded calcirudites with lenses and pinch-out geometry are intercalated in the upper portion of the succession (Fig. 6 of Plate 16). The resedimented beds consist of shallow-water derived elements, including orbitolinids, requienid fragments, gastropods and calcareous algae (Fig. 8 of Plate 16). Total thickness ranges from 0 m (Termini Imerese section), 5 m (Cozzo Famo section), up to 50 m (Rocca di Mezzogiorno and Sclafani Bagni sections). Locally, a 15–20 m-thick resedimented body, consisting of thick-bedded fossiliferous calcarenites dated on the basis of the occurrence of *Orbitolina paronai* (Prever) and *Orbitolina conoidea* (Gras) to the Barremian-Aptian (Montanari 1966), is intercalated in the upper portion of the pelagic succession (CRI_{3a}, Pizzo Cane section, Trabia Mountains).

Paleontological content: In the lower portion of the succession, Montanari (1966) recognised *Ticinella primula,* Luterbacher, *Gyroidinoides* cf. *multisepta* (Brotzen), *Thurammina* cf. *porosa* (Egger). Upwards, in the marly lithologies, *Dorothia gradata* (Berthelin), *D. filiformis* (Reuss), *D. oxycona* (Reuss), *Lenticulina subalata* (Reuss), *Marginulina planiscula* (Reuss), *M. complanata* (Reuss), *Saracenaria* aff. *forticosta* (Bartenstein), *Dentalina cylindroides* (Reuss) occur.

Chronostratigraphic attribution: On the basis of the fossil content, these deposits are dated to the Lower Cretaceous (Barremian-Albian).

Stratigraphic relationships: The lower boundary is an unconformity with onlap stratal terminations with the *Ellipsactinia* breccias (CRI_2, Figs. 2.34 and 2.36). The upper boundary is a submarine erosional truncation with the Rudistid breccias member (CRI_4) or a paraconformity with the pelagic marly limestone of the Caltavuturo formation, as can be clearly observed in the outcropping sections of the Palermo Mountains.

Depositional environment: Pelagic sedimentation in a deep-water basin interested by the occurrence of resedimented materials deriving from the erosion of shallow-water deposits (e.g., grainstone with benthic foraminifers and rudistid fragments) and deposited through grain flow processes (Basilone 2009b).

Carg abbreviation: CRI_3

Rudistid breccias member: Thick-bedded calcareous breccias, graded calcirudites and laminated calcarenites with shallow-water derived elements (Figs. 1 and 2 of Plate 18), including large rudistid fragments, *Orbitolina* sp., crinoid articles, *Inoceramus* fragments, calcareous algae, corals (Figs. 3–6 of Plate 18) and rare planktonic foraminifers [*Rotalipora appenninica* (Renz)]. These beds are cyclically alternated with centimetric-decimetric levels of grey-greenish marls rich in pyrite. Total thickness ranges between 20 and 80 m. In the resedimented beds turbiditic sedimentary structures are recognisable with the whole Bouma sequence, comprised in a single bed not more than 1 m-thick. Planar laminated pseudo-oolite calcarenites also occur in the upper portion of the turbiditic beds. Locally, a 2 m-thick polygenic conglomerate with dolomitized limestone and silicified limestone elements and with fragments of volcanic rocks occurs at the base of the succession (Cozzo Famo section, Termini Imerese Mountains). A 20 m-thick layer of grey to darkish thin- to thick-bedded graded and laminated bioclastic calcarenites (Figs. 7 and 8 of Plate 18) with benthic foraminifers (*Orbitoides media* (D'Archiach), *Siderolites* cf. *calcitrapoides* Lamarck) and regularly alternated with yellow to green marls with planktonic foraminifers showing pseudo-nodular texture and flaser geometry, locally follow upwards (*Orbitoid limestone*, Termini Imerese section, Rangin 1973, 1975; Basilone 2000).

Paleontological content—Chronostratigraphic attribution: Based on the occurrence of benthic [*Orbitolina* cf. *conica* (D'Archiac), *Orbitolina trochus* (Fritsch), *Orbitolina texana* (Renz)] and planktonic (*Rotalipora appenninica* (Renz), *Globigerinelloides breggiensis* (Gandolfi) and *Globotruncana* spp.) foraminifers, these deposits are dated to the Upper Cretaceous, mostly Cenomanian (Montanari 1966). The uppermost *Orbitoid limestone* contains *Orbitoides media* (D'Archiach), *Siderolites* cf. *calcitrapoides* Lamarck and *Globotruncana* spp. in the interlayered green marls are dated to the Campanian-Maastrichtian time interval.

Stratigraphic relationships: The lower boundary is a submarine erosional surface—marked by downlap stratal terminations—with the spongolithic member (CRI_3, Figs. 2.34 and 2.36); the upper boundary is an unconformity with the marly limestone of the Caltavuturo Formation that rests in onlap marking a long hiatus.

Depositional environment: The calcareous succession appears as a turbiditic system, characterised by erosional features, internal discordance, progradational geometries, planar and cross laminations (turbiditic fan, Basilone and Lo Cicero 2002). The reworked material, deriving from the erosion of the shallow-water deposits of the Pellegrino formation, was deposited at the base of slope.

Carg abbreviation: CRI_4

Chronostratigraphic attribution: On the whole, the formation is dated to the Lower Jurassic (Upper Toarcian)–Upper Cretaceous time interval.

Regional aspects: The unit, exclusively inserted in the Imerese deep-water succession, outcrops principally in the NW Sicily FTB, from the Madonie to the Palermo Mountains, through the Termini Imerese and Trabia Mountains. It also outcrops in the easternmost Sicanian Mountains, at La Montagnola (Broquet 1964; Basilone et al. 2011, 2014b).

Carg abbreviation: CRI

2.2.19 *Fanusi Formation°*

General remarks: The unit was proposed by Schmidt di Friedberg et al. (1960) on the basis of the study of the type section, located along the western side of Monte Fanusi (Madonie Mountains, Fig. 2.38), where massive and poorly stratified dolostone outcrops. The unit is here amended on the basis of the different lithological content and types of stratigraphic boundaries recognised from the several sections studied in the Termini Imerese Mountains (Figs. 2.35 and 2.39, Basilone 2000, 2009b).

Lithology and thickness: White to grey thick-bedded (from a few metres to some tens of metres) dolomitized breccias and dolorudites (rudstone-floatstone, Fig. 2 of Plate 19), cyclically alternated with thin-bedded (cm-dm) graded and laminated coarse to fine doloarenites and dolosiltites (Figs. 4 and 7 of Plate 19). Locally, yellowish and grey-greenish dolomitized marls in cm to dm beds are interlayered in the upper portion of the succession (Termini Imerese section, Fig. 5 of Plate 19). Vacuolar and porous massive dolostone (Fig. 6 of Plate 19) is widespread in the southern Palermo Mountains outcrops. The resedimented deposits display progradational geometries with clinostratifications, internal submarine erosional surfaces (Fig. 3 of Plate 19 and Fig. 2.34) and a regressive facies trend (Basilone 2000,

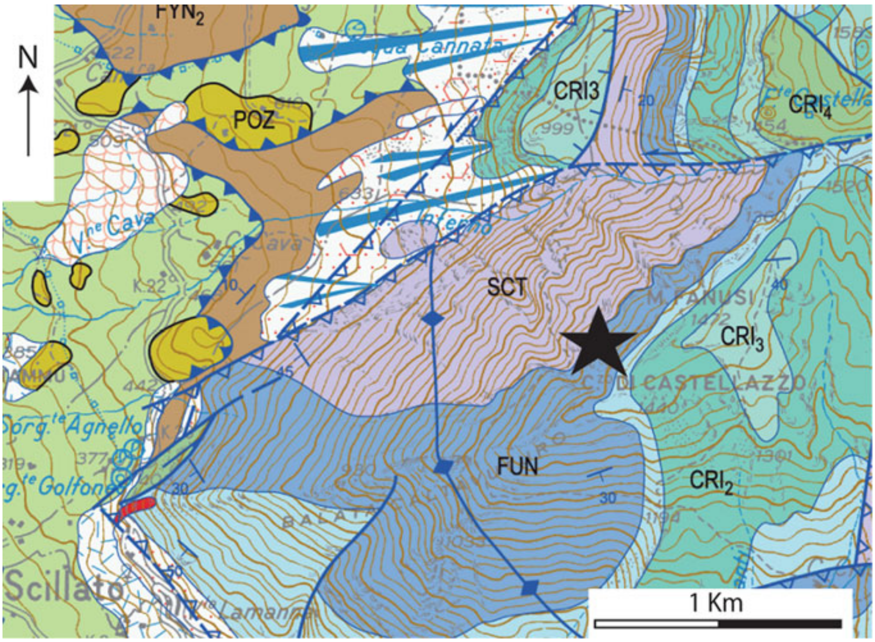


Fig. 2.38 Location of the original type section of the Fanusi formation (FUN). The map was extracted from geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

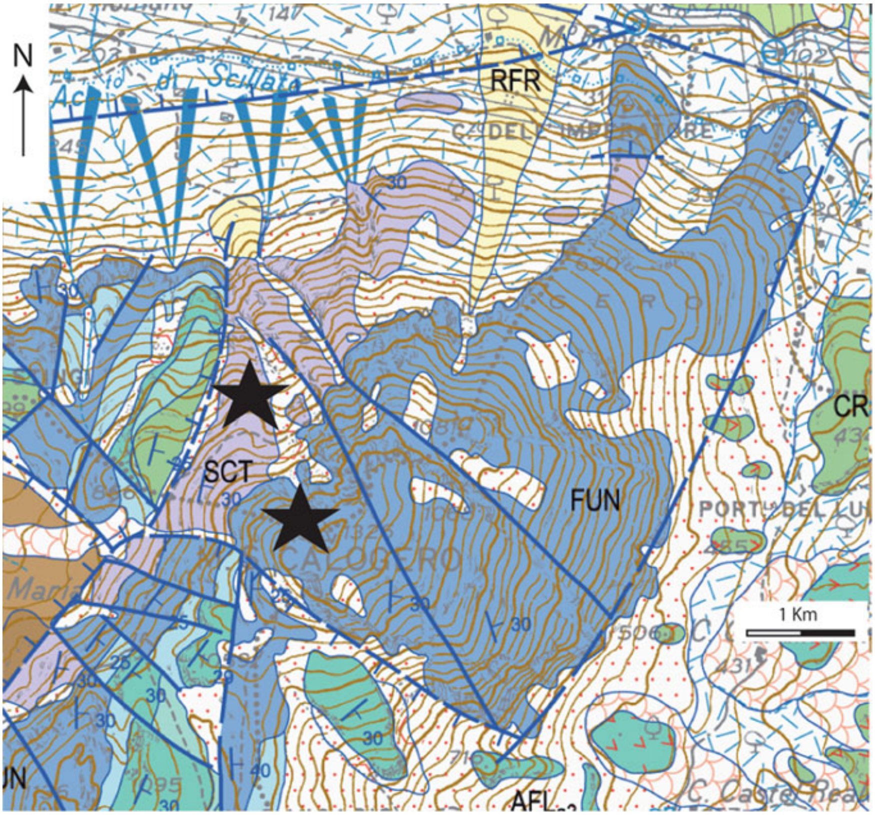


Fig. 2.39 Location of the paratype section (see Fig. 2.35) of the amended Scillato (SCT) and Fanusi (FUN) formations. The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

2009b). Petrographic and isotopic (oxygen and carbon) analysis has highlighted a marine origin of the dolomitization processes (Roure et al. 2002). Outcropping thickness ranges between 300 and 250 m (Fig. 2.35). Locally, the unit does not outcrop and is substituted by a cm-thick Fe–Mn crust (Chiarastella section, Trabia Mountains).

Paleontological content: The strong dolomitization of these rocks has not preserved much fossil content. Gemmellaro (1904) has recognised *Daonella lepsiusi* Gemmellaro, *Rhinconella pedata* (Bronn), *Spirigera oxycolpos* (Rumerich). *Nullipora* fragments and undeterminable bioclasts are reported by Montanari (1966).

Chronostratigraphic attribution: On the basis of its stratigraphic position, the unit is dated to the Lowermost Jurassic (Lower Liassic). It is comprised between the Upper Triassic pelagic cherty limestone of the Scillato Formation and the Pliensbachian-Toarcian crinoidal limestone and Altofonte breccias.

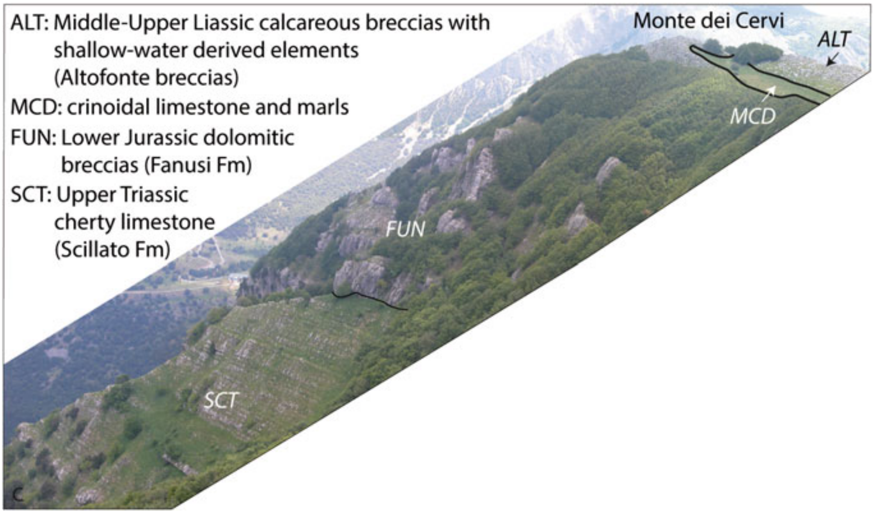


Fig. 2.40 Monte dei Cervi natural section (for location see Fig. 2.38) showing the erosional unconformity lower boundary of the Fanusi formation (FUN) with the underlying cherty limestone of the Scillato formation (SCT) and the upper unconformity boundary with the crinoidal limestone (MCD) and the breccias of Altofonte (ALT)

Stratigraphic relationships: The lower boundary is an erosional unconformity surface—marked by downlap stratal terminations with angulation ranging from 5° to 8° (Fig. 1 of Plate 19 and Fig. 2.40) and channelized geometries—with the cherty limestone of the Scillato formation. The upper boundary is an unconformity surface—marked by onlap stratal terminations—with the radiolarites member of the Crisanti Formation (Fig. 2.34) or with the Crinoidal limestone and Altofonte breccias (Fig. 2 of Plate 19 and Fig. 2.40).

Depositional environment: These deposits were originally considered as the product of shallow-water sedimentation (Ogniben 1960; Broquet 1968). Montanari (1966) and then Scandone et al. (1972) indicated these deposits as the product resedimentation of materials deriving from the dismantling and erosion of a carbonate platform margin. Sedimentological and physic-stratigraphic study has suggested a carbonate apron depositional setting (Basilone 2000, 2009b).

Regional aspects: The unit outcrops primarily in North-Western Sicily. In the Madonie, Termini Imerese and Trabia Mountains, it displays the same lithological characteristics. In the outcrops of the Palermo Mountains, they appear as massive and vacuolar highly dolomitized limestone.

Carg abbreviation: FUN

2.2.20 Gratteri Formation°

General remarks: The formation was described by Ogniben (1960) as a "pre-flysch" unit due to its transitional sedimentation tending towards clastic. In the Costa Giuffre outcropping section, located in the Gratteri type area (Fig. 2.41, Madonie Mountains), the lithostratigraphic characteristics of the unit can be observed. Unfortunately, because the section is incomplete and without the lower and upper stratigraphic boundary, it can't be used as type section.

Synonyms and priority: The unit was considered by Schmidt di Friedberg et al. (1960) as a more clayey lithology of the Caltavuturo formation. In contrast, Ogniben (1963a) highlighted the differences between the two formations on the basis of tectonic and paleogeographic considerations.

Lithology and thickness: Alternations of yellowish, red and green marls and marly clays with thin-bedded blackish to grey planar laminated mudstone-wackestone (Fig. 3 of Plate 11). The marls display planar to undulate laminations and, locally, fragments of bioconstructed carbonates. Upwards (Isnello section), thick-bedded grey-yellowish graded and laminated biocalcarenites (calciturbidites) with large benthic foraminifers and calcareous sandstones are

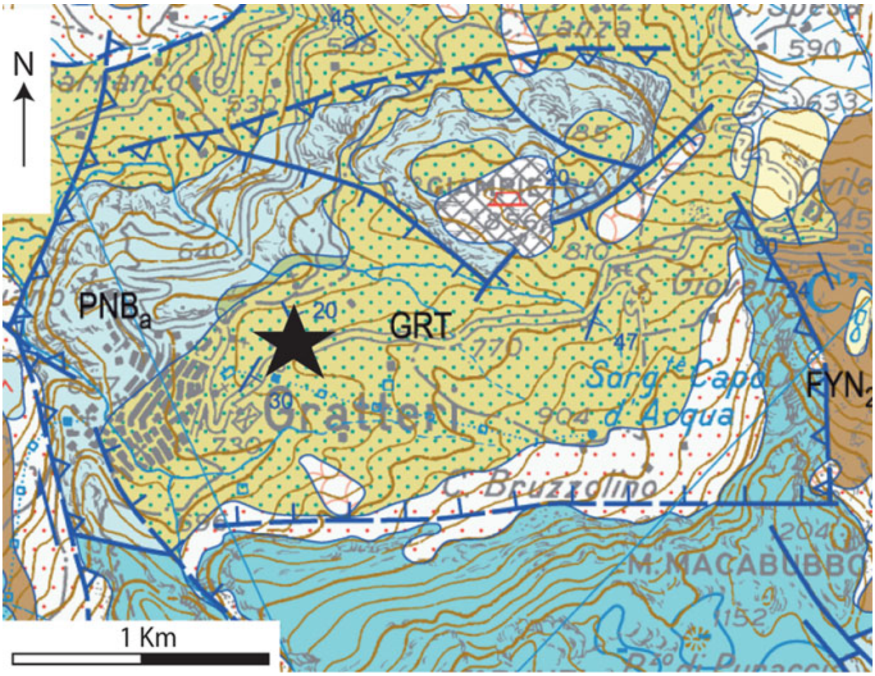


Fig. 2.41 Location (black star) of the type section of the Gratteri formation (GRT). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

intercalated (Fig. 4 of Plate 11). The calcareous sandstones display increasing quartz content upwards. Thickness ranges between 120 and 200 m.

Paleontological content: Planktonic foraminifers (*Globorotalia opima nana* (Bolli)*, Globigerina tripartita* Koch). In the resedimented beds, a rich fauna of reworked large benthic foraminifers (*Nephrolepidina* sp., *Eulepidina* sp., *Heterostegina* sp., *Operculina* sp., *Sphaerogypsina* sp, *Amphistegina* spp.), bivalve fragments, bryozoans and *Lithotamnium* sp. was described by Checchia Rispoli (1936) and Benedetti and D'Amico (2012).

Chronostratigraphic attribution: On the basis of the fossil content featuring the *Turborotalia cerroazulensis* s.l. and *Globorotalia opima opima* biozones, the unit is dated to the Upper Eocene–Lower Oligocene.

Stratigraphic relationships: The lower boundary is a sharp paraconformity surface with the Amerillo Formation (Vallone Cuba, NE-wards of Gratteri village). Frequently, it is an unconformity surface with the eroded and karstified Mesozoic shallow-water limestone, marked by large hiatus (Gratteri section). Upper boundary is a transitional contact with the clays of the Numidian flysch (Portella Colla member). Generally, the top of the succession is eroded or shows a tectonic contact with the quartz sandstones of the Geraci Siculo member (Numidian flysch).

Depositional environment: These lithologies were deposited in a gentle slope adjacent to a prograding carbonate platform margin from which the reworked bioclastic materials were resedimented through gravity-induced processes (turbiditic currents and grain flows). Benedetti and D'Amico (2012) suggest that due to the occurrence of abundant taxa with calcareous shell (e.g., *Dorothia, Karreriella, Vulvulina*), the Oligocene calcareous beds of the Gratteri formation were deposited in oxygenated and rich in $CaCO_3$ waters respect to the poorly-oxygenated waters, where the coeval deposits of the Caltavuturo formation were formed (Benedetti and Pignatti 2008).

Regional aspects: The unit, which characterises the Panormide succession (Fig. 2.1; Table 2.5), outcrops exclusively in the northern Madonie Mountains (northern side of Pizzo Dipilo, where the town of Gratteri is situated, and, with lesser extension, near the town of Isnello), as recently mapped in the geological maps of the Carg project (Termini Imerese-Capo Plaia and Castelbuono 1:50,000 scale-maps, performed by Catalano et al. (2011b) and Grasso et al. (2010), respectively). The event causing the resedimentation of the shallow-water carbonate materials has been related to the extensional tectonics dislocating the Panormide Carbonate Platform during the Lower Oligocene (Catalano and D'Argenio 1981; Abate et al. 1982c).

Carg abbreviation: GRT

2.2.21 *Hybla Formation*

General remarks: The unit was originally described by Rigo and Barbieri (1959) as the middle member of the Alcamo formation (no longer considered a valid unit).

The unit was amended and proposed in the rank of formation by Patacca et al. (1979), by studying the deep boreholes drilling the subsurface of the Hyblean Plateau. The Punta di Calabianca section (Castellammare del Golfo) that was investigated in its biostratigraphic (Rio and Sprovieri 1986) and sedimentological-petrographic features (Azzaro et al. 1991; Bellanca et al. 2002) can be considered the outcropping supported section. The formation has been included in the Traditional Unit of the Italian Formations Catalogue (Cita et al. 2007a).

Synonyms and priority: Informally these deposits are known as "marls with *Apthycus*" and they correspond to the "*Fucoid* marls" outcropping in the southern and central Apennine.

Lithology and thickness: Thin-bedded and laminated grey pelagic limestone with bedded cherts regularly alternated with grey and darkish marls (Fig. 5 of Plate 11). The calcilutite beds consist mostly by wackestone with radiolarians, planktonic foraminifers, *Apthycus* fragments, crinoids and echinoids (Fig. 6 of Plate 11). The marls, described as black shale (Bellanca et al. 2002), were compared with the coeval anoxic clays outcropping in the Apennine successions and referred to the so-called "Selli event". Downwards, mud-supported pebbly conglomerates are present locally. The equivalent lithologies outcropping in the Sicanian Mountains display thicker white marl intercalations rich in belemnites [*Duvalia lata* (Blainville)]. Thickness ranges between 20 and 80 m.

Paleontological content: Radiolarians, planktonic foraminifers (*Hedbergella similis* Longoria, *Hedbergella excelsa* Longoria, *Globigerinelloides aptiense* Longoria, *Globigerinelloides ferreolensis* Moullade, *Leupoldina cabri* Sigal, *Ticinella primula* Luterbacher, *Ticinella praeticinensis* Sigal, *Ticinella breggiensis* Gandolfi), calcareous nannofossils [*Lithraphidites bollii* Thierstein, *Calcicalathina oblongata* (Worsley), *Rucinolithus irregularis* Thierstein, *Rhagodiscus gallagheri* Rutledge & Bown, *Micrantholithus obtusus* Stradner, *Assipetra infracretacea* (Thierstein), *Chiastozygus litterarius* (Gorka), *Parhabdolithus achlyostaurion* Hill, *Biscutum costans* (Gorka)], *Apthycus* fragments and belemnites [*Duvalia lata* (Blainville)].

Chronostratigraphic attribution: On the basis of the rich planktonic fossil content, the unit is dated to the Upper Valanginian–Albian time interval. In detail, the calcareous nannofossils of the CC 2-6 and CC 7-10 biozones dated these deposits to the Valanginian–Barremian and to the Aptian–Albian, respectively. Planktonic foraminifer associations of the *Globigerinelloides algeriana* and *Schakoina cabri* biozones date these deposits to the Aptian and the *Ticinella primula* biozone to the Lower Albian. In the Punta di Calabianca section, several hiatuses, comprising the Barremian, uppermost Aptian and middle Albian, have been recognised (Bellanca et al. 2002).

Stratigraphic relationships: The lower boundary is a conformable sharp surface with the calpionellid limestone of the Lattimusa (Fig. 2.16; Table 2.4). Where this boundary is represented by a transitional contact, it is characterised by the disappearance of calpionellids, a decrease in chert and an increase in marly content. The upper boundary is a sharp conformity surface with the pelagic limestone of the

Amerillo Formation (Fig. 2.16); it is well recognisable on the basis of the colour change from darkish and whitish carbonates towards reddish and whitish tints in the younger carbonates.

Depositional environment: Deep-water, where the pelagic and hemipelagic sedimentation was locally accompanied by reworking of intraformational conglomerates.

Regional aspects: The unit outcrops in various parts of W Sicily, from the Egadi Islands, Sciacca, Trapani and the Castellammare del Golfo Mountains, where it is comprised in the Trapanese and Saccense successions. It has been drilled both in the Hyblean subsurface and in the Sicily Channel (Patacca et al. 1979; Antonelli et al. 1991). The unit forming part of both the Sicanian deep-water succession outcropping in the Sicanian Mountains and the Panormide shallow-water succession outcropping in the San Vito Lo Capo Mountains (Catalano et al. 2011a) displays various stratigraphic relationships and few facies differences.

Carg abbreviation: HYB

2.2.22 Inici Formation

General remarks: These deposits, first described by Floridia (1931), were proposed as the Inici Formation by Rigo and Cortesini (1961), studying the Inici Mount section (Castellamare del Golfo), where Warmann and Arkell (1954) later described a 300 m-thick incomplete section. The lithological description here reported is mostly based on a detailed section recently measured and studied along the eastern side of Inici Mount (Fig. 2.42, Catalano et al. 2011a). The formation has been included in the Traditional Units of the Italian Formations Catalogue (Cita et al. 2007a).

Synonyms and priority: The unit was described as "Casale limestone" of Rocca Busambra (Gemmellaro 1878; Carapezza and Tagliarini 1894; De Gregorio 1922), "crystallized limestone" (Baldacci 1886), "reefoid unit" (Schmidt di Friedberg 1959). The equivalent deposits outcropping in Eastern Sicily were called "Villagonia formation" (Rigo and Barbieri 1959). The identical lithologies drilled in the subsurface of the Hyblean Plateau are described as "Siracusa Formation" (Patacca et al. 1979). The unit is the equivalent of the "Calcare Massiccio" of the Apennines (Giacometti and Ronchi 2000).

Lithology and thickness: White shallow-water limestone and dolomitized limestone with algae and molluscs alternated with stromatolitic fenestral limestone and oolitic limestone. Outcropping thicknesses 300–400 m. The unit consists of some lithofacies organized in shallowing upward cycles (peritidal cycles): (i) the algae and molluscs limestone (subtidal lithofacies) is a thick-bedded (1.5–2 m-thick) wackestone and, locally, packstone with bioclasts, calcareous algae [abundant *Paleodasycladus mediterraneus* (Pia) and *Thaumatoporella parvovesiculifera* (Raineri)], peloids, large oncoids, intraclasts, benthic foraminifers (Figs. 5 and 6 of Plate 20), pertaining to a lagoon depositional environment; (ii) stromatolitic

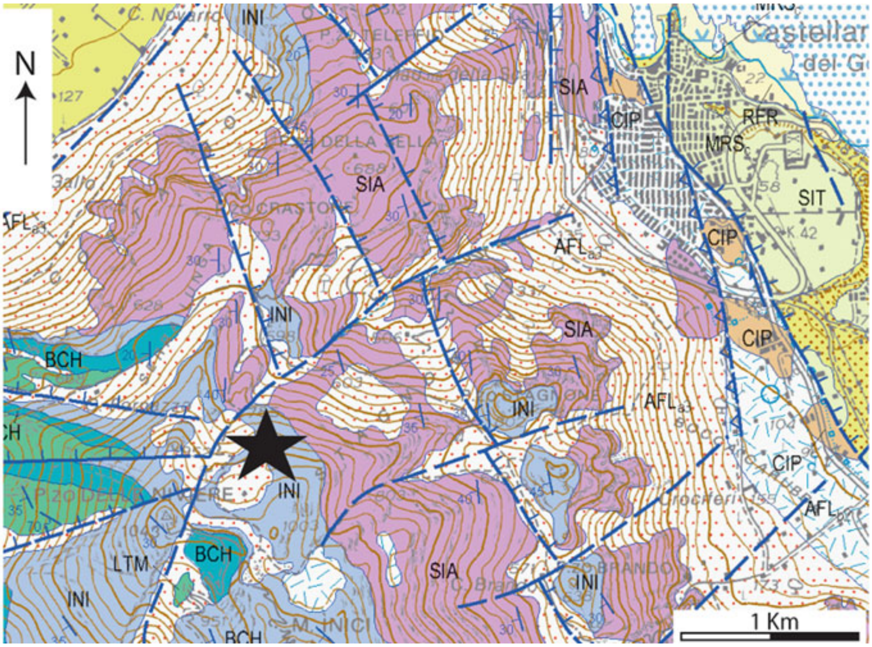


Fig. 2.42 Location of the here proposed outcropping type section of the Inici Formation (INI). The map was extracted from the geological Sheet n. 593 "Castellammare del Golfo" (1:50,000 scale map), performed by Catalano et al. (2011a)

limestone (infratidal lithofacies) consists of 30–50 cm-thick bioclastic, intraclastic and peloidal planar to undulate laminated packstone-grainstone with birds eyes and *Stromatactis* structures (Figs. 4 and 7 of Plate 20), developed in tidal flat depositional environments; (iii) the oolitic limestone (sand bar lithofacies) consists of 40–80 cm-thick grainstone and, locally, packstone with well-developed ooids partly micritized, mollusc shell fragments, peloids, coated grains, intraclasts, benthic foraminifers, calcareous algae (Figs. 3 and 8 of Plate 20). This lithofacies, characterising the top of each cycle, is bounded downwards by an irregular submarine erosional surface and was formed in a sand shoal depositional environment.

Paleontological content: Calcareous algae (*Thaumatoporella parvovesiculifera* (Raineri), *Paleodasycladus mediterraneus* (Pia), *Cayeuxia* sp.), benthic foraminifers (*Involutina liassica* Jones, *Lituosepta* sp., *Agerina martana* Farinacci), ammonites, gastropods, echinoids and small megalodontids.

Chronostratigraphic attribution: On the basis of the algae association (*Thaumatoporella parvovesiculifera* and *Paleodasycladus mediterraneus* biozones of the biostratigraphic scheme of Chiocchini et al. 1994), ammonites of the *Arietites bucklandi* and *Echioceras raricostatum* biozones (Gemmellaro 1878; Carapezza and Tagliarini 1894; Fucini 1912; De Gregorio 1922; Gugenberger 1936a, b; Arkell 1956; Wendt 1969) the formation is dated to the Hettangian-Sinemurian time interval. The occurrence of *Agerina martana* permit the age of the unit to be extended to the lower Pliensbachian (Di Stefano P et al. 2002b).

Stratigraphic relationships: The lower boundary is a paraconformity surface with the shallow-water dolostone of the Sciacca Formation; the upper boundary is marked by thick Fe–Mn crust (hardground), locally laminated and with pinnacle morphology (Di Stefano and Mindszenty 2000; Sulli and Interbartolo 2015). This boundary represents a regional unconformity surface where the younger crinoidal limestone and/or reddish *Bositra* limestone of the lower member of the Buccheri Formation rest with onlap stratal terminations. This surface is frequently dissected by fractures and synsedimentary faults, where the younger deposits rest in buttress unconformity (Fig. 8 of Plate 21, Basilone 2009a, 2011a). A dense network of neptunian dykes, sub-vertical and sub-horizontal to the bedding and filled by Jurassic reddish ammonite limestone (Buccheri Formation), Cretaceous pelagic limestone with planktonic foraminifers (Amerillo Formation), and glauconitic-calcareous sandstone of the Corleone calcarenites (Figs. 9–11 of Plate 21), characterised the top of the unit and highlighted that synsedimentary extensional tectonics was active up to the Lower Miocene (Wendt 1965, 1971, 2017; Basilone 2009a).

Depositional environment: Low-energy subtidal carbonate platform bordered by tidal flat (landward) and by sand bars (seaward).

Regional aspects: The unit, pertaining to the Trapanese-Saccense and Hyblean carbonate successions, outcrops widely in W Sicily (Kumeta and Busambra ridges, Monte Maranfusa, Monte Inici, Monte Bonifato, Montagna Grande, Monte Erice and Sciacca Mountains sections), in the Egadi islands and in the subsurface of the Hyblean region and offshore Southern Sicily.

Carg abbreviation: INI

2.2.23 Lattimusa

General remarks: The formation, included in the Traditional Units of the Italian Formations Catalogue (Cita et al. 2007a), comprises the Upper Jurassic-Lower Cretaceous pelagic limestone with calpionellids inserted in the Trapanese, Saccense and Sicanian successions. Among the several study sections outcropping in Western Sicily, from which Catalano and Lima (1964), Catalano (1965) and Catalano and Liguori (1970) have highlighted a detailed biostratigraphic subdivision, the Punta di Calabianca type section (Figs. 2.43 and 2.44, Castellammare del Golfo) is proposed here due to its easy access, reduced tectonic disturbance and to the occurrence of both the lower and upper stratigraphic boundaries.

Synonyms and priority: Lattimusa is a term derived from the typical milk-like colour of the rock and is used by the workers who mined this unit for ornamental purposes. The unit is informally known as calpionellid limestone and was classified as Busambra member of the Alcamo Formation (Rigo and Barbieri 1959). It corresponds

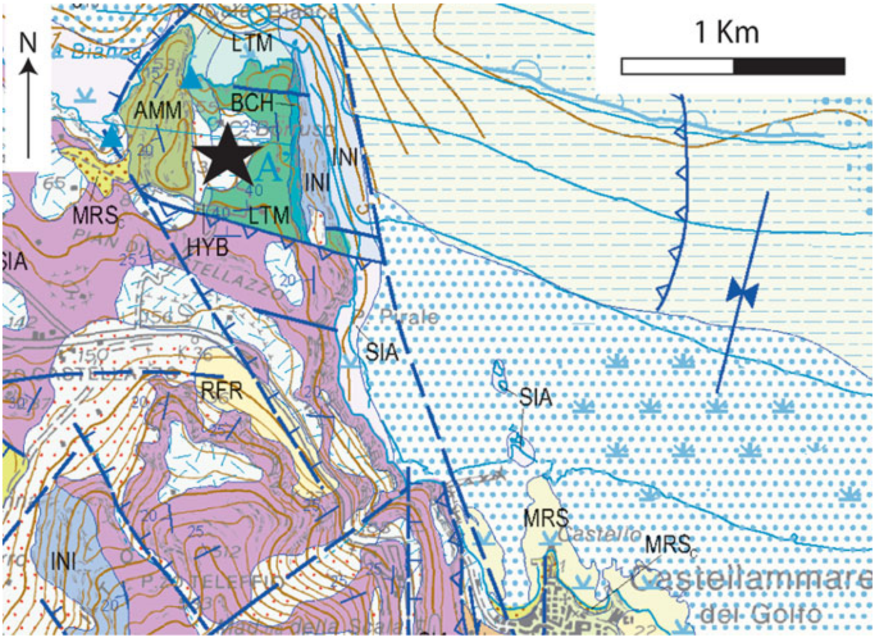


Fig. 2.43 Location of the proposed type section of the Lattimusa calpionellid limestone (LTM), measured at Punta di Calabianca (Castellammare del Golfo). The map was extracted from the geological Sheet n. 593 "Castellammare del Golfo" (1:50,000 scale map), performed by Catalano et al. (2011a)

to the Chiaramonte Formation drilled in the Hyblean subsurface (Patacca et al. 1979) and to the "Maiolica" and "Biancone Veneto" outcropping in the Apennines and Alps.

Lithology and thickness: Whitish, locally greenish and pinkish, thin-bedded calcilutites with darkish chert nodules and bedded cherts (Fig. 5 of Plate 7). The dm-thick limestone beds, characterised by the typical conchoidal fracture, alternate with thin whitish marls, especially in the upper portion of the succession, where the limestone beds tend to greyish tints (Fig. 2.44). Locally, whitish intraformational conglomerates are interlayered (Pizzo Marabito section, Busambra ridge, Basilone 2009a, 2011a). Microscopically, the limestone beds are fossiliferous, laminated and bioturbated mudstone (Fig. 6 of Plate 7). The measured thickness in the Punta di Calabianca type section is about 63 m. It reaches 70 m at Kumeta ridge and has values around 10–30 m in the outcropping sections of the Sicani Mountains (Fig. 2.9b). In the Barracù section (Western Sicanian Mountains) these deposits are characterised by several seismically-induced soft-sediment deformation structures (SSDSs) frequently associated with synsedimentary faults (Basilone 2017). The calpionellid limestone, drilled in the Hyblean Plateau, consists of calpionellid mudstone-wackestone and radiolarian mudstone, 50–200 m thick and extends laterally for many tens of kilometres.

Paleontological content: Macrofossil content consists of echinoids, crinoid articles, *Apthycus*, brachiopods [*Pygope diphya* (Verona)], ammonites [*Tithopeltoceras paraskabensis* Arkell, *Olcostephanus asterianus* d'Orbigny,

Fig. 2.44 Natural section of the Upper Tithonian-Neocomian thin-bedded white limestone and marls with calpionellids of the Lattimusa formation (Punta di Calabianca section, Castellammare del Golfo)

Tirnovella gr. *alpillensis* (Mazenot), *Corongoceras* sp., *Spiticeras spitiense* (Blanford)], belemnites [*Duvalia lata* (Blainville), *Duvalia dilatata dilatata* (Blainville)]. Microfossils are radiolarians, foraminifers (*Spirillina* sp. Lagenids, Textularids, Valvulinids), *Stomiosphaera* sp., *Globochaete alpina* Lombard, calcareous nannofossils (*Nannoconus steinmanni* Kamptner) and calpionellids [*Crassicollaria intermedia* (D. Delga), *Cr. brevis* Remane, *Cr. parvula* Remane, *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadish, *Remaniella ferasini* (Catalano), *Remaniella cadischiana* (Colom), *Tintinnopsella carpathica* (Murgeanu and Filipescu), *T. longa* (Colom), *Calpionellopsis oblonga* (Cadisch), *Calpionellopsis simplex* (Colom), *Calpionellites darderi* (Colom)].

Chronostratigraphic attribution: On the basis of the calpionellid *Crassicolaria*, *Calpionella*, *Calpionellopsis and* Calpionellites biozones (Allemann et al. 1971; Remane 1985; Grun and Blau 1997), these deposits have been dated to the Upper Tithonian–Valanginian. A similar age is suggested by the temporal distribution of ammonites and belemnites (Caracuel et al. 2002).

Stratigraphic relationships: The lower boundary in the type section is a sharp paraconformity surface with the Buccheri Formation, locally marked by transitional contact (Piano Pilato section, Busambra). This contact is characterised by the disappearance of the nodular texture and of the abundant bioclasts, mostly crinoid fragments, and by the changing colour of the rocks—towards whitish tints—and by the increase in cherty content. As regards the unit pertaining to the deep-water succession outcropping in the Sicani Mountains, this lower boundary appears as an unconformity with the *Aptychus* pseudonodular limestone and the reddish radiolarites of the Barracù formation, marked by discordance (Fig. 2.24b). The upper boundary is a paraconformity with the Lower Cretaceous marly limestone of the Hybla Formation; it is recognisable in the field due to the changing colours—towards grey-greenish tints—of the younger beds and by the increase in marly content.

Depositional environment: Pelagic sedimentation of carbonate ooze in deep-water flat basin and structural highs (e.g. seamount) with open circulation.

Regional aspects: These deposits, characterising the Trapanese pelagic carbonate platform and the Sicanian Basin, outcrop most frequently in the Trapanese and Castellammare del Golfo (Inici Mt) Mountains and in the Sicani Mountains, respectively. Sporadically, they outcrop in the Panormide carbonate platform succession of the Madonie and San Vito Lo Capo Mountains, mostly as filling of neptunian dykes crossing the top of the Piano Battaglia reef limestone.

Carg abbreviation: LTM

2.2.24 Mischio

General remarks: Mischio[1] is a historical noun first used by Baldacci (1886) to describe the shallow-water limestone with large benthic foraminifers commonly outcropping in the Trapani Mountains. In the Sicilian geological literature, this term was extensively and sometimes erroneously used to describe other rock successions such as the Corleone glauconitic calcarenites (see Rigo de Righi 1957; Schmidt di Friedberg 1964–1965).

Lithology and thickness: The formation consists of the following lithofacies: (i) grey-yellowish and greenish thin-bedded glauconitic calcarenites with planar lamination and cross stratification rich in bivalves, bryozoans, fish teeth and large (2–3 cm) algal nodules frequently affected by boring (coastal facies); (ii) boundstone with molluscs, corals, rodoficean and coralline algae (Fig. 8 of Plate 7, reef lithofacies); (iii) bioclastic grainstone and rudstone with reef-derived elements (fore-reef lithofacies). Outcropping thickness ranges between 1 and 30 m.

[1]Seventeenth century Sicily is dominated, especially in the Jesuit sphere, by the use of so-called "mixed and cross-mixed marbles and arabesques" (Lo Iacono 1939; Piazza 1992; Hills 1999). In the nineteenth century, the cultivation of "Mischio" Miocene limestone was documented in Trapani. It was sold under the name "Pietra Misca" and used as a decorative material, mainly in the construction of small columns and ornamental mouldings and was used rather widely also in the province of Palermo (e.g. in the Duomo of Termini Imerese, Cappella dell'Immacolata).

Paleontological content: Bivalves (*Pecten burdigalensis* Lamarck), gastropods, echinoids (*Clypeaster* sp.), corals, bryozoans, fish tooth, rodoficean algae (*Lithotamnium* sp.), large benthic foraminifers (*Heterostegina complanata* Silvestri, *Amphystegina hauerina* d'Orbigny, *Amphystegina lessonii* d'Orbigny, *Sphaerogypsina* sp.), *Balanus* sp., *Melobesia* sp. and planktonic foraminifers (*Globigerinoides trilobus* Reuss).

Chronostratigraphic attribution: The fossil content suggests dating this unit to the Burdigalian (Wendt 1971).

Stratigraphic relationships: The lower boundary is an erosional unconformity with pelagic limestone and the calcareous megabreccia of the Amerillo Formation (Sparagio section, San Vito Lo Capo Mountains) or with the shallow-water limestone of the Pellegrino formation (Fig. 7 of Plate 7), marked by downlap and onlap stratal terminations, respectively. The upper boundary, when present, is an unconformity with Lower Miocene clays (Abate et al. 1991a).

Depositional environment: Coastal high energy environments (shoreface) laterally becoming a reef margin (Abate and Incandela 1998).

Regional aspects: These deposits outcrop in the Trapani and San Vito Lo Capo Mountains. The most interesting outcropping sites are Rocche Emilio, Monte Sparagio and Purgatorio, where detailed sedimentological studies have revealed the primary paleoenvironmental setting of the unit (Incandela 1995; Abate and Incandela 1998; Abate et al. 1991a). They have been drilled by the deep boreholes of the western Sicily offshore (Agip wells) and have been considered as equivalent to the uppermost lithofacies of the Fortuna Formation, which is well described on the basis of the outcropping sites of North Africa and from the deep boreholes in the south-western Sicily offshore (see www.videpi.it and Antonelli et al. 1991). These deposits and their facies are very similar to those described from various peri-Mediterranean regions and considered formed in an open shelf and ramp setting (Carannante et al. 1988; Brandano and Civitelli 2007).

Carg abbreviation: HIO

2.2.25 Modica Formation

General remarks: The unit was proposed by Patacca et al. (1979) to describe the Lower Jurassic pelagic carbonates drilled in the subsurface of the Hyblean Plateau. The proposed type section is the rock interval crossed from 2170 to 2523 m in the Modica 1 well (T.D. 3060.30 m), located north of Modica (Lat. 33° 53′ 14″N; Long. 14° 46′ 41.40″) and performed by Agip Mineraria in 1956–1957.

Synonyms and priority: These deposits correspond to the Lower Jurassic (Middle-Upper Liassic) pelagic carbonates of the Villagonia formation proposed by Rigo and Barbieri (1959) in the Peloritani Mountains outcropping sections belonging to the Longi-Taormina Unit (Amodio Morelli et al. 1976).

Lithology and thickness: Alternations of light grey cherty limestone and mottled marly limestone with grey-greenish marls and clays with radiolarians, sponge spiculae, ostracods, ammonites, benthic foraminifers. Locally, resedimented oblique to planar laminated packstone with shallow-water bioclasts are interlayered. The previously described lithofacies association are locally alternating with or laterally become red nodular ammonite-bearing limestone, consisting of bioclastic bioturbated wackestone with ammonite, thin-shelled bivalves, benthic foraminifers. Sporadic basalts and hyaloclastites have been drilled by some boreholes. Coarse-grained resedimented limestone with shallow-water derived elements were drilled by several boreholes. Total thickness ranges from some tens of metres to about 500 m in the type section.

Paleontological content: *Globochaete* sp., *Stomiosphaera* sp., *Lagenidae*, *Involutina liassica*, *Frondicularia exagona*, *Spirillina* sp., echinoid and algae fragments, *Apthycus*, arenaceous foraminifers (*Ammodiscidae*, *Textulariidae*, *Ataxophragmiide, Lituolidae, Ophtalmiidae*).

Chronostratigraphic attribution: The unit was dated to the Sinemurian-Pliensbachian. On the basis of the planktonic nannofossils Ronchi et al. (2000), in their study of the boreholes in the Ragusa offshore (Sicily Channel), date the unit to the Lower Pliensbachian.

Stratigraphic relationships: The lower boundary is a gradational contact with the Streppenosa Formation. It can be considered an unconformity surface with the Lower Jurassic shallow-water limestone of the Siracusa Formation (here described as the Inici Formation), as observed in the Siracusa 1 well (Patacca et al. 1979), while in the upper portion of the succession, lateral (heteropic) relationships with the shallow-water deposits of the Inici Formation are observed (Fig. 2.45). The upper boundary is a sharp conformity surface with the ammonite limestone of the Buccheri Formation.

Depositional environment: The fine-grained carbonates are related to the periplatform ooze deposited in a intraplatform deep-water basin, which was also affected by turbiditic currents. The different facies associations observed in the Hyblean subsurface reveal the occurrence of proximal (resedimented carbonates) to distal sectors of the Ragusa belt (Patacca et al. 1979).

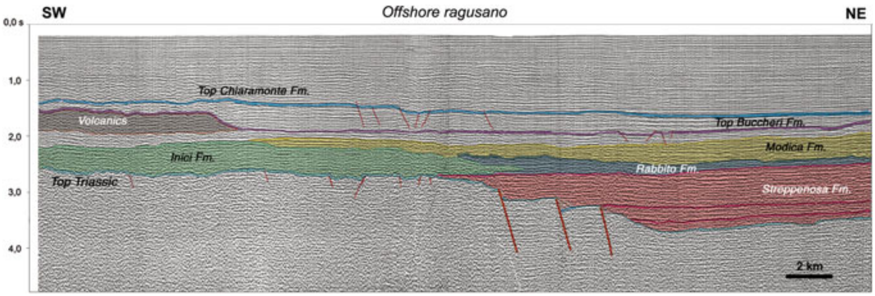


Fig. 2.45 Seismic profile and interpretation crossing the Hyblean offshore and showing the stratigraphic relationships among the Triassic-Jurassic formational unit forming the Hyblean carbonate succession (Catalano, unpublished data)

Regional aspects: The unit extends in the subsurface of the entire Ragusa belt and locally in the Siracusa belt, too. It was recognised in the subsurface of Western Sicily, during the study of the rocks succession drilled by the Marineo 1 well, located South of Kumeta Ridge (Catalano et al. 2000; Di Stefano P et al. 2002a).

*2.2.26 Monte Bosco Formation**

General remarks: In this unit are comprised the calcareous and clastic deposits of the Eocene-Miocene succession outcropping in the area comprised between Monte Bosco and Monte Luziano (Trapani Mountains) and deposited in the so-called Oligo-Miocene "Trapani Basin" (Rigo De Righi 1957; Trimaille 1982; Sestini and Flores 1986). These clastic and carbonate successions cover unconformably the Meso-Cenozoic carbonates (Giunta and Liguori 1972, 1973; Broquet and Mascle 1972; Andreieff et al. 1974; Catalano and D'Argenio 1982a; Broquet et al. 1984a; Montanari 1986, 1987; Oldow et al. 1990; Abate et al. 1991b). The following lithological description is based on the Monte Bosco type section (Fig. 2.46) described in detail by Abate et al. (1996a), Abate and Incandela (1998) and Catalano et al. (2014).

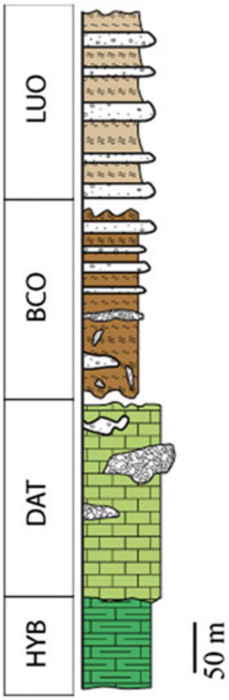


Fig. 2.46 Composite succession, reconstructed at Monte Bosco and Monte Luziano (Trapani Mountains, after Catalano et al. 2014). HYB: calcilutites and marls of the Hybla Formation, DAT: pelagic limestone of the Dattilo limestone (i.e., the Amerillo Formation), BCO: clays and quartz-sandstones of the Monte Bosco formation, LUO: marls and glauconitic sandstones of the Monte Luziano formation

Lithology and thickness: Alternating darkish grey laminated clays to marly clays and planktonic foraminifera-bearing calcilutites with intercalations of dm-thick glauconitic biocalcarenites and biocalcirudites with lenticular geometry (BCO_a). The resedimented deposits display an erosional lower boundary, gradation and lamination (Ta-b of Bouma sequence) and a rich fossil content, consisting of gastropods, pelecypods, corals, large benthic foraminifers (*Chapmanina gassinensis* (Silvestri), nummulitids, alveolinids, discocyclinids), encrusting algae, merged in a pelagic micrite rich in planktonic foraminifers. The resedimented grain-supported calcarenites consist of subrounded calcareous and siliceous grains. Intercalated are thick-bedded (up to 1 m) calcareous breccias with shallow-water derived elements, thin-bedded brown graded and laminated quartz sandstones with planktonic and arenaceous foraminifers, and lenses of conglomerate with erosional basal boundary and channelized geometry (BCO_b). Slumps are frequent. Total outcropping thickness, 100 m on average, ranges between 50 and 250 m.

Paleontological content: Ostracods, agglutinated benthic foraminifers, planktonic foraminifers (*Turborotalia cerroazulensis* (Cole), *T. cerroazulensis cocoaensis* (Cushman), *T. cerroazulensis cunealensis* (Toumarkine and Bolli), *T. cerroazulensis pomeroli* (Toumarkine & Bolli), *Globigerina eocaena* Güembel, *G. ciperoensis* Bolli, *Globigerinatheka index* Finlay, *Globorotalia opima nana* Bolli, *Gl. opima opima* Bolli, *Gl. kugleri* (Bolli), *Catapsydrax dissimilis* (Cushman & Bermudez), *Orbulinoides beckmannii* Saito, *Cribrohantkenina inflata* (Howe), *Paragloborotalia siakensis* (Le Roy), *Globoquadrina dehiscens* (Chapmann, Parr, Collins), *Gq. dehiscens dehiscens* (Chapman, Parr & Collins), *Globigerinoides trilobus* Reuss) and calcareous nannofossils [*Sphenolithus predistentus* Bramlette & Wilcoxon, *Dictyococcites bisectus* Bukry & Percival, *Helicosphaera euphratis* Haq, *Sphenolithus ciperoensis* (Bramlette & Wilcoxon), *Sphenolithus distentus* (Bramlette & Wilcoxon)]. The reworked calcareous beds contain large benthic foraminifers (*Nummulites* sp., *Lepidocyclina* sp.), rudistid fragments, algae (*Subterraniphyllum tomasi* (Elliot), *Lithothamnium* sp., *Lithophillum* sp., *Melobesia* sp.).

Chronostratigraphic attribution: On the basis of the planktonic foraminifer markers of the *Turborotalia cerroazulensis* s.l., *Globorotalia opima opima*, *Globoquadrina dehiscens dehiscens-Catapsidrax dissimilis* and *Globigerinoides trilobus* biozones and the calcareous nannofossil NP21–NP23, NP24 biozones, the unit has been dated to the Upper Eocene–Lower Miocene (Catalano et al. 2014).

Stratigraphic relationships: The lower boundary is a sharp surface with local stratal discordance with the pelagic limestone of the Amerillo Formation (Fig. 2.46); this surface is frequently disharmonic (tectonic) contact or thrust. The upper boundary is a conformable transitional contact with the marls and glauconitic sandstones of the Monte Luziano formation.

Depositional environment: These deposits are considered to have formed in base of slope and deep-water environments, where gravity flows discharged the reworked materials (Abate et al. 1996a).

Regional aspects: These deposits commonly outcrop in the south-western sector of the Trapani Mountains, with a slight extension in the Serra Conzarri-Calatubo (Alcamo) and in the Belice Valley.

Carg abbreviation: BCO

2.2.27 Monte Carruba Formation

General remarks: The unit was proposed by Grasso et al. (1982) as a formation constituting part of the Upper Miocene Sortino Group, in his study of the 34 m-thick Monte Carrubba type section (East of Carlentini, Siracusa). The formation was successively amended in its lithological content by Pedley et al. (2007).

Synonyms and priority: The unit was described as alternations of marls and limestone by Di Grande (1972), "Lumachella" limestone by Grasso et al. (1979).

Lithology and thickness: The Monte Carrubba Formation in the type section is almost exclusively composed of cross-stratified oolitic grainstone and coral boundstone (21 m) changing laterally and upward to peritidal carbonates and lagoonal wackestone (11 m) with oligotipic fauna, mostly represented by bivalves (*Cardidae*) and gastropods, alternated with yellowish calcarenites with pectinids. Faunas are frequently of low diversity. Euryhaline mollusc associations are dominant, although *Pecten vigolenesis* (Eichwald) occurs in the lower beds. The sequence starts with reefoidal to restricted ramp carbonates and associated basic volcanics which proceeding upwards give way to pelagic marls. Most of the carbonate strata consist of thinly bedded to laminated pale grey to cream coloured lime mudstones which were deposited on a ramp. Sparse corals occur in the lower part of the formation, whereas oolitic shoals and lagoonal mudstones characterise the upper parts. Several thin clay partings are present.

Paleontological content: Bivalves (*Cerastoderma* and *Lymnocardium* genus, *Ervilia podolica* (Eichwald), *Abra* cfr. *reflexa* Eichwald, Tellinidae (*Donax*), Mytilidae (*Modiolus*?), *Venerupis* sp., *Callista* cf. *chione* (Linné), *Cardites* cf. *antiquatus pectinatus* (Brocchi), *Arca noae*, *Pinna* sp., *Pecten vigolensis* (Eichwald), *Anadara turonica* (Dujardin). Small gastropods (*Cerithium*) are also present in association with *Ostraea* sp., corals (*Porites* sp., *Favites* sp.), echinoids, benthic foraminifers, ostracods and coralline algae.

Chronostratigraphic attribution: Upper Tortonian-Upper Messinian. *Pecten vigolenensis* suggests Tortonian age. The upper stratigraphic relationship constrains the upper portion of the succession to the Lower Messinian (Grasso et al. 1982).

Stratigraphic relationships: The lower boundary is an unconformity surface with the volcanoclastic deposits of the Carlentini formation; it is a diachronous contact spanning between the Late Tortonian and the Early Messinian. The upper boundary is an unconformity with the Upper Messinian evaporites; it may be marked by truncational erosion followed by conglomerates and marly limestone equivalent to the Late Messinian "Lago-Mare" unit. These discontinuous, thin and often continental sedimentary veneers are locally capped by beds containing hypersaline and brackish water faunas, i.e. the *Congeria* beds (Grasso et al. 1982; Pedley et al. 2007).

Depositional environment: The described facies association shows evidence of considerable variability in depositional depth and salinity. The lower stratigraphic interval is believed to have formed in a low energy shallow-water environment (about 20 m in depth, Grasso et al. 1982; Di Geronimo and Barrier 1984). The upper lithofacies are deposited in a restricted lagoon with high salinity and are considered as a pre-evaporitic episode (Grasso et al. 1979). A distally steepened ramp with a shoal water barrier and a lagoonal inner ramp complex with restricted circulation are envisaged (Pedley et al. 2007).

Regional aspects: The paleoenvironmental reconstruction suggests that the formation was deposited around an island or a landmass lying in the northern sector of the Hyblean Plateau. The formation represents the youngest marine Miocene carbonate deposit of the Hyblean region. It is extensively exposed in the northern part of the region and immediately underlies the Pliocene Trubi Formation. It is also extensively exposed directly beneath the Quaternary unconformity around the south Hyblean coastline near Scoglitti and as inland outliers in the Scicli and Rosolini regions of the south-east. Many of the outcrops are associated with normal fault scarps oriented NE–SW (Pedley et al. 2007).

Carg abbreviation: MUC

*2.2.28 Monte Luziano Formation**

General remarks: In this unit are comprised the calcareous and clastic deposits of the Miocene succession outcropping in the area comprised between Monte Bosco and Monte Luziano (Trapani Mountains) and deposited in the so-called Oligo-Miocene “Trapani Basin” (Rigo De Righi 1957; Trimaille 1982; Sestini and Flores 1986).

Lithology and thickness: The unit, at the bottom, consists of alternating dark laminated marls and white marly limestone with intercalations of dm-thick fine glauconitic breccias and bioclastic calcarenites with algae and mollusc shell fragments. The resedimented calcareous beds display Ta-b Bouma sequences and an erosional lower boundary (Fig. 2.46). Upwards, clay and marl alternate with planktonic foraminifers and minor intercalations of dm-thick planar to cross laminated and bioturbated quartz sandstones with lenticular geometry (LUO_a). The latter display a grain-supported texture of rounded quartz grains with siliceous and, rarely, calcite cements. Clays are characterised by the occurrence of siderite nodules and cm- to dm-thick arenaceous pebbles. At the Rocche Emilio section (Paceco, Trapani) a 10 m-thick boundstone with large pelecypods, algae, echinoids and corals, frequently in life position, is intercalated (Abate et al. 1996a). This horizon, with lenticular geometry, represents a small patch-reef laterally becoming the previously described bioclastic and glauconitic calcareous resedimented beds, showing large-scale oblique laminations. Frequently, at the base of the succession, there is a metres-thick layer of conglomerates with cm-dm elements, chaotic stratification, lenticular geometry and an erosional lower boundary. Outcropping thickness ranges between 50 and 120 m.

Paleontological content: Benthic and planktonic foraminifers [*Globigerina ampliapertura* Bolli, *Globigerina ciperoensis* Bolli, *Globorotalia opima nana* Bolli, *Globorotalia kugleri* (Bolli), *Praeorbulina glomerosa sicana* (De Stefani), *Globigerinoides trilobus* Reuss, *Globigerinoides sicanus* De Stefani, *Globoquadrina dehiscens* (Chapman, Parr & Collins), *Globoquadrina dehiscens dehiscens* (Chapman, Parr & Collins), *Paragloborotalia siakensis* (Le Roy)], calcareous nannofossils (*Sphenolithus predistentus* (Bramlette & Wilcoxon), *Dictyococcites bisectus* Bukry & Percival, *Helicosphaera euphratis* Haq).

Chronostratigraphic attribution: Oligocene–Lower Miocene (Langhian). The *Cassigerinella chipolensis-Pseudohastigerina micra* planktonic foraminifers biozone and the NP21-NP23 calcareous nannofossil biozones permit recognition of the Lower Oligocene. The markers of the *Globorotalia kugleri, Globoquadrina dehiscens dehiscens-Catapsidrax dissimilis, Globigerinoides trilobus* and *Paragloborotalia glomerosa* s.l. (pars) biozones date these deposits to the Lower Miocene.

Stratigraphic relationships: The lower boundary is a continuity sharp surface with the Oligocene "Monte Bosco clays and quartz sandstones" (Fig. 2.46). It can be an erosional unconformity—marked by karst features—with the Mesozoic shallow-water of the Sciacca and Inici formations or with the Eocene pelagic limestone of the Amerillo Formation, as is well exposed in the Sparagio and Monaco sections (San Vito Lo Capo Mountains, Catalano et al. 2011a). Upwards, these deposits give way to the clays and quartz sandstones of the Numidian flysch (Abate et al. 1991b, 1993; Bommarito et al. 1995).

Depositional environment: Coastal to shallow-water depositional environments changing upward to slope and base-of-slope environments affected by turbiditic currents (Abate et al. 1996a).

Regional aspects: These deposits widely outcrop in the SW Trapani Mountains and surrounding area (Trapani basin).

Carg abbreviation: LUO

2.2.29 Monti Climiti Formation

General remarks: The unit consists of two main lithologies classified, from the bottom, as the Melilli and Siracusa limestone members, which also show lateral (heteropic) relationships (Carbone et al. 2011).

Lithology and thickness: The Melilli member (FNL_1) is a monotonous sequence of medium to thick-bedded white fine to coarse bioturbated calcarenites with pectinids and anellids (*Ditrupa* spp.), progressively changing upwards to an alternation of thick-bedded marly limestone and marls with planktonic foraminifers. The Siracusa limestone member (FNL_2) consists of white to greyish cross-bedded calcarenites and calcirudites with *Lithotamnium* sp. and bryozoans, echinoids, algae and bivalves, locally karstified, then becoming boundstone with rodoficean algae, colonial corals and abundant *Clypeaster* sp. Locally, a 15 m-thick layer of calcarenites with large benthic foraminifers (*Amphistegina* sp., *Heterostegina* spp., *Miogypsina* spp.) of Burdigalian age outcrop north of Augusta. Outcropping thickness is about 100 m.

Paleontological content: Planktonic foraminifers (*Paragloborotalia mayeri* (Cushman & Ellisor), *P. partimlabiata* (Ruggieri & Sprovieri), rare *Orbulina universa* Brönnimann and *O. suturalis* d'Orbigny).

Chronostratigraphic attribution: Upper Oligocene–Tortonian. Planktonic foraminifers are comprised in the *Paragloborotalia partimlabiata* biozone (*Paragloborotalia mayeri* subzone, MMi7b of the biostratigraphic scheme of Sprovieri et al. 2002); the occurrence of *Orbulina* spp. is indicative of the Serravallian.

Stratigraphic relationships: The lower boundary is an unconformity with the Upper Cretaceous rudistid limestone and volcanites of the Porto Palo and Capo Passero members of the Amerillo. The upper boundary is an unconformity with the volcanites of the Carlentini formation.

Depositional environment: Carbonate platform to upper slope.

Regional aspects: The unit widely outcrops in the northern sector of the Hyblean Plateau.

Carg abbreviation: FNL

2.2.30 Mufara Formation°

General remarks: The unit was proposed by Schmidt di Friedberg (1962) on the basis of the description of the outcropping type section reconstructed at Monte Mufara (Madonie Mountains), where the lower boundary is a tectonic surface (floor thrust). The unit is amended here based on new data from the Platani 2 borehole section (Cammarata, Sicani Mountains), where the formation displays both the upper and lower stratigraphic boundaries (Basilone et al. 2016a). Furthermore, it is revised here and described in detail in the different lithofacies recognised in the unit widely outcropping in Western Sicily and mapped in the geological maps of the Carg project (Catalano et al. 2010a, b, 2011b, 2013a, b). The formation has been included in the Validated Units of the Italian Formations Catalogue (Delfrati et al. 2006b).

Synonyms and priority: The unit is informally known as "limestone and marls with halobids". It has been also called "Carnian flysch" (Mascle 1979) and "marly limestone of Portella Arena" (Ogniben 1960; Grasso et al. 1978).

Lithology and thickness: Regular alternations of darkish-grey thin-bedded mudstone-wackestone and brown clay to yellowish marl (Fig. 1 of Plate 22) with pelagic pelecypods (mostly halobids), ammonoids, radiolarians, conodonts, echinoids, crustacean carapaces (esterids), microgastropods, palynomorphs and rare arenaceous foraminifers (Figs. 2 and 3 of Plate 22). Calcareous beds, cm-dm in thickness, frequently display planar lamination, ichnites and various degree of dolomitization. Blackish marls rich in organic content and pyrite, interpreted as anoxic episodes (Bellanca et al. 1995), occur locally. There are intercalations of quartz-micaceous turbiditic sandstones (Mascle 1979) and micaceous claystones with plant rests. Locally, basaltic lavas and ultrabasic dykes are present (Vianelli 1970; Grasso and Scribano 1985). The controversial interpretation and debated age of these magmatic rocks have been recently discussed by Cirrincione et al. (2014). Grey calcareous graded breccias with shallow-water limestone derived elements and biocalcarenites with calcareous algae, sponges (*Tubiphytes* sp.), crinoids, echinoid spines, benthic foraminifers and tooth fish are interlayered in the upper portion of the Palermo Mountain outcropping sections, pertaining to the Imerese succession. They form thick resedimented bodies with lenticular geometry dispersed in the marl/limestone couplets succession (Cozzo Paparina section, Palermo Mountains, Abate et al. 1982d; Di Stefano et al. 2010) or display cyclic sequences of calcareous breccias megabeds, resedimented laminated calcarenites and plurimetric beds package of marls/limestone couplets (Valle Cuba section, Monreale, Basilone 2000, 2009b). The calcareous breccia elements of the Cozzo Paparina section highlight the occurrence of reworked fossils derived from erosion and dismantling of a Ladinian-Anisian carbonate platform (Senowbari-Daryan and Abate 1986; Senowbari-Daryan and Di Stefano 2001). Thin oolitic grainstone and skeletal packstone (Fig. 4 of Plate 22) intercalations have been sampled in the Cammarata section (E Sicani Mountains) and drilled in the adjacent Platani 2 well for about 400 m (Fig. 1.7, Basilone et al. 2016a). Total outcropping thickness ranges between 30 and 200 m.

Paleontological content: Pelagic pelecypods (*Halobia* sp., *Posidonomya* sp.), ammonites [*Trachiceras aon* (Münster)], ostracods, benthic foraminifers (*Ophtalmidium* sp.), conodonts [*Paragondolella polygnathiformis* Budurov & Stefanov, *Paragondolella carpathica* (Mock), *Gladigondolella tethydis* (Huckriede)], palynomorphs [*Foveosporites visscheri* (Van Erve), *Enzonalosporite vigens* (Leschik), *Parinasporites densus* (Leschik)].

Chronostratigraphic attribution: On the basis of the halobids content, these deposits were dated to the Carnian (Cafiero and De Capoa Bonardi 1982) and, due to the occurrence of *Trachiceras aon* (Münster), to the Lower Carnian (Broquet 1968 and reference therein). On the basis of a modern conodonts biostratigraphy (Gullo et al. 1997; Di Stefano and Gullo 1997b; Di Stefano et al. 1998b), for the presence of the markers of the *Gladigondolella tethydis* and *Paragondolella polignathiformis noha* biozones (of the biostratigraphic scheme of Kozur 1989; Kozur and Mock 1991) and on the basis of the palynomorphs content (Buratti and Carrillat 2002; Frixa and Trincianti 2006; Basilone et al. 2016a), these deposits are currently dated to the Julian-Tuvalian time interval.

Stratigraphic relationships: The lower boundary, which in the field is generally represented by a tectonic surface (floor thrust of the Mesozoic carbonate tectonic units), has been detected in the Platani 2, Casteltermini 1 and Valledolmo 1 boreholes (Fig. 1.7), where the Carnian pelecypods bearing marly limestone of the

Mufara Formation pass gradually downwards into the Ladinian-Lower Carnian Daonella limestone (Figs. 1.6 and 1.7, Basilone et al. 2016a). The upper boundary is a conformity surface with the cherty limestone of the Scillato Formation. It is a transitional contact marked by a change towards calcareous lithology that offers clear morphologic discontinuity in the field. Locally, this surface is a tectonic surface (i.e., detachment) characterised by disharmonic features.

Depositional environment: Pelagic to hemipelagic sedimentation in a slope-to-basin depositional environment, where gravity-induced processes (i.e., debris flow, Abate et al. 1982d) reworked the shallow-water carbonates at the base of the slope in a slope-apron depositional setting (Basilone 2009b; Di Stefano et al. 2010).

Regional aspects: This unit widely outcrops in Western Sicily, from the Madonie to the Palermo Mountains through the Termini Imerese and Trabia Mountains, pertaining to the Imerese succession, and in the Sicani Mountains and in Central-Eastern Sicily (Altesinella, Judica and Scalpello Mountains), where it is comprised in the Sicanian succession. It represents the floor thrust sequence of the Mesozoic carbonate tectonic units. The unit also appears mechanically merged with the Permo-Triassic deposits and they form a tectonic melange. The middle-upper Carnian pelecypod-bearing marly limestone of the Mufara Formation display similar lithological characteristics in all the outcrop and subsurface sections (Figs. 1.6 and 1.7), pertaining to both the Imerese and the Sicanian Mesozoic deep-water carbonate successions (Tables 2.2 and 2.3).

Carg abbreviation: MUF

2.2.31 Noto Formation

General remarks: This unit was proposed by Patacca et al. (1979) to describe the dolomitic limestone and black shale alternations drilled in the subsurface of the Hyblean Plateau and situated between the shallow-water dolomitized limestone of the Gela formation (i.e., Sciacca Formation) and the black shale of the Streppenosa Formation (Fig. 2.1). The proposed type section is the rock interval crossed between 2862 and 3076 m in the Noto 2 well (T.D. 3200.00 m), located East of Rosolini (Hyblean Mountains) and performed by Agip Mineraria in 1957–58.

Synonyms and priority: These deposits were previously comprised in the lower portion of the Streppenosa Formation by Rigo and Barbieri (1959).

Lithology and thickness: Alternation of thin-bedded dark laminated dolomite and dolomitized limestone and black shale with flaser lamination, laterally becoming whitish porous dolomitized calcarenites. Sporadic volcanites occur along the succession. Small sedimentary dykes, mudcracks and associated collapse breccias are common features. Locally, fine-grained peloidal wackestone with *Thaumatoporella* fragments, *Lagenidae*, arenaceous foraminifers, rare thin-shelled ostracods and algal filaments are present. The clastic carbonate lithofacies mainly consists of cross-laminated ooidal and bioclastic packstone-grainstone with fragments of small gastropods, brachiopods, large bivalves (*Estheria*) and arenaceous foraminifers, and of bioclastic packstone with *Thaumatoporella*. The thickness ranges from tens of metres to about 300 m.

Paleontological content: Echinoid and algal fragments, arenaceous foraminifers (*Trochamminidae*, *Ammodiscidae*), *Thaumatoporella* sp., *Aeolisaccus* sp.

Chronostratigraphic attribution: RHAETIAN.

Stratigraphic relationships: The lower boundary is a sharp contact with the Naftia or Gela formations (here comprised in the Sciacca Formation). The upper boundary is a sharp conformity surface with the Streppenosa Formation.

Depositional environment: The sequence consists of tidal flat carbonates deposited in a channelled belt (Patacca et al. 1979). The different facies associations, recognised in the several investigated boreholes, reflect a marginal—characterised by beach ridge environment—to central area of the original depositional basin.

Regional aspects: The unit extends in the subsurface of the entire Ragusa belt and in the Siracusa belt, too, where the marginal lithofacies were drilled.

2.2.32 Oolitic Limestone and Belemnitic Conglomerates

General remarks: This unit is represented by the oolitic calcarenites and the belemnitic conglomerates that characterise with variable thickness the lowermost portion of the Jurassic (Liassic) Sicanian succession (Table 2.3; Fig. 2.1). The reduced thicknesses and lateral discontinuity of the unit do not justify its classification in the rank of formations. The Cozzo Ledera type section proposed here (Fig. 2.47, Eastern side of Monte Cammarata, Sicani Mountains) has been detailed study (Daina 1967; Broquet 1965; Broquet et al. 1967; Basilone 2013; Basilone et al. 2013a, 2016a).

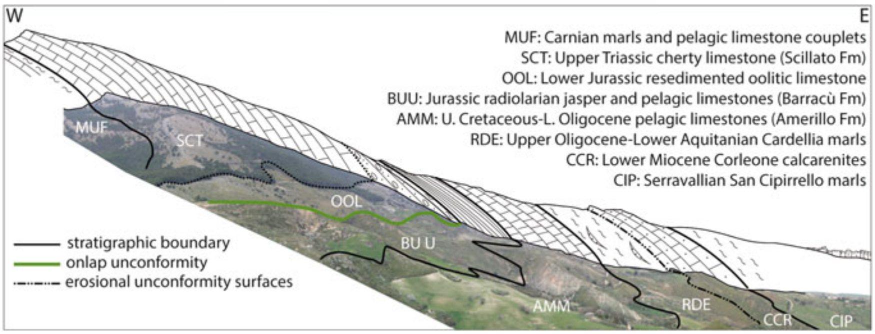


Fig. 2.47 Monte Cammarata natural section displaying the entire Upper Triassic-Miocene Sicanian succession (E Sicani Mountains, after Basilone 2013)

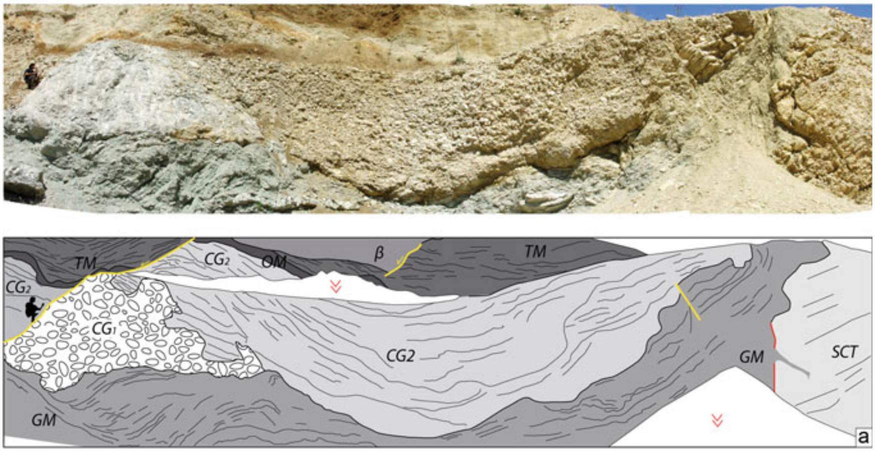


Fig. 2.48 Sinemurian channelized-belemnitic breccias (CG_2) cutting the underlying grey marls (GM) and well-cemented breccias (CG_1) (Pizzo Lupo section, E Sicani Mountains, after Basilone et al. 2014a, b)

Lithology and thickness: White thin- to thick-bedded (dm to m) oolitic grainstone, calcirudites with sponge and coral fragments and crinoidal grainstone, a few metres thick (Figs. 1–4 of Plate 23). Upwards, through an erosional boundary and channelized geometry, mud-supported conglomerates reach 15–20 m in thickness (Fig. 2.48). The conglomerate elements that are the product of the erosion and reworking of the underlying Upper Triassic cherty limestone of the Scillato Formation are merged both in unconsolidated greenish marls rich in belemnite rostra (Cozzo Ledera section) and in a well-cemented white mud limestone (Fig. 5 of Plate 23, Pizzo Lupo section, Basilone et al. 2013b, 2014a, b). Locally, about 15 m of greenish marls with benthic foraminifers and ostracods follow upwards (Broquet 1968).

Paleontological content: Belemnites, ostracods, *Dentalina* cfr. *varians* Terquem and in the topmost marls, benthic foraminifers of the genus *Lenticulina, Marginulina, Lingulina, Frondicularia* (see Sigal in Broquet 1965).

Chronostratigraphic attribution: The fossil content has allowed the belemnitic conglomerates to be dated to the Sinemurian and the green marls to the Pliensbachian (Carixian, see Broquet et al. 1967).

Stratigraphic relationships: The lower boundary is a sharp unconformity surface—marked by discordance and, locally, by erosion—with the cherty limestone of the Scillato Formation. The upper boundary is an unconformity, where the radiolarites of the Barracù formation rest with onlap stratal terminations.

Depositional environment: Slope to base-of-slope, dominated by grain flow (oolitic limestone) and debris flow (belemnitic conglomerates) gravity-induced processes.

Carg abbreviation: OOL

2.2.33 Palazzolo Formation

General remarks: The unit was established by Rigo and Barbieri (1959) when they were describing the Miocene shallow-water carbonates outcropping in the Siracusa area (SE Sicily). The proposed type section outcrops on the sinistral side of the Tellaro River, located in the proximity of the town of Palazzolo Acreide (near Siracusa).

Lithology and thickness: Bioclastic fine-grained yellowish calcarenites, white-yellowish laminated and bioturbated packstone, calcareous marls and thin to thick-bedded (15–20 cm) grey-yellowish marly limestone alternating with nodular marly limestone. Measured thickness is 110 m in the type section.

Paleontological content: Benthic foraminifers.

Chronostratigraphic attribution: Middle-Upper Tortonian.

Stratigraphic relationships: The lower boundary is a sharp surface with the shallow-water limestone of the Monti Climiti Formation. The unit dysplays lateral (heteropic)-to-vertical relationships with the marls of the Tellaro Formation.

Depositional environment: Open carbonate shelf.

Carg abbreviation: PAL

2.2.34 Pellegrino Formation*

General remarks: This unit was proposed in the framework of the geological map of the CARG project (Catalano et al. 2013a, b) and was based on the Pizzo Croce di S. Pantaleo section outcropping along the northern side of Monte Pellegrino (Fig. 2.49, near the town of Palermo), where its sedimentological features were studied in detail by Di Stefano and Ruberti (1998, 2000) and Basilone and Sulli (2018). The formation includes the shallow-water carbonate deposits with rudistid bioconstructions characterising the Upper Cretaceous rocks of the Panormide succession (Fig. 2.1; Table 2.5). The sub-vertical section outcropping along the Addaura coastal belt (see Fig. 2.49) immediately near Mondello (Palermo), is a spectacular site from which the lithostratigraphic characteristics of the unit are easily observable, as well as its stratigraphic boundaries. The paleontological and biostratigraphic content of the unit was thoroughly investigated by Montanari (1965) and Camoin (1983).

Synonyms and priority: These deposits, informally known as “rudistid limestone” (Caflisch 1966), comprise the deposits previously described as “reef

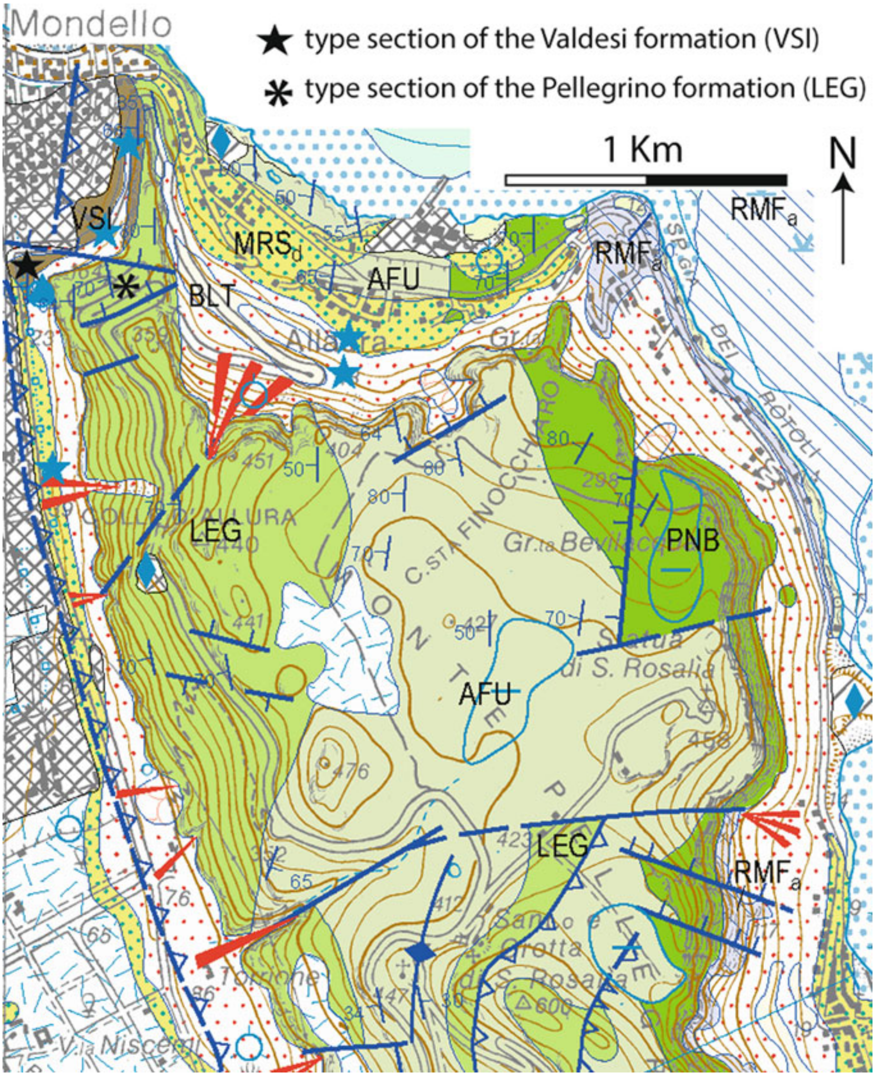


Fig. 2.49 Location of the proposed type section of the Valdesi (VSI) and Pellegrino (LEG) formations. The map was extracted from the geological Sheet n. 595 "Palermo" (1:50,000 scale map), performed by Catalano et al. (2013b)

Cretaceous limestone" (Baldacci 1886; De Stefani 1949), "ultradetritic deposits" (Montanari 1965). In the mining field these lithologies are known as "Perlato di Sicilia".[2]

Lithology and thickness: Caprinid and Radiolitid biolitites alternating with bioclastic calcarenites with *Orbitolina* sp., *Nerinea* sp., rudistid fragments and calcareous breccias (Figs. 1, 2 and 4 of Plate 24). The several recognised lithofacies, organized in shallowing upward cycles, consist of: (i) massive boundstone with rudistids in life position; (ii) thick-bedded coralgal rudstone-grainstone alternating with reworked oolitic grainstone and laminated wackestone-packstone with algae and benthic foraminifers (Figs. 2 and 8 of Plate 24); (iii) thick-bedded and massive conglomerates with coarse reef-derived elements (Fig. 3 of Plate 24); (iv) bioclastic grainstone-packstone with orbitolinids and rudistid fragments (Figs. 5–7 of Plate 24); (v) rare laminated fenestral limestone. Thicknesses range between 100 and 200 m. In Monte Pellegrino, a few metres (up to 5 m) of calcirudites and calcarenites with *Orbitoides media* (D'Archiac) and *Siderolites* cfr. *calcitrapoides* (*Orbitoides* limestone) follow upwards, through an unconformity submarine erosional surface marked by a cm-thick conglomerate whose elements derived from the dismantling of the underlying beds. Diabase dykes and pillow lavas (i.e., intraplate tholeiitic basalts, Bellia et al. 1981) are present in the Sparagio and Monaco sections (Fig. 1.1, San Vito Lo Capo Mountains).

Paleontological content: Caprinids (*Caprina schiosensis* Boehm, *Caprinula* sp., *Ichtyosarcolites rotundus* Polsak), Caprotinids (*Polyconites verneuilli* Bayle), Hippuritids, large Radiolitides (*Sauvagesia* sp., *Durania* sp.), hydrozoans, algae, corals and benthic foraminifers (*Orbitolina (Conicorbitolina) conica* (Moullade), *Cuneolina* cf. *pavonia* d'Orbigny, *Cuneolina* cf. *conica* D'Orbigny, *Trocholina elongata* Leupold, *Actinoporella podolica* Alth, *Conicospirillina basiliensis* Mohler). In the calcilutite intercalations, some planktonic foraminifers (*Rotalipora* spp.) are present. Recognised in the uppermost lithofacies are *Orbitoides tissoti* (Schlumberger), *O. media* (D'Archiac), *Siderolites* cfr. *calcitrapoides* (Lamark), *S. heracleae* (Arni).

Chronostratigraphic attribution: The markers of the *Orbitolina* (*Conicorbitolina*) *conica* biozone permit us to date the unit to the Upper Albian–Cenomanian. The rudistid fossil associations were assigned to the lower-middle Cenomanian by Camoin (1983) who also refers the upper beds of the unit, where *Ichthyosarcolites rotundus* Polsak and *Caprinula* sp. are abundant and *Orbitolina* spp. disappears, to the upper

[2]The "Perlato di Sicilia", extracted from the calcirudites of the Pellegrino formation, is marketed for ornamental use. More than half of the mining district of Custonaci (Trapani) is represented by quarries on these lithologies and most of them are located along the southern slope of Monte Sparagio. Its value varies according to the size of the sediment grain, i.e. the "pearls", and it is the most exported polished stone of the region.

Cenomanian. The uppermost beds represented by the *Orbitoides* lithofacies are dated to the Upper Campanian–Maastrichtian.

Stratigraphic relationships: The lower boundary is a paraconformity or a submarine erosional unconformity, characterised by downlap stratal terminations with the Capo Gallo limestone, marked by a hiatus comprising the upper Aptian-Albian p. p. time interval (Camoin 1983). Locally it is characterised by the occurrence of continental pelites (Costa Mazzone clays, Basilone and Di Maggio, 2016; Basilone et al. 2017) or by few centimetres of Fe-Mn crust (hardground, Basilone and Sulli, 2018). The upper boundary is an unconformity surface, where the pelagites of the Amerillo Formation rest in onlap and fill a dense network of neptunian dykes. Alternatively, it can be considered an erosional unconformity, where the Eocene shallow-water limestone of the Valdesi formation (Gallo and Pellegrino sections, Palermo Mountains) or the Miocene calcarenites of the Mischio formation (Sparagio section, San Vito Lo Capo Mountains) rest in downlap, marking a long hiatus.

Depositional environment: These deposits were formed in an open shelf environment, with isolated patch reef alternating with oolite sand shoal. This barrier, landwards, permitted the development of a protected lagoon and small tidal flats, and seawards, the resedimentation of reef-derived elements in a fore-reef and upper slope depositional setting.

Regional aspects: These carbonates outcrop with limited aerial extension in the Palermo Mountains (Pellegrino, Raffo Rosso, Monte Gallo and Carini sections), in the San Vito Lo Capo Mountains (Monaco, Sparagio, San Vito Lo Capo sections) and in the Madonie Mountains (Cefalù section). They largely outcrop in Central and Southern Appennines (Polsak et al. 1970; Carbone et al. 1971; Praturlon and Sirna 1976; Carannante et al. 2009 and reference therein)

Carg abbreviation: LEG

2.2.35 Piano Battaglia Reef Limestone*

General remarks: This unit was proposed in the frame of the geological maps of the CARG project (Basilone et al. 2001; Catalano et al. 2011a, b, 2013a, b) to describe the Upper Jurassic-Lower Cretaceous carbonate platform margin deposits inserted in the Panormide succession. These deposits are well-exposed at Piano Battaglia and Pizzo Dipilo (Madonie Mountains), where their biostratigraphic and sedimentological characteristics have been studied in detail by Catalano et al. (1974a). The following description is based on the detailed facies analysis conducted by Basilone (2011b) and Basilone and Sulli (2016) in the Palermo Mountains (Longa and Monte Pecoraro sections, Figs. 2.50, 2.51 and 2.52; Table 2.6).

Synonyms and priority: This unit has been described as "Tithonian detritic-organogen limestone" (Baldacci 1886), "Pizzo Canna limestone" (Lentini and Vezzani 1974), "biolitites and calcirudites with *Ellipsactinia* and nerineids" (Catalano et al. 1974a).

Lithology and thickness: The unit consists of carbonate platform margin deposits represented by three main facies associations with heteropic (lateral) relationships (FA 5-6-7 in Table 2.6). The reef complex facies association (PNB_a) consists of coral

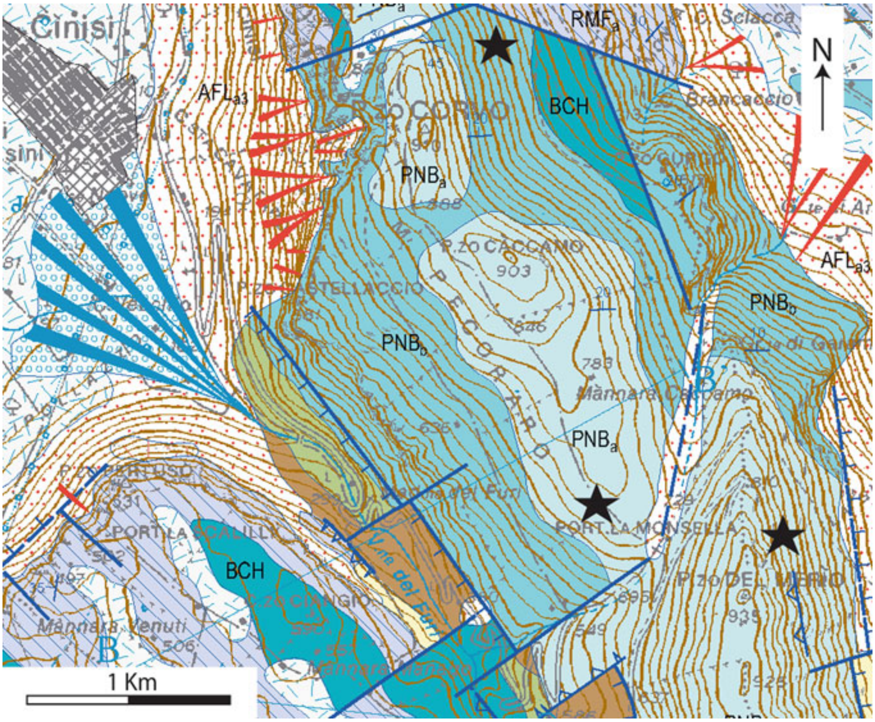


Fig. 2.50 Location of the paratype sections of the Piano Battaglia limestone (PNB) at Montagna Longa (Palermo Mountains). The map was extracted from the geological Sheet n. 585–594 "Partinico-Mondello" (1:50,000 scale), performed by Catalano et al. (2013a)

framestone and by *Ellipsactinia* sp. boundstone (Figs. I–K of Plate 25 and Fig. I of Plate 26). Characteristic feature of both the bioconstructed rocks is the intra-reef dissolution cavities, bordered by rim calcite cements and filled by white laminated vadose geopetal silt (Fig. J of Plate 25) or reddish pelagic mudstone with planktonic foraminifers (Figs. K and M of Plate 26). The fore-reef facies association (PNB_b) consists of alternating thick-bedded reef-derived carbonate breccias (rudstone) and thin-bedded coarse-grained grainstone (Fig. L of Plate 25 and Figs. L and N of Plate 26). The occurrence of well-washed, sorted and coarse-grained sands, thick cements, and cavities filled by silt suggest elevated hydrodynamic conditions along the shelf margin. Hydraulic competence was sufficiently high to promote the transport and dispersion of sediment. Oolite sand bar facies association (PNB_{c},) comprises oolitic and bioclastic grainstone—with reverse gradational structures locally—where the main components of the nuclei of the ooids are reef-derived bioclasts (Figs. G and H of Plate 25-01 and Fig. J of Plate 26), reef-derived fine breccias and coarse calcarenites organized in shallowing upward cycles (Fig. 2.53). The abundant, well-washed, fairly well sorted and reworked sediments reflect high-energy hydrodynamic conditions in an environment where bottom currents, mostly fair-weather

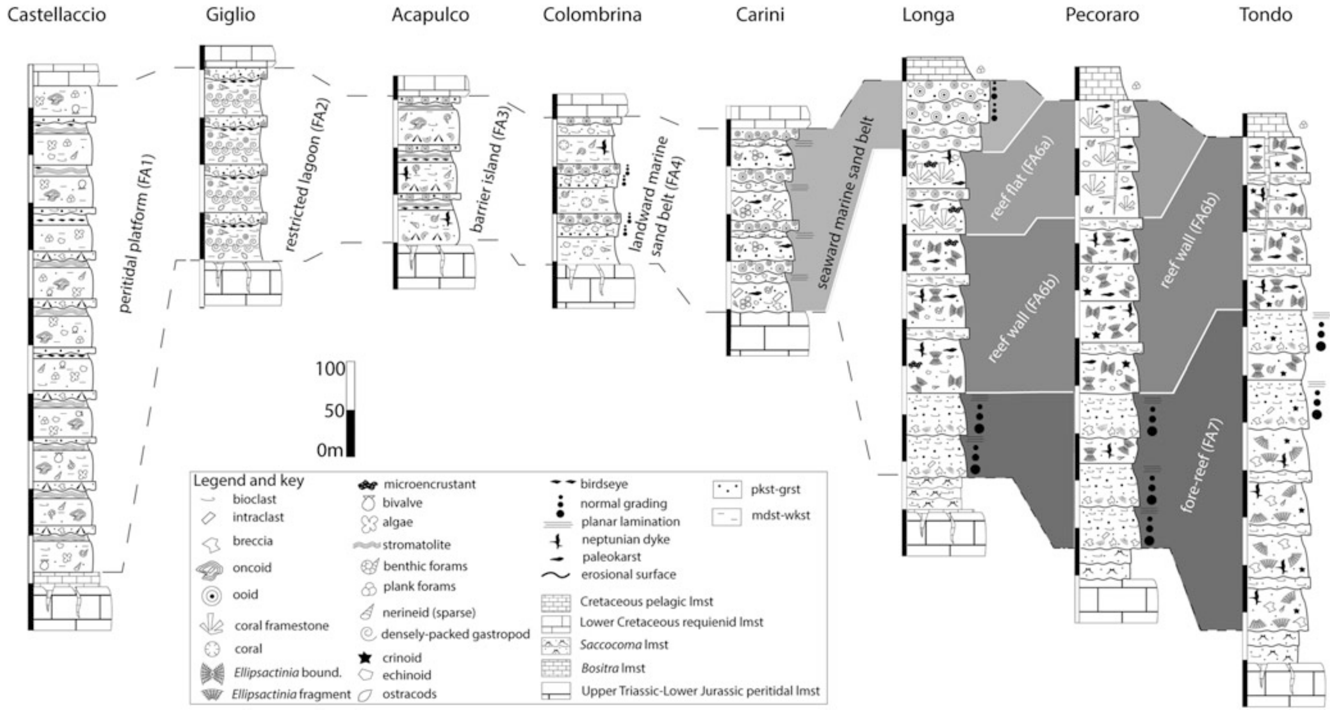


Fig. 2.51 Vertical distribution of facies in the measured stratigraphic and sedimentological columnar sections outcropping in the Palermo Mountains. Dotted lines highlight the correlation among the stratigraphic boundaries; white bold lines correlate the deposits forming the same Facies Associations (FAs), highlighting their lateral extent (after Basilone and Sulli 2016)

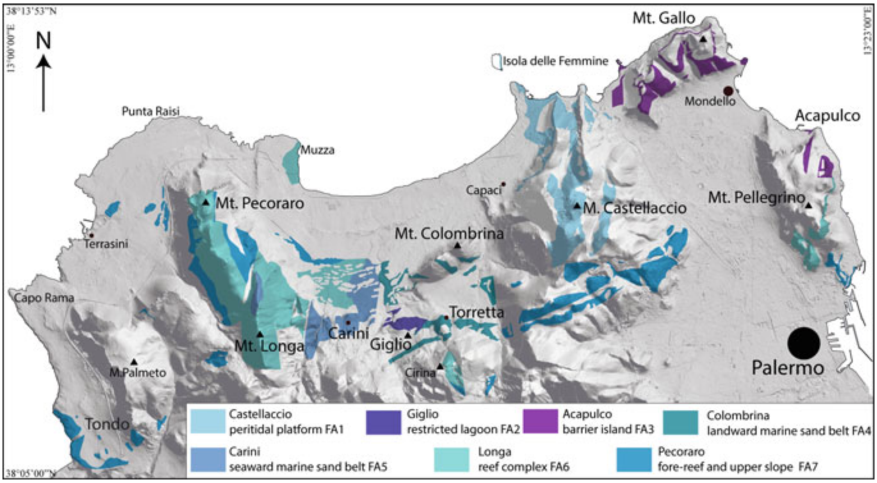


Fig. 2.52 Facies distribution map, where the mapped FAs of the Tithonian-Valanginian shallow-water carbonate are superimposed on the digital elevation model of the northern Palermo Mts

wave-base, caused strong erosion. Based on the predominantly reef-related composition, these sediment bodies are interpreted as bioclastic shoals on the external platform, in a sector landward of reef margin, where the abundance of algal, mollusc and coral sands was produced by the dismantling of the reef (Fig. 2.54). The uppermost portion of the succession is characterised by thin intercalations of calpionellid limestone of the Lattimusa (Monte Sparagio section, S. Vito Lo Capo Mountains) and neptunian dykes and dissolution cavities filled by the pelagic limestone with planktonic foraminifers of the Amerillo Formation (Fig. M of Plate 26, Piano Battaglia and Dipilo sections, Madonie Mountains and Pecoraro and Palmeto sections, Palermo Mountains). Outcropping thickness ranges from 300 to 500 m.

Paleontological content: Abundant *Ellipsactinia* sp., gastropods (*Nerinea* sp.), microproblematics (*Bacinella irregularis* Radoicic, *Tubiphytes morronensis* (Crescenti), *Lithocodium aggregatum* Elliot), algae (*Clypeina jurassica* Favre), corals, echinoid fragments, rare ammonites, bivalves, brachiopods, benthic foraminifers (*Protopeneroplis ultrangulata*, *Globochaete alpina, Trocholina alpina*) and calpionellids (*Calpionellopsis oblonga, Calpionellopsis simplex, Remaniella cadischiana, Tintinnopsella carpathica*) in the pelagic intercalations.

Chronostratigraphic attribution: On the basis of the fossil content and relative biozones the unit is dated to the Upper Tithonian-Valanginian (Fig. 2.55).

Stratigraphic relationships: The lower boundary is an unconformity surface—marked by downlap stratal terminations and, locally, by submarine erosion—with the Upper Jurassic *Saccocoma* limestone of the Buccheri Formation (Figs. 2.1, 2.4 and 2.56). The upper boundary is an unconformity—marked by an irregular erosional and karstified surface and neptunian dykes—with the Upper Cretaceous

Table 2.6 Summary of facies associations, with texture and main components, sedimentologic and diagenetic features, and environmental interpretation of each lithofacies of the Upper Tithonian-Valanginian shallow-water deposits of Piano Battaglia reef limestone and Pizzo Manolfo peritidal limestone (after Basilone and Sulli 2016)

	Lithofacies	Texture and main components	Sedimentary structures and diagenetic features	Environmental interpretation
Inner platform depositional facies	**FA1—Peritidal facies association** (Castellaccio section)			
	1a. Wackestone with algae and molluscs	m-thick grey bioturbated mudstone-wackestone and locally packstone with small nerineids, large diceratids, algae (*Salpingoporella* spp., *Cayeuxia piae*) benthic forams (*Pseudocyclammina lituus, Conicospirillina basiliensis*, miliolids, textularids), large oncoids, intraclasts (Fig. A in Plate 25). Small colonial corals in life position (patch reef, Fig. B in Plate 25) with some contribution from microbial organisms, which encrust other bioclasts and fill up the internal spaces of the framework	Burrows are filled by darkish pebbly mudstone; mollusc shells are frequently bored and micritized; oncoids are encrusted by *Bacinella irregularis* and *Lithocodium aggregatum* (Fig. A in Plate 25); mmcm dissolution cavities are filled by silt and bordered by scalenohedral dogtooth cements; radiaxial-fibrous syndepositional cements strengthen the reef framework	Protected lagoon
	1b. Fenestral limestone	dm-thick laminated stromatolitic peloidal-to-bioclastic packstone with lower fossil diversity (small gastropods, miliolids and textularids), coated grains, small (<1 mm) ooids, locally broken and eroded	mm-sized planar lamination and planar-type bird's eyes filled by sparry calcite and geopetal internal sediment (Fig. A in Plate 26); ooids with tangential and surficial structure	Tidal flat
	1c. Loferitic breccias	dm-thick in situ breccias with blackish angular coarse elements deriving from fragmentation of semi-consolidated deposits, arranged in tepee-type structures	Polygonal desiccation cavities (sheet cracks) partially enlarged by dissolution and filled by vadose geopetal silt and sparry calcite (Fig. 5 in Plate 25); lower erosional boundary	Algal mats in supra-tidal areas
	1d. Reworked grainstone	cm-thick grainstone and packstone with intraclasts, bioclasts (gastropods, coral and algae fragments, miliolids and cuneolinids) and ooids	Lamination and gradation; ooids with radial-fibrous structure (Fig. B in Plate 26), frequently broken and eroded	Tempestites
	FA2—Back barrier restricted lagoon facies association (Giglio section)			
	2a. Low-biodiversity mudstone	m-thick blackish peloidal mudstone with intact or partly disarticulated ostracod shells and few small gastropods (Fig. C in Plate 26)	Bioturbations	Restricted lagoon
	2b. Wackestone with densely-packed nerineids	m-thick dark-grey wackestone with densely-packed and similarly oriented small nerineids (Fig. D in Plate 25), benthic forams, few ostracods, microbialite encrustations and radial-fibrous ooids	Gastropod shells are filled by white vadose geopetal silt and later calcite cement (Fig. D in Plate 25); burrows and small neptunian dykes are filled by yellowish fine laminated silt (internal sediment)	Restricted lagoon

(continued)

Table 2.6 (continued)

	Lithofacies	Texture and main components	Sedimentary structures and diagenetic features	Environmental interpretation
	2c. Fenestral limestone	cm-thick peloidal packstone with birds eyes, benthic forams, small gastropods	Planar lamination; aligned cavities	Inter-tidal
	2d. Lithoclastic and intraclastic breccias	dm-thick graded floatstone with heterometric rounded darkish pebble conglomerates with large gastropod and thin to thick-shelled bivalve fragments, small corals, crinoids, ooids	Erosional basal boundary marked by Fe-Mn crust (ravinement surface, Fig. D in Plate 26); surficial ooids with tangential laminae	Transgressive lag
	2e. Washed bioclastic grainstone	cm-thick coarse grainstone-packstone with ooids, mollusc fragments, benthic forams, echinoid spines, algae, *Lithocodyum aggregatum*, *Tubiphytes* sp.	Normal gradation and lamination; ooids with tangential structure	Sand shoal
	FA3—Barrier island-sand shoal facies association (Acapulco section)			
	3a. Bioclastic mudstone	m-thick light grey bioturbated mudstone with benthic forams, *Salpingoporella annulata, Thaumatoporella* sp., ostracods and molluscs	Burrows are filled by packstone with *Cayeuxia* sp. and darkish pebbles eroded from the host deposits	Lagoon
	3b. Fenestral limestone	cm-thick peloidal and oolite packstone with benthic forams, algae, small surficial ooids	Aligned cavities and laminations; ooids with radial-fibrous structure	Inter-tidal
	3c. Oolitic grainstone	Few dm-thick darkish oolitic grainstone and packstone with small and well developed yellowish ooids, frequently broken and deformed, whose nuclei mainly consist of *Salpingoporella* sp., *Cayeuxia* sp., gastropods fragments, and intraclasts derived from the eroded mudstone of the adjacent subtidal FA3a	Normal gradation, lower erosional surface; ooids display thick calcite film with tangential structure (Fig. E in Plate 26)	Oolite sand bar
	3d. In situ breccias	Few dm-thick rudstone, whose elements deriving from the erosion of the oolitic grainstone and bioclastic mudstone (Fig. E in Plate 25)	Tepee-like structures, erosional lower boundary	Supra-tidal

(continued)

Table 2.6 (continued)

	Lithofacies	Texture and main components	Sedimentary structures and diagenetic features	Environmental interpretation
Outer platform depositional facies	**FA4—Landward sand belt facies association** (Colombrina section)			
	4a. Bioclastic wackestone	m-thick wackestone with peloids, algae, molluscs (small nerineids and large diceratids, Figs. F in Plate 25, F in Plate 26), benthic forams (textularids and miliolids), oncoids, angular intraclasts and microbialites	Small oncoids are frequently micritized; microbialites display planar to undulate-type morphology, stabilizing and/or encrusting bioclasts and intraclasts	Protected lagoon
	4b. Bioclastic sand	dm-thick bioclastic coarse- to fine-grained grainstone and rudstone with small *Nerinea* sp., large fragments of bivalves, corals, philloyd-type algae, benthic forams, microproblematics, dasycladales, echinoid plates, intraclasts with subangular to rounded shapes and fine-grained (1 mm) ooids (Fig. 6G)	Normal gradation and trattive structures. Small to large cavities, filled by white geopetal silt and bordered by fibrous calcite cements. Lower boundary is an irregular submarine erosional surface	Sand shoal
	4c. Oolitic packstonegrainstone	dm-thick (max 30 cm) coarse to fine grained oolitic packstone-grainstone with bioclasts (*Trocholina alpina*, miliolids, cuneolinids, echinoid spines and plates, *S. annulata, Cayeuxia* sp., small sponges, bryozoans, microproblematics), peloids, aggregate and surficially coated ooid sands with admixture of skeletal grains (Figs. G in Plate 25, H in Plate 26)	Normal gradation; the ooid grains (2 mm wide in average), frequently broken and abraded, display tangential calcite laminae enveloping bioclasts, pellets and intraclasts and are interested by microboring, destroying the original fabric	Sand shoal
	FA5—Seaward sand belt facies association (Carini section)			
	5a. Reef-derived breccias	m-thick floatstone and rudstone with reef-derived elements are merged in coarse grainstone with intraclasts, algae, abundant crinoid (steams), echinoid (plates) and mollusc fragments	Gradation	Back-reef debris/internal apron
	5b. Coarse grained bioclastic grainstone	dm-thick well-washed and sorted grainstone with *Scleractina*, algae (*S. pygmaea,Triploporella neocomiensis*, *Cayeuxia* sp., *Rivularia* sp.), benthic foraminifers (*Protopeneroplis striata, P. trochangulata*, *T. alpina, Kurnubia palastiniensis*), abundant crinoid stems, echinoid plates, gastropod, brachiopod and bivalve fragments (Fig. I in Plate 26)	Planar lamination and gradation. Erosional lower boundary. The reef-derived fragments are encrusted by *L. aggregatum* and *B. irregularis*	Back-reef debris/internal apron
	5c. OOLITE grainstone	Grainstone with well-developed ooid grains (more than 2 mm), frequently broken and abraded (Fig. J in Plate 26), and bioclasts like coral, echinoid, bryozoan, mollusc and stromatoporid fragments, benthic foraminifers and phylloid algae; intraclasts are frequent and have predominantly rounded shapes	Gradation, erosional lower boundary; the ooids, displaying tangential structures of the calcite laminae and boring to strongly micritized rims, enveloped reef-derived bioclasts	Seaward marine sand belt

Table 2.6 continued

	Lithofacies	Texture and main components	Sedimentary structures and diagenetic features	Environmental interpretation
Outer platform depositional facies	**FA6—Reef complex facies association** (Longa section)			
	6a. Coral framestone	m-thick massive coral framestone, where the main builder organisms are large colonial corals in life position (Fig. I in Plate 25), with the skeletal framework high more then 2 m and some metres wide, associated with molluscs, microproblematic and encrusting organisms, benthic forams, algae, microbialites, serpulids, bryozoans,		Reef flat
	6b. *Ellipsactinia* boundstone	m-thick massive boundstone dominated by stromatoporoids (*Ellipsactinia* sp.), which are present as isolated specimens or as densely packed mound-shaped structures (Figs. K in Plate 25). Corals are rare and for the most represented by large solitary morphologies, frequently enveloped by microbialites (Fig. J in Plate 25). Internal sediment of bioconstructions is represented by intraclastic breccias and intrareef bioclastic packstone-grainstone with sponges, bryozoans, echinoids, bivalves, small nerineids, annelid tubes and benthic foraminifers (Fig. L in Plate 26). The main biota components are associated with *Nerinea* sp., *L. aggregatum, B. irregularis, Koskinobulina socialis, Tubiphites morronensis, K. palastiniensis, T. alpina, Pseudocyclammina* sp., *S. pygmaea, Thaumatoporell*a sp., serpulids, bryozoans and large crinoid stems	Characteristic features of both the bioconstructed lithofacies are the intrareef dissolution cavities, bordered by rim calcite cements and filled by white laminated vadose geopetal silt (Fig. L in Plate 25) or reddish pelagic mudstone with planktonic foraminifers (Fig. K in Plate 26)	Reef wall
	FA7—Fore-reef to upper slope facies association (Pecoraro and Tondo sections)			
	7a. Reef-derived breccias	m-thick massive grey floatstone with darkish variously size-grained and angular reefderived breccia elements merged in a very coarse grain sized bioclastic grainstone with bivalve and gastropod fragments, small ammonites and small sponges	Chaotic fabric	Proximal fore-reef

(continued)

Table 2.6 (continued)

	Lithofacies	Texture and main components	Sedimentary structures and diagenetic features	Environmental interpretation
	7b. Coarse bioclastic grainstone	dm-thick very coarse-grained bioclastic grainstone with *Ellipsactinia* sp., coral and algae fragments (Fig. M in Plate 26), small sponges, abundant crinoid ossicles, echinoid spines and plates, bryozoans, *T. morronensis, T. obscurus*, bivalve fragments, *Nerinea* sp., *Apthycus* sp., and abundant *P. striata and P. trochangulata*, and minor ooids and intraclasts	High sorting, lamination, gradation. Frequently, a thin calcite film envelops bioclasts. Cavities and vugs, displaying geopetal fabric and bordered by scalenohedral dogthoot cements, are filled by grey and reddish pelagic limestone rich in planktonic foraminifers (Fig. M in Plate 26)	Distal fore-reef
	7c. Calciturbidites	dm-thick well-rounded fine-grained laminated grainstone with bored and micritized bioclasts (abundant *Ellipsactinia* sp. and algae fragments), benthic foraminifers and thin-shelled molluscs	Poorly sorted, lamination and gradation, bioclasts and intraclasts are enveloped by thin calcite film (Fig. N in Plate 26)	Upper slope

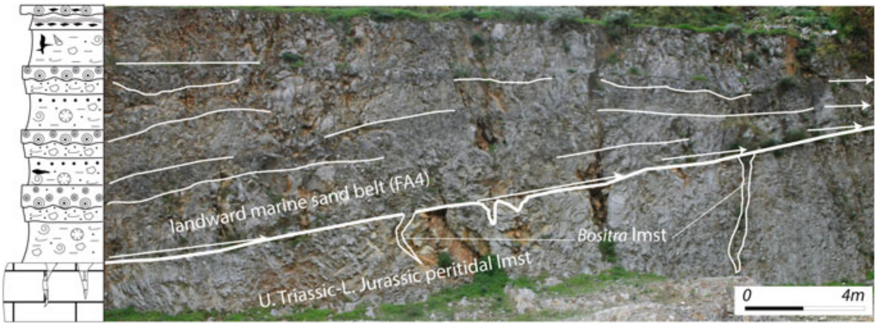


Fig. 2.53 Lower boundary of the FA4 (Colombrina section) marked by onlap stratal terminations with the Upper Triassic–Lower Jurassic peritidal limestone, which is cut by neptunian dykes filled by *Bositra* pelagic limestone (Torretta outcropping site, Palermo Mountains)

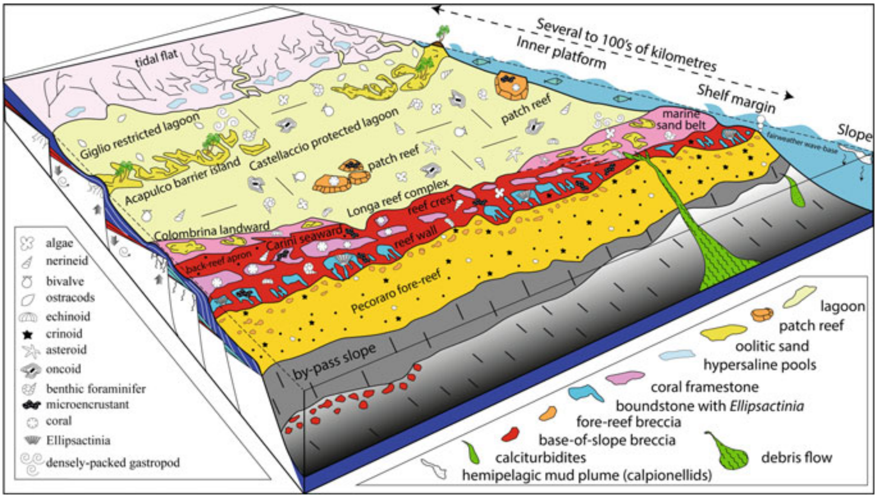


Fig. 2.54 Depositional model of the Upper Tithonian–Valanginian Panormide carbonate platform pointing out the distribution of the depositional facies and environments along the shelf (after Basilone and Sulli 2016)

pelagic limestone of the Amerillo Formation or with the Oligocene hemipelagic marls of the Gratteri Formation that rest with onlap stratal terminations and infilling geometry, suggesting large hiatus.

Depositional environment: Carbonate platform high-energy reef margin changing seaward to a fore-reef/upper slope and landward to an oolitic sand barrier (Fig. 2.54; Table 2.6).

Regional aspects: These deposits outcrop in the Palermo (e.g., Pellegrino, Pecoraro, Palmeto sections, Fig. 2.22), San Vito Lo Capo (Sparagio and Monaco sections, Fig. 2.4) and Madonie Mountains.

Carg abbreviation: PNB

2.2.36 Pizzo Manolfo Limestone*

General remarks: This unit was proposed in the frame of the geological maps of the CARG project (Basilone et al. 2001; Catalano et al. 2011a, b, 2013a, b) to describe the Upper Jurassic-Lower Cretaceous shallow-water carbonates inserted in the Panormide succession (Table 2.5), based on the Castellaccio type section (Palermo Mountains), where the unit and its stratigraphic boundaries are well-exposed and easily accessible. The following description is based on the detailed facies analysis conducted by Basilone and Sulli (2016) in the Palermo Mountains (Figs. 2.51 and 2.52; Table 2.6). The biostratigraphic and facies characteristics of an incomplete supporting section in the coastal belt of Sferracavallo (Palermo) was studied by Nicchitta (1998).

Synonyms and priority: This unit was informally described as "*Nerineids* and *Diceratids* limestone" studying in detail the outcrops of Palermo and Madonie Mountains (Catalano et al. 1974a, 1979; Abate et al. 1978).

Lithology and thickness: Darkish-grey micritic limestone (wackestone-packstone) with gastropods (*Nerinea* sp., Fig. D of Plate 25), large diceratids (Fig. F of Plate 25), large oncoids whose nucleus are represented by algae fragments, benthic foraminifers and corals (Fig. A of Plate 25, subtidal lithofacies) alternating with stromatolitic and loferitic limestone (Fig. C of Plate 25), consisting of peloidal laminites with fenestrae (e.g. micrite with birds eyes, Figs. A and B of Plate 26), locally dolomitized (tidal flat lithofacies); locally, loferitic breccias are the subaerial erosional product of the underlying deposits (Fig. C of Plate 25, supratidal lithofacies). This facies association (CTI_a, Table 2.6), organized in shallowing upwards cycles, laterally changes to sand bar facies association (CTI_b, Table 2.6) represented by oolitic grainstone-packstone with fibrous ooids (Figs. E and G of Plate 25 and Figs. E–H of Plate 26) and bioclastic calcirudites with corals and algae (Fig. H of Plate 25). Outcropping thickness ranges from 250 to 450 m.

Paleontological content: Diceratids, gastropods (*Nerinea* sp.), cyanoficean (*Cayeuxia* sp.) and dasycladacean (*Clypeina jurassica* FAVRE AND RICHARD, *Campbeliella striata* CAROZZI, *Salpingoporella annulata* CAROZZI, *Actinoporella podolica* ALTH) algae, benthic foraminifers (*Montsalevia salevensis* CHAROLLAIS, BRONNIMANN and ZANINETTI, *Vercorsella camposaurii* (SARTONI and CRESCENTI), *V. laurentii* (SARTONI and CRESCENTI), *Campanellula capuensis* DE CASTRO, *Debarina* sp., *Belorussiella* sp., *Praechrysalidina infracretacea* LUPERTO-SINNI) and *Bacinella irregularis* RADOICIC.

Chronostratigraphic attribution: On the basis of the fossil content comprised in the *Clypeina jurassica* biozone (Chiocchini and Mancinelli 1977; Chiocchini et al. 1994) and the *Salpingoporella annulata* and *Campanellula capuensis* biozones (De Castro 1991), the unit is dated to the Upper Tithonian-Neocomian time interval (Fig. 2.55).

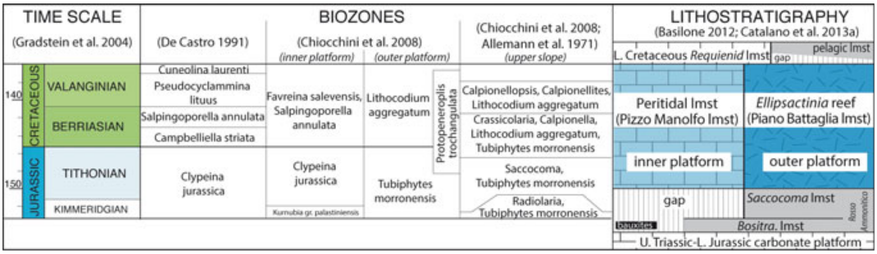


Fig. 2.55 Biozonation (schemes of Allemann et al. (1971) for calpionellids; Chiocchini et al. (2008) and De Castro (1991) for benthic foraminifers and algae) and lithostratigraphy of the Upper Jurassic–Lower Cretaceous carbonate platform deposits of Western Sicily (time scale from Gradstein et al. 2004). The Pizzo Manolfo peritidal limestone represents the inner platform facies associations, while the Piano Battaglia reef limestone the outer platform (after Basilone and Sulli 2016)

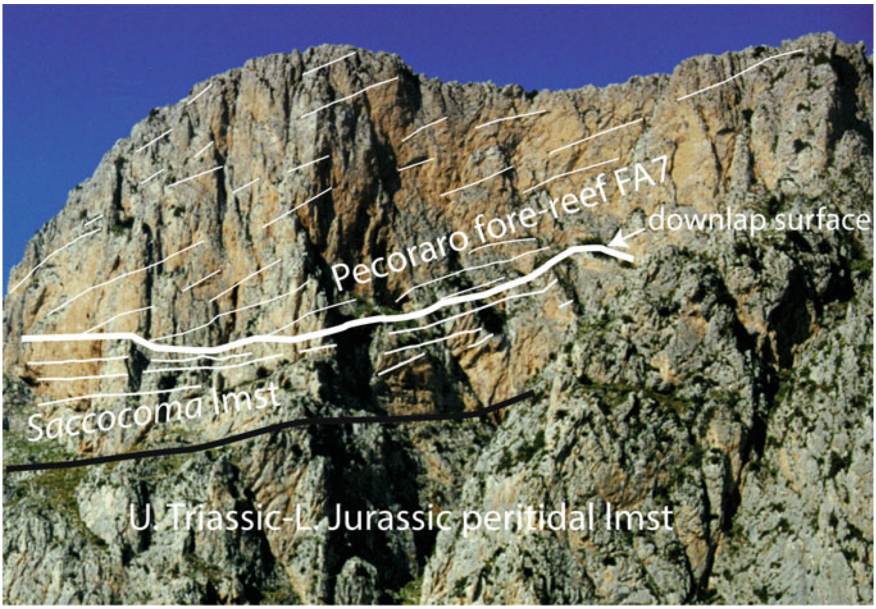


Fig. 2.56 The FA7 carbonates of the Piano Battaglia reef limestone rest above the *Saccocoma* slope-to-basin limestone, displaying clinostratification and downlap stratal terminations (Monte Pecoraro, Palermo Mountains)

Stratigraphic relationships: The lower boundary is an unconformity surface—marked by onlap stratal termination—with the *Bositra* limestone of the Buccheri Formation (e.g., Pizzo Manolfo section, Fig. 2.22). It can be an angular unconformity surface with the eroded, karstified and rotated beds of the Upper Triassic shallow-water limestone of the Capo Rama and Sciacca formations (Monte Gallo section, Fig. 2.57). The upper boundary is a paraconformity surface with the Capo Gallo limestone, locally marked by the occurrence of Fe–Mn crusts and calcareous pelagites (Colombrina section). Lateral (heteropic) relationships with the Piano Battaglia reef limestone have been evidenced (Fig. 2.52) (Catalano et al. 2013a; Basilone and Sulli 2016).

Depositional environment: Textural features and paleontological content suggest back-reef lagoon environments for these deposits, locally with restricted circulation, becoming landward a tidal flat subjected to cyclic subaerial exposition (e.g., peritidal cycles), where the interlayered bioclastic material produced by high-energy environmental conditions is believed to be the product of storm events (tempestites, Di Stefano et al. 1997b; Nicchitta 1998). Detailed facies analysis has highlighted that these lagoonal deposits change seaward to a sand shoal margin and/or to a reef barrier (Fig. 2.54; Table 2.6, Basilone 2011b; Basilone and Sulli 2016).

Fig. 2.57 Angular unconformity between the Upper Triassic–Lower Jurassic peritidal limestone of the Capo Rama and Sciacca formations and the Upper Tithonian-Valanginian Pizzo Manolfo limestone (FA1-3), where Jurassic bauxites fill the irregular erosional and karst surface (northern side of Monte Gallo)

Regional aspects: These deposits outcrop both in the Palermo Mountains (Castellaccio and Gallo sections) and in the Madonie Mountains (Dipilo-Monte Purraccia section).

Carg abbreviation: CTI

2.2.37 Rabbito Formation

General remarks: This unit was suggested by Patacca et al. (1979), describing the proximal basin facies of the Modica Formation drilled by the Rabbito 1 well.

Synonyms and priority: These deposits partly correspond to the lower portion of the Villagonia formation proposed by Rigo and Barbieri (1959).

Lithology and thickness: Coarse-grained resedimented limestone with shallow-water derived elements, 100–350 m thick. This facies association displays litho-bioclastic and oolite packstone with small rounded intraclasts, algae fragments (*Thaumatoporella* spp., *Cyanophycean*), coated grains, crinoidal plates and arenaceous foraminifers. Some levels of intraformational pebbly mudstone also occur. Volcanic intercalations are present.

Paleontological content: *Globochaete* sp., *Stomiosphaera* sp., *Lagenidae*, *Involutina liassica*, *Frondicularia exagona*, *Spirillina* sp., echinoid and algae fragments, *Apthycus*, arenaceous foraminifers (*Ammodiscidae*, *Textulariidae*, *Ataxophragmiide, Lituolidae, Ophtalmiidae*).

Chronostratigraphic attribution: The unit was dated to the Hettangian-Sinemurian and, locally, up to the Pliensbachian.

Stratigraphic relationships: The lower boundary is an unconformity with the black shale of the Streppenosa Formation (Fig. 2.45). In the upper portion of the succession, lateral (heteropic) relationships with the shallow-water deposits of the Siracusa Formation (i.e., Inici Formation) are observed in the Siracusa 1 well (Patacca et al. 1979). The upper boundary is a sharp surface with the ammonite limestone of the Buccheri Formation.

Depositional environment: The coarse-grained resedimented carbonates are related to slope depositional environments, becoming the distal sectors of the Ragusa belt represented by the pelagic limestone of the Modica Formation (Patacca et al. 1979).

Regional aspects: The unit extends in the subsurface of the entire Ragusa belt and was drilled primarily by the boreholes located in the Ragusa offshore.

2.2.38 Ragusa Formation

General remarks: This formation was proposed by Rigo and Barbieri (1959) while studying the San Leonardo river section, located immediately to the north of Ragusa (SE Sicily) and the Monterosso Almo section (20 km North of Ragusa). In

Western Sicily, similar deposits have been described by Montanari (1961, 1982), Mascle (1979), Vitale (1990) in reference to the Sciacca Mountains (Saccense and Hyblean successions, Fig. 2.1). The formation has been mapped in the "S. Margherita Belice" 1:50,000 scale-map of the CARG project (Di Stefano et al. 2013).

Synonyms and priority: This unit has been called "Ragusa limestone", known for its oil split, "marly limestone with cherty nodules" by Travaglia (1880), "middle and lower portion of the succession" by Cafici (1880), "part of the Lower and Middle Miocene" by Baldacci (1886), "Aquitanian–Langhian" by Floridia (1960), "*Lepidocyclina* limestone" by Mascle (1979) and "*Lepidocyclina* and rodoficean limestone" by Catalano and D'Argenio (1982). It also corresponds to the rocks described by Rocco (1959) in the Gela 1 well.

Lithology and thickness: The formation has been subdivided in two members. The lower Leonardo member consists of thick-bedded white marly limestone alternating with white to grey marls. Biocalcarenites with *Lepidocyclina* sp. and rodoficean algae and resedimented yellow biocalcirudites are frequently intercalated. The upper Irminio member, downlapping above the older deposits, consists of grey-yellowish marly thick-bedded calcarenites alternating with thin-bedded (10–15 cm-thick) marly limestone. The reworked deposits are fine grain-sized porous calcarenites, displaying sedimentary structures formed by waves and currents, such as sigmoidal and oblique stratification, planar, concave and cross (ripples) lamination. They contain an abundant shallow-water fauna, mostly large benthic foraminifers. Outcropping thickness of the entire succession ranges between 50 and 200 m. The Leonardo member was drilled up to 400 m in the Leonardo1 well (Ragusa), 20–50 m in the Sciacca area. The Irminio member reaches 130 m in thickness in the type section and 60 m in the Sciacca Mountains.

Paleontological content: Abundant large benthic foraminifers (lepidocyclinids and *Miogypsina* spp., *Miogypsinoides* spp., *Asterigerina* spp.), bivalves [*Aturia aturi* (BASTEROT)], echinoids, thoot of *Carcharodon* sp., *Squalodon* sp. (Trevisan 1949), red algae nodules, melobesiae and crinoids are diffused in the calcareous beds of the upper member and in the coarse calcarenite intercalations of the lower member.

Chronostratigraphic attribution: The markers of the *Globigerina opima opima, Globigerina ciperoensis ciperoensis, Globorotalia kugleri* and *Globoquadrina dehiscens dehiscens* planktonic foraminifer biozones date the unit to the Upper Oligocene–Lower Miocene. High-resolution stratigraphy of borehole successions in SE Sicily refer the top of the unit to the lower Langhian (Di Stefano et al. 2011).

Stratigraphic relationships: The lower boundary is an unconformity surface with the Amerillo Formation, locally marked by the presence of a 5–10 m-thick polygenic conglomerate layer with calcareous and reddish to brown quartz elements. In the Sciacca area, the Irminio member outcrops with lateral discontinuity and the lower boundary of the Ragusa Formation can be considered an unconformity where the Leonardo member lies with discordance on the pelagites of the Amerillo Formation or, through an erosional surface, above older units. The upper boundary is a sharp surface, with local transitional contact with the Tellaro Formation and an unconformity, marked by a hiatus with the Palazzolo Formation. In Western Sicily, it is an unconformity surface with the Corleone glauconitic calcarenites and it is marked by downlap relationships.

Depositional environment: Carbonate ramp.

Regional aspects: These lithologies are widely outcropping in the Hyblean region (SE Sicily) and particularly in the Ragusa area, where they have been mapped in detail by Grasso (1997) and studied by the boreholes (Patacca et al. 1979; Di Stefano et al. 2011). They also outcrop in the Sciacca area (SW Sicily), particularly at Rocca Nadore, Monte San Calogero and Pizzo Telegrafo (Di Stefano et al. 2013).

Carg abbreviation: RAG

2.2.39 San Cipirello Marls

General remarks: The unit, described by Ruggieri (1966), was proposed by Ruggieri and Sprovieri (1970) while studying the type section located in the town of San Cipirello (Palermo).

Synonyms and priority: "Miocene clay" (Di Napoli 1937), "clays with *Globigerina*" (Borghi 1937).

Lithology and thickness: Grey to bluish marls and marly clays (33% in $CaCO_3$) with quartz sands, glauconite, pyrite and a rich planktonic fauna. Upwards, quartz, quartz-micaceous and glauconitic sandstones are intercalated. Outcropping thickness reaches 200 m.

Paleontological content: The rich content of calcareous plankton consists both of planktonic foraminifers and calcareous nannofossils; benthic foraminifers (*Uvigerima barbatula* Macfad), echinoids, crustaceans, bryozoans and fish fragments are also abundant. Borghi (1937) reported finding *Aturia aturi* (Basterot) in the type section.

Chronostratigraphic attribution: The markers of the *Orbulina suturalis–Paragloborotalia peripheroronda* (MMI 5), *Dentoglobigerina altispira altispira* (MMI 6), *Paragloborotalia partimlabiata* (MMI 7), *Neogloboquadrina atlantica preatlantica* (MMI 8) and *Neogloboquadrina acostaensis* (MMI 11) planktonic foraminifer biozones and of the *Sphenolithus heteromorphous/Reticulofinestra peseudoumbilicus*, *Calcidiscus praemacintyrei/Discoaster kugleri* (MNN 6a, 7a), *Minilytha convallis* calcareous nannofossil biozones warrant the dating of this unit to the upper Langhian–lower Tortonian time interval (Sprovieri et al. 1996a).

Stratigraphic relationships: The lower boundary is a conformity surface with the Corleone calcarenites; locally, it is an erosional unconformity with older units (Maranfusa section). The upper boundary is an erosional unconformity with the conglomerates and sandstones of the Castellana Sicula or Terravecchia formations (Cozzo Riddocco section, W Sicani Mountains).

Depositional environment: The hemipelagic marls are believed to have been deposited in a slope depositional environment, up to—500 m of paleobathymetry, as suggested by the occurrence of psicrosferic ostracods (Ruggieri and Sprovieri 1970).

Regional aspects: This unit commonly outcrops in Western Sicily (Sicani, Trapani and Castelvetrano Mountains) and pertains to the Trapanese and Saccense and to the Sicanian deep-water successions.

Carg abbreviation: CIP

2.2.40 Santa Maria del Bosco Limestone

General remarks: Originally recognised by Broquet et al. (1966) and Mascle (1979), these deposits were successively described in detail by Abate et al. (1982c), Di Stefano et al. (1986) and Di Stefano and Gullo (1987) and mapped by Di Stefano and Vitale (1993) and Di Stefano et al. (2013). Recent biostratigraphic and petrographic studies (Bucefalo Palliani et al. 2002), conducted in the type area of Monte Genuardo (Giuliana section, Sicani Mountains), have defined the lithostratigraphic characteristics and the time of deposition of the unit.

Lithology and thickness: Thin-bedded (15–45 cm) white and greyish calcilutites (wackestone) with chert nodules and bedded cherts, radiolarians, ammonites, belemnites and ichnites. In the lower portion of the succession, cross laminated calcarenites with echinoid fragments and ammonites and marls with benthic foraminifers are intercalated. Upwards, the pelagic limestone displays nodular texture and thick intercalations of pillow lavas and ialoclastites, related to intraplate magmas formed during extension and crustal thinning (Ferla et al. 2002b). Thickness ranges from 35 m (Campofiorito section) up to 100 m (Giuliana section), where the basalt intercalations reach 50 m in thickness.

Paleontological content: Radiolarians, calcareous nannofossils, sponge spiculae, benthic foraminifers (*Paralingulina* gr. *tenera* (Bornemann), *Marginulina prima* d'Orbigny, *Berthelinella* sp., *Brizalina* sp., *Falsopalmula* sp.), echinoids, ammonites.

Chronostratigraphic attribution: Upper Pliensbachian–Lower Bajocian.

Stratigraphic relationships: The lower boundary is a paraconformity or a transitional contact with the Lower Jurassic "oolitic limestone"; the upper boundary is an unconformity—marked by onlap stratal terminations—with the Jurassic radiolarites of the Barracù formation (Di Stefano et al. 2004, 2013).

Depositional environment: Deep-water (lower depositional slope-to-basinal flat).
Regional aspects: This unit outcrops exclusively in the Sicani Mountains.
Carg abbreviation: BOO

2.2.41 Sciacca Formation°

General remarks: This unit represents the oldest outcropping carbonate platform rocks in Sicily and pertains to various Mesozoic-Paleogene carbonate successions (see Figs. 2.1, 2.4, 2.22 and 2.24). The name was informally used to describe the Upper Triassic carbonate platform unit drilled in the Sciacca area and its offshore. In the Sciacca 1 well, realised by AGIP, these lithologies were drilled for about 2500 m (Antonelli et al. 1991). Frixa et al. (2000) propose the use of the Sciacca Formation for the coeval carbonate platform facies of the Hyblean subsurface (Gela and Naftia formations), highlighting that these rocks display east-west lateral continuity in the offshore of southern Sicily. The unit, based on the description of the proposed type section reconstructed along the eastern side of Monte Inici (Fig. 2.42, Castellammare del Golfo), has been officially adopted by ISPRA for the geological maps of the CARG project, and it is included in the Validated Units of the Italian Formations Catalogue (Basilone et al. in Delfrati et al. 2006b).

Synonyms and priority: The unit is the equivalent of the Taormina formation of Rigo and Barbieri (1959), describing the dolostones belonging to the Longi-Taormina unit of Amodio Morelli et al. (1976) and to the Gela Formation of Patacca et al. (1979), crossed by several oil exploration wells (AGIP Mineraria) in the Hyblean Plateau.

Lithology and thickness: White and light greyish thick-bedded (several metres of) massive dolostone often fractured and karstified with algae and bivalves cyclically alternating with stromatolitic and fenestral dolostone and with yellowish dolomitized marls. Due to the intensive dolomitization process that masks the original texture, the rock appears massive and crystalline (porous dolomite). The detailed study of the outcropping type section proposed here, reconstructed along the western side of Monte Inici (Fig. 2.58), highlights the occurrence of a thick shallow-water succession consisting of several lithofacies. Organized in shallowing upwards cycles (peritidal and subtidal cycles), from the bottom of each cycle, they consist of: (i) metre-thick massive dolomitized wackestone-packstone with algae and molluscs (*Megalodus* spp.) frequently in life position, intraclasts, peloids, bioclasts, oncolites and coralgal boundstone (patch reef) (subtidal lithofacies, Fig. 1 of Plate 20); (ii) dm-thick white to brown stromatolitic dolostone with tabular geometry. The algae (mostly represented by *Cianophycean* "*Spongiostromata*" type) display planar, undulate to irregular lamination (LLH type sensu Logan et al. 1964, Fig. 2 of Plate 20). This lithofacies (tidal flat environment) that appears darker than the adjacent lithofacies, also occurs as fenestral dolostone with aligned cavities (birds eyes) filled by sparry calcite. Intraclasts and bioclasts are trapped by the algal laminae, showing tempestite layers; (iii) loferitic breccias (supratidal lithofacies) appear as cm- to dm-thick dolorudites consisting mainly of fragments of algal laminites and micritic mud, merged in a whitish doloarenite. This lithofacies, not always present, is associated with an uneven erosion surface marked by paleokarst and interpreted as the product of the in situ subaerial erosion of the underlying lithofacies; (iv) white-yellowish and greenish azoic dolomitized marls and

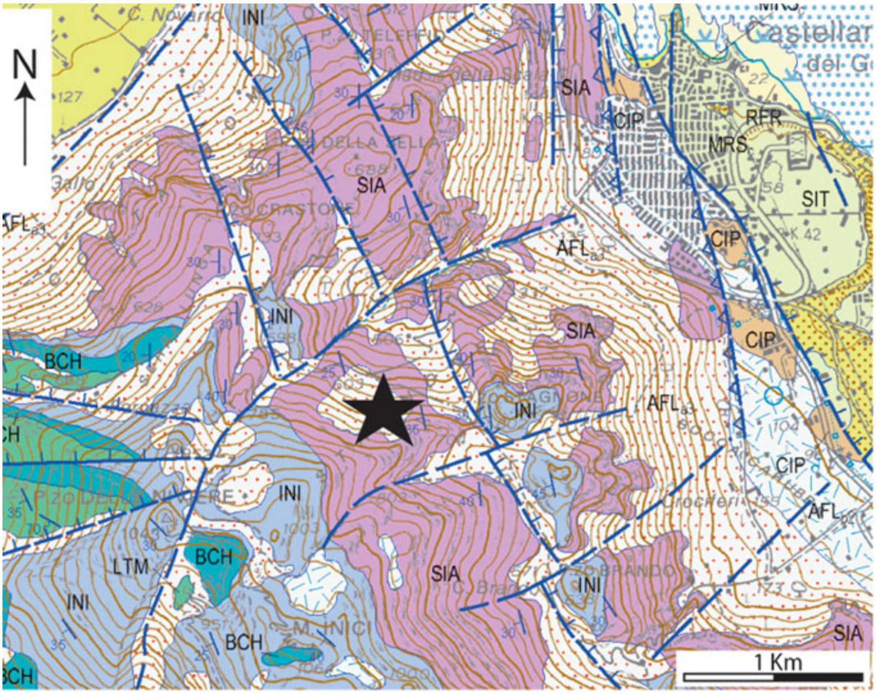


Fig. 2.58 Location of the proposed outcropping type section of the Sciacca Formation (SIA) at Monte Inici. The map was extracted from the geological Sheet n. 593 “Castellammare del Golfo” (1:50,000 map scale), performed by Catalano et al. (2011a)

clayey marls in decimetric levels locally alternating with the previously described lithofacies, which, when they occur, rest at the top of the cycle sequence. The unit outcropping in the Palermo Mountains displays a thickness ranging between 150 and 200 m (Fig. 2.24) and appears as whitish massive vacuolar dolostone and dolomitized limestone alternating with centimetric-decimetric levels of white-yellowish marls. In outcropping areas where the unit is represented by dolomitized limestone, it is possible to observe rare megalodontids, algal laminae and ghosts of gastropods and corals (Gallo section, Mondello, Palermo). In the peninsula of San Vito Lo Capo, along the road to Calampiso (inside the Zingaro natural reserve), this unit is affected by the intrusion of extremely altered igneous rocks, with a typical vertical dyke (filonian geometry) that evolves upwards to pillow lavas (Abate et al. 1991a). Subsurface investigations in the Termini Imerese Mountains (Cerda 2 Agip well) have evidenced the occurrence of medium-fine grain whitish dolostone with mollusc fragments and dolomitized greenish marls with traces of pyrite, which have been assigned to this formation (Miuccio et al. 2000). In the Hyblean subsurface, the equivalent rock unit (the Gela and Naftia formations of Patacca et al. 1979), which has been drilled to a depth of to 3000 m, displays intraformational breccias and sporadic mafic volcanites in its lower portion, and at the top, darkish algal dolostone alternating with grey and whitish crystallized evaporitic porous dolostone and dolomitized breccias. In the Egadi Islands, the unit displays a prevalently micritic-peloidal lithofacies alternating with thin darkish clays (Abate et al. 1996b, c; Catalano et al. 2014; Gasparo Morticelli et al. 2016). Outcropping thickness ranges between 500 and 800 m; subsurface investigations (deep borehole for oil exploration, seismic reflection profiles) suggest values up to 3000 m.

Paleontological content: The fossil content, largely described by Gemmellaro (1904) and Di Stefano (1912), consists of bivalves (*Megalodon gumbeli* Stoppani, *Megalodon seccoi* Paronai, *Megalodon marianii* Paronai, *Megalodon paronai* (Ale), *Dicerocardium curionii* Stoppani, *Dicerocardium* n sp. aff. *gemellaroi* Di Stefano, *Gervilleia exilis* Stoppani, *Myophoria inaequicostata, Myophoria tommasii* Di Stefano, *Cardita dolomitica, Pleuromya lata, Pleuromya infida* Di Stefano), gastropods [*Turritella schopeni* Di Stefano, *Purpuroidea taramellii* Stoppani, *Purpuroidea nassaeformis* Di Stefano, *Worthenia contabulata* (ex *Worthenia solitaria* Benecke)], colonial corals, ostracods, benthic foraminifers (*Lagenidae, Ammodiscidae, Ataxophragmiidae, Alpinophragmium* sp., *Aulotortus* sp., *Glomospira* sp., *Tolypammina* sp., *Frondicularia* sp., *Triasina* sp. and *Galeanella panticae* Bronnimann), algae (*Cayeuxia* sp., *Ortonella* sp.), rare dasycladacean [*Gyroporella vesiculifera* (Gumbel), *Diplopora tubispora* Ott, *Diplopora borzai* Bystricky, *Heteroporella zankli* (Ott)].

Chronostratigraphic attribution: On the basis of the macrofossil content and by the palynologic content recognised in the Egadi islands outcrops, the unit is dated to the Upper Triassic (Norian-Rhaetian).

Stratigraphic relationships: The lower boundary does not outcrop. The upper boundary is a regional paraconformity with the shallow-water limestone of both the Inici Formation (Trapanese succession, Figs. 2.1 and 2.58; Table 2.4) and the Capo Rama formation (Panormide succession, Figs. 2.1, 2.4, 2.22 and 2.24; Table 2.5). It can be considered an erosional angular unconformity with bed truncation where both the Jurassic bauxites and the shallow-water Pizzo Manolfo limestone display infilling geometry and onlap stratal terminations, respectively (Figs. 2.22, 2.24 and 2.57).

Depositional environment: These deposits were formed in a protected lagoon (subtidal environment) bordered by a large tidal flat that was cyclically exposed to subaerial erosion. Freshwater channels cutting the tidal flat eroded and transported the clastic deposits (marls) in the marine coastal areas.

Regional aspects: This formation represents the older outcropping and drilled unit of the Mesozoic carbonate platform successions (Panormide, Trapanese, Saccense and Hyblean, Tables 2.4 and 2.5; Fig. 2.1). It is widely distributed in W Sicily, from the Madonie Mountains (Dipilo section) to Trapani (Erice section) and the Sciacca Mountains (San Calogero, Genuardo, Arancio, Telegrafo section), through San Vito Lo Capo (Sparagio, Monaco sections), Alcamo (Bonifato section), Castellammare del Golfo (Inici, Montagna Grande sections) and the Palermo (Palmeto, Castellaccio, Gallo sections) Mountains. The unit is present in the subsurface of the Hyblean Plateau and has been drilled in the Southern Sicily offshore

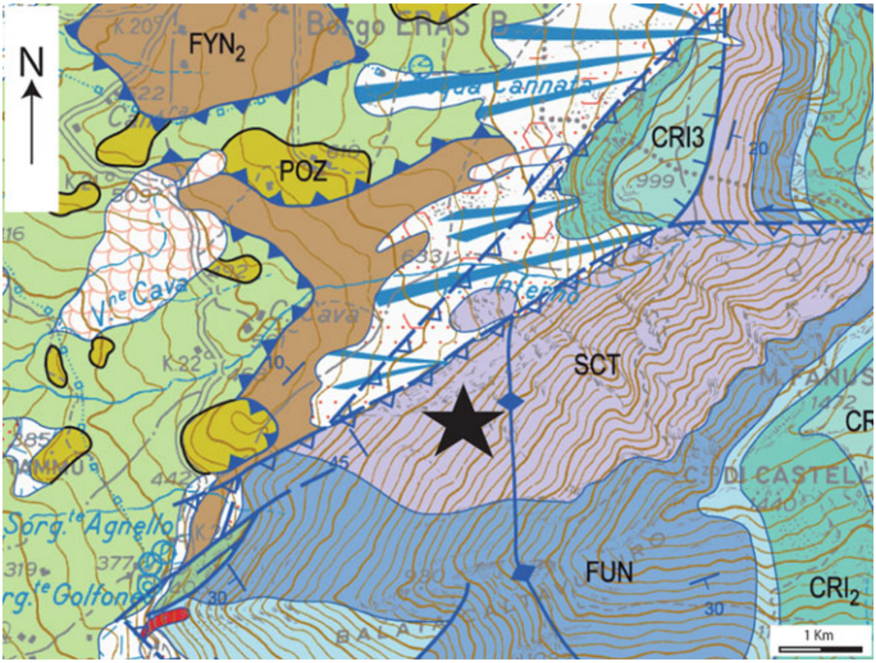


Fig. 2.59 Location of the original type section of the Scillato formation (SCT). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

(Antonelli et al. 1991; Frixa et al. 2000). Similar deposits have been drilled in the subsurface of Tunisia and Malta and their offshore.

Carg abbreviation: SIA

2.2.42 Scillato Formation°

General remarks: The unit comprises the well known Upper Triassic "cherty limestone" widely outcropping in Sicily (Imerese and Sicanian successions, Tables 2.2 and 2.3) and in the Southern Apennines (Lagonegro succession). The Scillato formation was proposed by Schmidt di Friedberg (1964–65) when describing the type section located on the western flank of Monte Fanusi (Fig. 2.59, Madonie Mountains). Several supported stratigraphic sections have been reconstructed from the Madonie (Catalano and D'Argenio 1990), Termini Imerese (Figs. 2.18, 2.35 and 2.39, Basilone 2000, 2009b) and Sicani Mountains (Figs. 2.7 and 2.9a, b, Broquet et al. 1967; Montanari and Renda 1976; Di Stefano et al. 1996, 1998b). The Mondello section (Sicani Mountains) that was studied with paleomagnetic (Muttoni et al. 2001, 2004) and biostratigraphic (Di Stefano et al. 1998a) methodologies has been proposed as the candidate GSSP section for the Carnian/ Norian boundary (Nicora et al. 2007; Balini et al. 2008, 2010).

Synonyms and priority: This unit was named Mirabella formation by Caflisch (1966), which distinguished the dolomitized cherty limestone outcropping in the Palermo Mountains (Mirabella section), considering it as the lateral lithological variation of the equivalent lithotypes outcropping in the Madonie Mountains.

Lithology and thickness: The unit consists of a monotonous sequence of grey thin-bedded calcilutites (Fig. 1 of Plate 27), laminated wackestone-packstone with bedded cherts and black to yellow cherty nodules that are not uniformly distributed along the beds (Figs. 2 and 3 of Plate 27). These lithologies alternate regularly with thin grey-greenish and blackish marls and marly clays, often rich in pyrite and ichnofacies, forming marl-limestone couplets. The limestone contains radiolarians, sponge spicules, ammonoids and halobids (Fig. 7 of Plate 27 and Fig. 5 of Plate 22) whose shells are often concentrated in the lower portion of the bed. In the upper portion of the succession, dolomitized calcilutites with intercalation of thick-bedded graded and laminated calcarenites and calcirudites (calciturbidites, Fig. 8 of Plate 27), with ooids, *Thaumatoporella* sp. fragments, *Tubiphytes obscurus* (Maslov) and benthic foraminifers (*Galeanella panticae* Zaninetti & Bronnimann, *Floriotortus spinosus* Piller & Senowbari-Daryan), deriving from the dismantling and erosion of a carbonate platform margin, occur frequently (Figs. 6–8 of Plate 22). Conglomerate lenses (Fig. 6 of Plate 27) and intraformational channelized breccias a few metres-thick alternating with polychrome claystone (figure of Plate 27) and nodular limestone (Fig. 4 of Plate 27) characterise the topmost portion of the San Calogero section (Termini Imerese Mountains, Basilone 2009b). In the Pizzo Lupo section (Eastern Sicanian Mountains) the topmost beds are characterised by seismically-induced soft-sediment deformation structures associated with synsedimentary faults (Basilone et al. 2014a, 2016c). Dolomitized cherty limestone characterise the upper portion of the formation outcropping in the Southern Palermo Mountains, where the monotonous succession of thin-bedded dololutites and dolosiltites with poor cherts content are mapped and classified as Mirabella lithofacies (Catalano et al. 2013a). Thickness is 400–500 m on average, ranging between 650 and 100 m.

Paleontological content: Pelagic pelecypods (*Halobia styriaca* Mojsisovics, *H. norica* Mojsisovics, *Daonella* sp.), sponge spiculae, pelagic crustacean (*Cyzicus* sp.), ostracods, calcareous nannofossils, ammonoids, conodonts.

Chronostratigraphic attribution: On the basis of the distribution of halobids (Cafiero and De Capoa Bonardi 1982), radiolarians (De Wever et al. 1979) and conodonts (Catalano et al. 1992a; Gullo et al. 1997), the unit is dated to the Late Carnian-Rhaetian. More specifically, the occurrence of conodonts pertaining to the *Epigondolella pseudodiebeli-Metapolygnathus communisti* and *Epigondolella triangularis-Norigondolella hallstattensis* biozones of the biozonational scheme of Kozur (1989) warrants attribution to the upper Tuvalian–Lacian time interval. The recognition of conodonts of the *Misikella posthernsteini* biozone dates the topmost beds of the outcropping section in the Sicani Mountains to the Rhaetian (Gullo 1996).

Stratigraphic relationships: The lower boundary is a sharp conformity surface with the marls/calcilutites couplets of the Mufara Formation, with transitional contact locally. It is easily recognisable in the field due to the lithological change and different morphological expression of the two lithological units. The upper boundary is a submarine erosional unconformity where the dolostones of the Fanusi formation rest with downlap stratal terminations (Fig. 2.40 and Fig. 1 of Plate 19). Similar physical relationships occur in the outcropping sections of the Sicani Mountains, where the erosional unconformity is covered by Lower Jurassic oolite limestone, belemnitic conglomerates or Prizzi breccias. This upper boundary can be considered an unconformity surface where the Jurassic radiolarite member of the Crisanti formation or the radiolarite of the Barracù formation rest with onlap stratal terminations, evidencing long hiatus, as can be observed in the Chiarastella section (Trabia Mountains) and the Barracù section (Fig. 2.9a, b, Sicani Mountains), respectively. Locally, it is marked by a very long hiatus where the Upper Cretaceous pelagic limestone of the Amerillo Formation rest in onlap on the top-most beds of the Scillato Formation (Fig. 2.7, Santo Stefano di Quisquina and Castronovo di Sicilia sections, Eastern Sicani Mountains, Fig. 1.1).

Regional aspects: This unit outcrops extensively in the north-western areas of the Sicilian FTB, from the western Madonie to the southern Palermo Mountains, through the Termini Imerese and Trabia Mountains and throughout the Sicani Mountains. It also outcrops in the Judica and Scalpello Mountains (SE Sicily).

Carg abbreviation: SCT

2.2.43 Streppenosa Formation

General remarks: The unit was first proposed by Rigo and Barbieri (1959) in describing the 600 m-thick black shales drilled by the Streppenosa 1 well located South of Ragusa (Hyblean Plateau). The formation was amended by Patacca et al. (1979). They related the lower portion of the sequence described by Rigo and Barbieri (1959), characterised by Upper Triassic dolomitic limestone and clay alternations, to the Noto Formation and dated the Streppenosa Formation widely occurring in the Ragusa belt to the Lower Jurassic. Recently, Frixa et al. (2000), in studying some onshore and offshore boreholes in the Hyblean region, distinguished three different members (corresponding approximately to the three main facies described by Patacca et al. 1979) and dated the unit to the Upper Norian-Hettangian on the basis of modern palynomorph and calcareous nannofossil biostratigraphy.

Synonyms and priority: Black shales *Auct.*

Lithology and thickness: Black shales alternating with thin-bedded limestone, frequently laminated and rich in plant debris and organic matter. The thin-bedded limestone intercalations are mainly dolomitic to marly limestone and bioclastic wackestone with radiolarians, sponge spiculae, ammonites, small bivalves and dwarf gastropods. Intraclastic-peloidal and fossiliferous to oolitic packstone and fine quartz-sandstone are interlayered. The resedimented limestone displays turbiditic sedimentary structures (Td-e intervals of the Bouma sequence) and frequent *Chondrites*-type burrowing that suggest deposition from the low flow regime of turbiditic currents. The terrigenous component is represented by quartz, white mica and feldspar. Basaltic lavas, tuffs and rare olivine gabbro dykes also occur. Thickness is more than 2500 m.

Paleontological content: Calcareous nannofossils (*Prinsiosphaera triassica* Jafar, *Eoconusphaera zamblachensis, Schizosphaerella punctulata* Deflandre and Dangeard), palynmorphs [*Corollina meyeriana* (Klaus), *Rhaetogonyaulax rhaetica* (Sarjeant), *Patinasporites densus* Leschik, *Dapcodinium densus, Corollina classoides* (Pflug)]. The fossil content of the resedimented limestone includes echinoderms, brachiopods, algae (*Thaumatoporella* sp.), arenaceous foraminifers (*Ataxophragmiidae* spp., *Ammodiscus* sp., *Lagenidae*, *Spirillins* sp.), *Aeolisaccus* sp.

Chronostratigraphic attribution: Upper Norian-Hettangian

Stratigraphic relationships: The lower boundary is an unconformity surface with the shallow-water dolomitic limestone of the Sciacca Formation and with the Noto Formation. The upper boundary is a conformity surface with the pelagic limestone of the Modica Formation (Figs. 2.1 and 2.45).

Depositional environment: Intraplatform basin in anoxic conditions.

Regional aspects: The basin of the Streppenosa Formation is believed to be an intraplatform basin (Catalano and D'Argenio 1978) that was bordered by normal faults with the carbonate platform deposits of the Sciacca Formation (Fig. 1.11). It occurs in the subsurface of the Hyblean Plateau and its offshore. The formation in the marginal areas of the basin is represented only by the younger deposits that cover unconformably the shallow-water dolomitic limestone of the Noto Formation. The Lower Jurassic synsedimentary tectonics changed the paleogeography of the Southern Tethyan continental margin, where some intraplatform basins (Marineo, Streppenosa, Erice, Cala Rossa), interpreted as pull-apart basins (Catalano and D'Argenio 1982b; Basilone et al. 2016b), have occurred.

2.2.44 Tellaro Formation

General remarks: The unit was proposed by Rigo and Barbieri (1959) when they were describing the Miocene marls outcropping along the Tellaro River (Siracusa, SE Sicily). The proposed type section outcrops on the sinistral side of the Tellaro River, located about 3 km SW of the town of Palazzolo Acreide.

Lithology and thickness: Thick-bedded (60–80 cm) grey-yellowish to bluish marls and calcareous marls alternating with grey limestone, upwards becoming massive marls. Thick-bedded (30–50 cm-thick) whitish marly calcarenites, frequently slumped, with bivalves, gastropods and corals are sporadically intercalated (Grasso et al. 2004). Frequently, the unit contains variable amounts of alkaline basalts (Schmincke et al. 1997). Measured thickness is 170 m in the type section. It reaches 310 m in the subsurface (Buccheri 1 well).

Paleontological content: Planktonic foraminifers [*Orbulina suturalis* Bronnimann, *Orbulina universa* d'Orbigny, *Globoquadrina altispira* (Cushman and Jarvis), *Globoquadrina quadraria advena* Bermudez, *Globorotalia mayeri*

(Cushman and Elliot), *Globigerinoides trilobus* (Reuss), *Globigerinoides obliquus extremus* Bolli and Bermudez, *Neogloboquadrina acostaensis* Blow, *Siphonodosaria pauperata* (d'Orbigny), *Siphonodosaria verneuilli* (d'Orbigny), *Globorotalia scitula* (Brady), *Globorotalia menardii* (d'Orbigny)]; benthic foraminifers (*Bilivinoides miocenicus* Gianotti, *Spiroplecta carinata* (d'Orbigny), *Cassidulina cruysi* Marks, *Anomalina flinti* Cushman). *Entalina tetragona* Brocchi, *Ostrea neglecta* Michelotti, *Limopsis calabra* Brocchi are recognised in the resedimented beds (Grasso et al. 2004).

Chronostratigraphic attribution: Langhian-Tortonian.

Stratigraphic relationships: The lower boundary is a sharp surface, and locally, it displays transitional contact with the shallow-water limestone of the Ragusa Formation. The upper boundary is a sharp surface, with local heteropic relationships with the shallow-water limestone of the Palazzolo Formation.

Depositional environment: Outer shelf.

Regional aspects: The unit widely outcrops in the northern sector of the Hyblean Plateau (see also Grasso et al. 2004).

*2.2.45 Valdesi Formation**

General remarks: The so-called "nummulitid calcarenites" outcrop has a limited extension in the Palermo Mountains, where they were detailed described by Montanari (1965) while studying the section of Valdesi located at foot of the NW side of the Monte Pellegrino (Palermo, Fig. 2.49). The following description refers to the type section proposed here; which was based on the measurement and analysis of the vertical succession outcropping along the coastal belt of Valdesi (Fig. 2.49).

Lithology and thickness: Tabular thick-bedded bioclastic calcarenites with large benthic foraminifers (nummulitids, alveolinids), bryozoans, calcareous red algae, echinoderms and coral fragments (Figs. 1–2 of Plate 7). Corals boundstone alternating with bioclastic calcarenites, oolite grainstone and packstone with large benthic foraminifers and large rodoficean algae, organized in shallowing upwards sequences, are predominant in the upper portion of the section. Locally, thin whitish pelagic calcilutites with planktonic foraminifers alternating with fossiliferous calcirudites and pebbly conglomerates deriving from the erosion and reworking of the underlying beds, occur. The succession displays an overall progradational geometry. Thickness 50–70 m.

Paleontological content: Alveolinids (*Fasciolites oblungus* (D'Orbigny), *F. ellipsoidalis* (Schwager), *F. siculus* (De Stefani), *F. schwageri* (Checchia-Rispoli), *F. destefanoi* (Checchia-Rispoli), *F. giganteus* (Checchia-Rispoli), nummulitids (*Nummulites crassus* Boubé, *N. millecaput* Boubé, *N. molli* (D'Archiac), *N. paronai* (Prever), *N.* cf. *planatus coussaccensis* (Schaub), *Discocyclina roberti* Douvillé), *Orbitolites lehmanni* Moorkens.

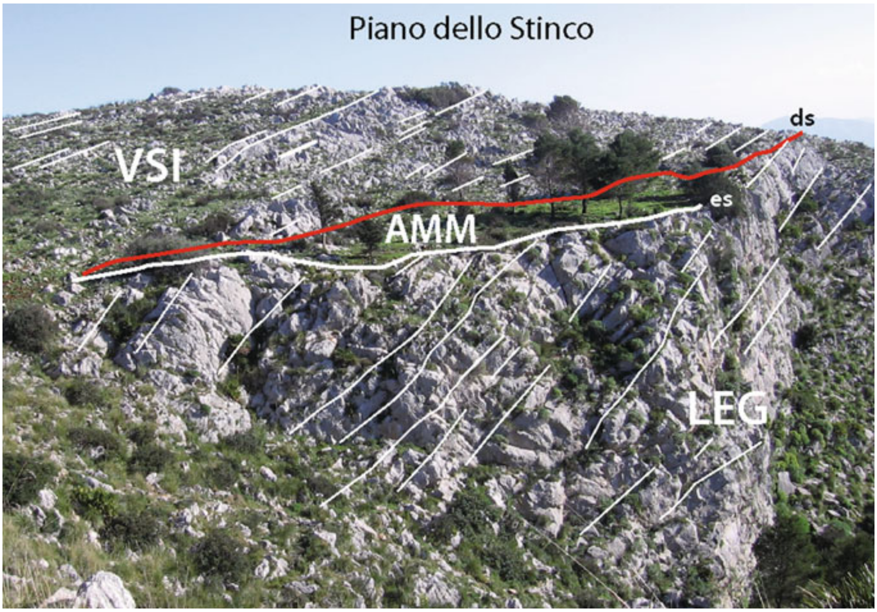


Fig. 2.60 Downlap (ds) and erosional relationships (es) among the Eocene Nummulitid limestone of the Valdesi formation (VSI) and the Upper Cretaceous pelagic limestone of the Amerillo Formation (AMM) and the rudistid limestone of the Pellegrino formation (LEG)

Chronostratigraphic attribution: Based on the fossil content, these deposits can be dated to the Middle-Upper Eocene (De Stefani 1948; Montanari 1965). The occurrence of the markers of the *Fasciolites oblungus* and *Fasciolites schwageri* subzones dates them to the lower Cuisian and the *Fasciolites giganteus* subzone to the Upper Lutetian. This chronological attribution is confirmed by the markers of the SBZ10 and SBZ15 (shallow benthic zones) of the large benthic foraminifers biozonation schemes of Schaub (1981), Cahuzac and Poignant (1997) and Serra-Kiel et al. (1998).

Stratigraphic relationships: The lower boundary is an erosional unconformity surface with the Upper Cretaceous shallow-water limestone of the Pellegrino formation, marked by a 5 cm-thick conglomerate whose elements derive from the erosion and reworking of the underlying rudistids limestone of the Pellegrino formation (Fig. 2.60). Alternatively, it can be considered an unconformity surface with the Eocene pelagic limestone of the Amerillo Formation, marked by downlap stratal terminations (Gallo section).

Depositional environment: These deposits were formed in an open shelf environment, where isolated patch reef with well-developed colonial corals were the barrier of small protected lagoon areas.

Regional aspects: This unit outcrops exclusively in the Panormide succession of the Palermo Mountains and particularly at Monte Gallo (ex Semaforo, Fig. 2.19), Monte Pellegrino and the Valdesi coastal belt, and with lesser extension, at Monte Castellaccio (Tana Vipera).

Carg abbreviation: VSI

2.3 Sicilide Complex

The "Sicilide Complex" (Ogniben 1960) comprises a number of lithological units that are strongly deformed and tectonized; they are generally part of isolated patches forming overthrust nappes. They are thrusted above various tectonic units, most frequently on the Numidian flysch, and represent the highest geometrical units of the Sicilian FTB (inner units). They outcrop extensively in Sicily, especially in the Nebrodi Mountains, where detailed studies have defined their lithological and structural settings and their provenances (Ogniben 1960, 1964; Coltro 1963; Duée 1962, 1969, 1970; Wezel and Guerrera 1973; Vezzani 1972, 1974; Lentini and Vezzani 1978; Lentini et al. 1987; Montanari 1989). The "Sicilide" deposits are believed to have developed in a deep-water environment structured on an oceanic crystalline basement. In the original definition, Ogniben (1960) grouped two different stratigraphic sequences in the "Sicilide Complex" and differentiated them on the basis of their structural position, calling them "Troina and Cesarò nappe".

Lithological units of the 'Sicilide' include clastic clayey-arenaceous with quartz and feldspar sandstones (Monte Soro flysch), Cretaceous varicoloured clays, Eocene thin-bedded pelagic carbonates and marly limestone (Polizzi and Troina formations), andesitic volcanoclastics (Tusa tuffites) and micaceous turbiditic sandstones (Reitano formation) that follow unconformably (Fig. 2.1). These units, whose lithological, biostratigraphic and chronostratigraphic features are defined individually—although related by their original stratigraphic relationships which today cannot be well observed after the tectonic disarticulation—can be considered as broken formations forming a lithostratigraphic complex (Salvador 1994).

2.3.1 Monte Soro Flysch

General remarks: The clay and sandstone deposits outcropping in the thick section of Monte Soro (Nebrodi Mountains) were studied by several Authors (Ogniben 1960; Dueé 1969; Vezzani 1974; Andreieff et al. 1974; Bianchi et al. 1989; Lentini et al. 1991) who highlighted their lithological, paleontological and mineralogical features. Detailed stratigraphic sections have been reconstructed by Dueé (1969), Vezzani (1974) and Torricelli (2001). Although the name of the unit is indicative of a genetic connotation (i.e., flysch) that is not recognised by official nomenclature and procedure (Salvador 1994), in this case the original noun—widely used in the Sicilian geological literature and recently included in the terminology of the geological maps of the CARG project—has been maintained (e.g., Grasso et al. 2010).

Lithology and thickness: The unit consists of 1000–1500 m-thick clay, marly clay, marly limestone and quartz-sandstone alternations. Vezzani (1972, 1974) proposed its subdivision into three members. The lowest clay and limestone member consists of grey-blackish and red to greenish laminated clays alternating with whitish marly limestone and grey thin-bedded (10–50 cm) pelagic limestone with conchoidal fracture; rare grey-greenish quartz-sandstones and fine calcareous breccias are intercalated. They gradually become the clayey-sandstone member consisting of a thickening and coarsening upwards sequence of grey and blackish scaly clays alternating regularly with cm-thick greenish fine-grained graded and laminated sub-arkose quartz-arenites with abundant and various turbiditic current features (Puglisi 1981, 1987; Carmisciano et al. 1983). Upwards, the sandstone-clay member consists of grey-yellowish and greenish m-thick (3–4 m) fine-grained arenites with quartz and feldspar angular grains alternate with grey and red to greenish scaly clays.

Paleontological content: Radiolarians, calcareous nannofossils, calpionellids [*Calpionella alpina* (Lorenz)], *Nannoconus* sp., benthic and planktonic foraminifers (*Rotalipora* sp., *Hedbergella* spp., *Globigerinelloides* spp.), *Microcodium*, belemnites, *Apthycus* fragments, pelecypods and echinoids.

Chronostratigraphic attribution: On the basis of the fossil content, this unit has been dated to Upper Tithonian–Lower Cretaceous (Duée 1969; Vezzani 1972, 1974; Lentini et al. 2000; Torricelli 2001).

Stratigraphic relationships: The lower boundary does not outcrop. It is always represented by a tectonic surface (thrust). The upper boundary is a conformity surface with the Cretaceous varicoloured clays, marked locally by disharmonic contact (detachment surface).

Regional aspects: This unit outcrops diffusely in the Nebrodi Mountains, particularly in the Monte Soro, San Fratello, Alcara Li Fusi, Serra Pignataro and Santa Domenica Vittoria-Monte Peturizzo regions, in the area comprised between the towns of San Teodoro and Cesarò and along the Monte Pomiere-Monte Pelato ridge.

Carg abbreviation: SOR

2.3.2 Varicoloured Clays

General remarks: This unit comprises the red, grey and green clays that appear strongly tectonized, with the translucent detachment surfaces and chaotic structure that justified their definition as 'scaly-clays' (Bianconi 1840). These clays were tentatively formalized as "upper and lower scaly-clays" based on their structural position (Ogniben 1960, 1963a). This term was considered incongruent for a lithostratigraphic unit, as it described tectonically-derived characteristics (Broquet 1968).

Synonyms and priority: These deposits have been described as "upper and lower variegated clays" (Vezzani 1974), "variegated clays" (Grasso et al. 1978), "scaly-clays" (Truillet 1961, 1968; Carbone et al. 1990; Lentini et al. 1991, 2000), "internal flysch" (Broquet et al. 1963, 1975); "Olistostroma Lavanche" (Schmidt di Friedberg 1964–1965), "varicoloured clays" (Dueé 1969; Broquet 1968; Mascle 1979).

Lithology and thickness: Grey-greenish, whitish-grey, red to yellow scaly-clays and marls (Figs. 2.61 and 2.62) with intercalation of cm-dm-thick variegated jasper, frequently brecciated and with whitish quartz veins. Marly limestone, green basalts, calcareous breccias with large benthic foraminifers (nummulitids and alveolinids) and fine-grained limestone rich in radiolarians and chlorite, are intercalated. The Upper Albian–Cenomanian *Exogyra* marls (AVF_a), consisting of blackish marls with chaotic fabric and rich in planktonic fossils and oysters (*Exogira* sp.), are intercalated in the lower portion of the succession. These marly deposits are known in the geological literature as "Cenomanian African facies" (Seguenza 1882; Di Stefano 1900a; Trevisan 1935, De Stefani 1947) and correspond to the deposits of the Brancaleone formation outcropping in Calabria (Moroni and Ricco 1968; Ruggieri and Di Giacomo 1971). Despite their outcropping complexity, they have been the subject of several studies by prestigious geologists and palaeontologists who described primarily the ostreid fauna (Calcara 1845; Meneghini 1864; Seguenza 1882; Montanaro-Gallitelli 1937). The Contrada Prestanfuso outcropping section (Caltavuturo town, Madonie Mountains) was study in depth by Trevisan (1935), who

Fig. 2.61 Strongly deformed grey, red and greenish clays and claystones of the varycoloured clays (Salso river, Madonie Mountains)

Fig. 2.62 Stratigraphic relationships between the varicoloured clays, followed upwards by the white limestone of the Polizzi Formation (Polizzi Generosa, Madonie Mountains, see Fig. 2.63 for location)

revised the previous interpretations, excluded that the oysters were reworked and, with well-argued reasoning, confirmed that they could be considered as fossils originating in that place. Calcareous breccias up to 50 m thick, conglomerates and bioclastic packstone and grainstone with rudistid fragments (Caprinid breccias, AVF_b), occurring as lenticular bodies or isolated large blocks, are intercalated with the Albian-Cenomanian black and greenish clays of the *Exogyra* marls.

Paleontological content: Planktonic foraminifers (*Rotalipora* spp., *Globotruncana* spp., *Morozovella* spp.) calcareous nannofossils (*Prediscosphaera cretacea* (Gartner), *Lithraphidites quadratus,* Bramlette & Martini, *Eiffellithus* spp.). In the *Exogira marls* are present oysters (*Exogyra* sp.), echinoids, nautiloids, ammonites, belemnites, banks of *Gryphea* sp., planktonic foraminifers [*Rotalipora appenninica* (Renz), *Planomalina buxtorfi* (Gandolfi)]. In the calcareous breccias, caprinids (*Caprina schiosensis* Boehm), radiolitids, corals, gastropods (*Nerinea* sp.), orbitolinids, *Inoceramus* are abundant. In the lutitic matrix of the breccias, *Rotalipora* sp. and *Globotruncana* spp. are present.

Chronostratigraphic attribution: On the basis of the planktonic fossil content, these deposits have been dated to the Cretaceous (Albian)–Paleocene. The planktonic foraminifers of the *Rotalipora apenninica, Rotalipora brotzeni, Rotalipora reicheli* and *Rotalipora cushmani* biozones date the lower portion of the succession to the Upper Cretaceous. The occurrence of *Globotruncana* sp. and the calcareous

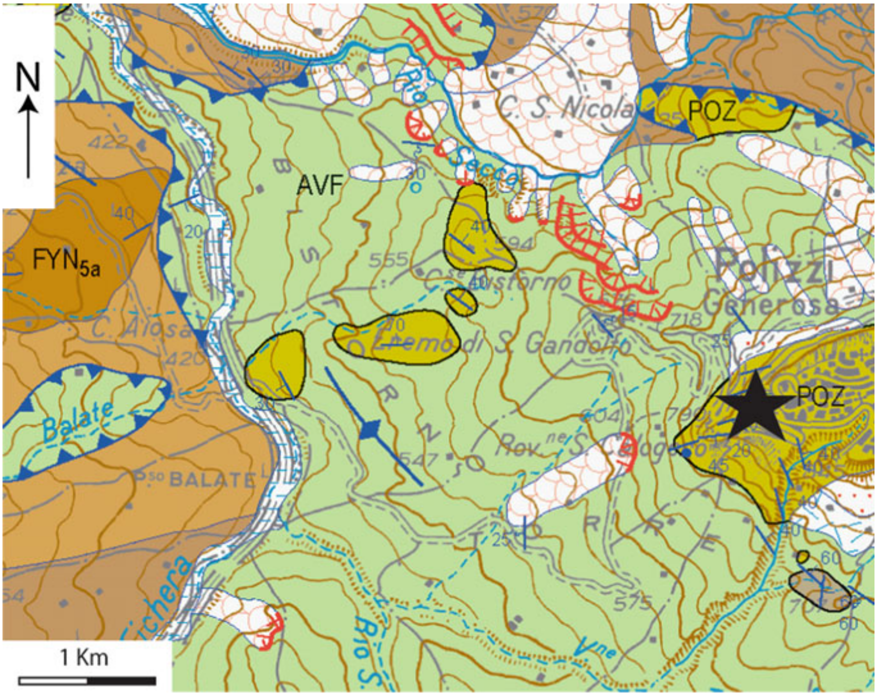


Fig. 2.63 Location of the type section of the Polizzi formation (POZ) at Polizzi Generosa (Madonie Mountains). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map, Catalano et al 2011b)

nannofossils of the CC 25-26 biozones date the upward clays to the Senonian–Maastrichtian. *Morozovella* spp. dates the Paleocene. The planktonic fauna found in the lutitic matrix of the calcareous Caprinid breccias warrants dating them to the Albian-Turonian time interval.

Stratigraphic relationships: The lower boundary is characterised by a transitional contact with the arenaceous lithology of the Monte Soro flysch (Vezzani 1974; Duée 1969). The upper boundary is a sharp surface, with local transitional contact with the pelagic limestone of the Polizzi Formation (Fig. 2.63), but it frequently displays tectonic disharmony (detachment surface, Fig. 2.61).

Depositional environment: These deposits are believed to have formed in abyssal environments. The oysters of the *Exogyra* marls are indicative of a deep-water environment. The calcareous reworked materials indicate the occurrence of a slope adjacent to a reef carbonate platform margin (Camoin 1983).

Regional aspects: This unit outcrops extensively in Sicily, mainly in the area of the Nebrodi, Madonie and Termini Imerese Mountains. They are found also in Southern Sicily and its offshore (i.e., Gela nappe), and also occur in the Southern Apennines.

Carg abbreviation: AVF

Fig. 2.64 Strongly deformed white calcareous marls and thin-bedded calcilutites of the Polizzi formation (Masseria Nicolosi, north of Pizzo Nicolosi, Rocca Busambra ridge)

2.3.3 Polizzi Formation

General remarks: The unit was first described by Seguenza (1873) and Baldacci (1886), who conducted an in-depth study of the large benthic foraminifers widely found in this formation. These deposits were defined as "parautocton" marine deposits embedded in the varicoloured clays (Beneo 1950; Campisi 1958). Successively, Ogniben (1960), considering that the boundary with the underlying clays is essentially a stratigraphic contact, proposed their formalization as "Polizzi calc-schist formation". The type section was proposed by Coltro (1963) that reconstructed it from the outcrop of Polizzi Generosa (Figs. 2.62 and 2.63, Madonie Mountains).

Lithology and thickness: Grey-whitish marly limestone with chert nodules and bedded cherts alternate with white-greyish to purple marls with abundant planktonic foraminifers (Fig. 2.64). Bioclastic calcarenites and fine breccias with large benthic foraminifers and, locally, thin-bedded volcanoclastics (e.g., Contrada Bifarera, Rocca Busambra, Basilone 2011a), are intercalated. The thin-bedded (15–40 cm) fossiliferous mudstone-wackestone displays various ichnofacies (*Palaeodictyon* isp., *Nereites* isp., *Helminthoida* isp.). The resedimented limestone is graded and laminated packstone, with large benthic foraminifers (nummulitids, alveolinids and discocyclinids) and bivalve fragments (pectinids), coralline algae, crinoid articles and echinoid spines. Outcropping thickness ranges from 50 to 100 m.

Paleontological content: Planktonic foraminifers [*Truncorotaloides rohri* (Bronnimann & Bermudez), *Globigerinatheka seminvoluta* (Keijzer), *Turborotalia cerroazulensis* (Cole), *Morozovella rex* (Martin), *Morozovella* cfr. *aragonensis* (Nuttal)] and calcareous nannofossils [*Nannotetrina* spp. (Achuthan & Stradner), *Discoaster sublodoensis* (Bramlette & Sullivan), *Discoaster saipensis* (Bramlette & Riedel), *Discoaster barbadiensis* (Tan), *Istmolithus recurvus* (Deflandre)]. The reworked calcareous beds contain *Nummulites* spp., *Assilina* spp., *Pellatispira* sp., *Discocyclina* spp., *Asterocyclina* sp., *Fasciolites* spp.

Chronostratigraphic attribution: On the basis of the fossil content collected along the type section, the unit was dated to the Eocene (Coltro 1963). New biostratigraphic studies, in the frame of the Carg project, have enabled the recognition among the planktonic foraminifers of *Acarinina bullbrooki*, *Globorotalia cerroazulensis pomeroli*, *Globorotalia cerroazulensis*, and among the calcareous nannofossils the markers of the *Discoaster sublodoensis–Sphenolithus pseudoradians* (NP 14–NP 20) biozones, permitting the unit to be dated to the Middle-Upper Eocene (Catalano et al. 2011b). The calcareous reworked deposits were dated to the Lower Oligocene by Montanari (1967b), while studying these lithologies from the Contrada Pàtara section (Termini Imerese Mountains).

Stratigraphic relationships: The unit is stratigraphically intercalated in the varicoloured clays and is generally bounded by disharmonic surfaces.

Depositional environment: The carbonate pelagites of the Polizzi formation are attributed to a deep-water paleoenvironment, where gravity-induced current permitted the resedimentation of shallow-water derived elements. This interpretation is also confirmed by the presence of the *Nereites* ichnofacies, which is associated with a deep-sea environment (Seilacher 1967).

Carg abbreviation: POZ

2.3.4 Troina Sandstone

General remarks: This formational unit is well exposed in the type area of the Troina-Cerami region (Nebrodi Mountains), where the most complete succession outcrops at Monte Capitano. The deposits display strong similarities with the pelagic limestone of the Polizzi formation, but differ in the occurrence of clastic facies dominated by clays and arenites.

Synonyms and priority: “Troina formation” (Accordi 1958); lateral facies of the “calc-schist formation of Polizzi” (Ogniben 1960), “Troina-Tusa flysch” (Carbone et al. 1990; Lentini et al. 1991), “Troina sandstone formation” (De Capoa et al. 2000).

Lithology and thickness: The biostratigraphic and lithological content of these deposits were recently studied by Cassola et al. (1996) and De Capoa et al. (2000), which subdivided the unit into three main lithofacies: (i) a layer some metres thick of channelized coarse conglomerates and arkose sandstones; (ii) thin to thick-bedded (from dm- to 1 m-thick) alternations of greyish silty clays and grey-yellowish marls with intercalations of thick-bedded (up to 3 m) grey-bluish and greenish fossiliferous marly limestone; (iii) thick-bedded (a few metres) coarse arkose sandstones, with reworked elements of Mesozoic limestone, alternating regularly with thin silty-sandstones, with local intercalations of packstone-grainstone with large benthic foraminifers. Outcropping thickness ranges from 500 to 600 m.

Paleontological content: Planktonic foraminifers (*Globigerina* spp., *Hantkenina* spp., *Globorotalia* sp.), large benthic foraminifers (*Nummulites* spp., *Discocyclina* spp., *Chapmanina gassinensis* (Silvestri), *Fabiana* sp., *Halkyardia* sp.).

Chronostratigraphic attribution: The unit was traditionally attributed to the middle-upper Eocene (Accordi 1958; Ogniben 1960). Recent investigation has dated it to the lower Miocene (Cassola et al. 1990, 1996; De Capoa et al. 2000).

Stratigraphic relationships: The lower boundary is a transitional contact with the varicoloured clays. The boundary is, at times, tectonized locally.

Depositional environment: Slope to deep-water environments, where reworked limestone, deriving from erosion of shallow-water carbonate platform, was resedimented by gravity-induced flows (mostly grain flow).

Regional aspects: These deposits outcrop exclusively in the Troina and Cerami region (Nebrodi Mountains) and, with minor extension, in the area around the town of Capizzi.

Carg abbreviation: TRO

2.3.5 Tusa Tuffites

General remarks: These deposits were well studied by Ogniben (1960), which described them as a lateral (heteropic) facies of the Polizzi formation. Wezel and Guerrera (1973) and Guerrera and Wezel (1974) reconstructed in detail the proposed Castel di Tusa type section from the archaeological site of "Halesa", where a 600 m-thick reversed sequence was recognised. In the same section, De Capoa et al. (2002) detailed the petrographic, sedimentological and biostratigraphic features. The following description also considered the subdivision of the formation into two members, as proposed by Catalano et al. (2011b) in their study of the Poggio Maria section (Fig. 2.65, Capo Plaia).

Synonyms and priority: The unit was called "Tusa formation" by Ceretti (1960) and "Castel di Tusa formation" (Ceretti and Ciabatti 1965). The term "Tusa tuffites", although the noun is imprecise because the volcanic material is the product of the resedimentation of an eroded, originally volcanic rock (tuffites, Wezel and Guerrera 1973), was widely used in Sicilian and Southern Italy geological literature (Ogniben 1960, 1963b, 1964; Lentini et al. 1987; Abate et al. 1988a, b). These deposits were also described as "Tusa flysch" (Wezel and Guerrera 1973; Guerrera and Wezel 1974) and "Troina-Tusa flysch" (Carbone et al. 1990; Lentini et al. 1991).

Lithology and thickness: The succession consists of rhythmic alternations of pelites, marly limestone and grey siltitic marls (Fig. 2.66b), micaceous sandstones (Fig. 2.66a), lithic volcaniclastites (Fig. 2.66c) and greenish shales. These elements

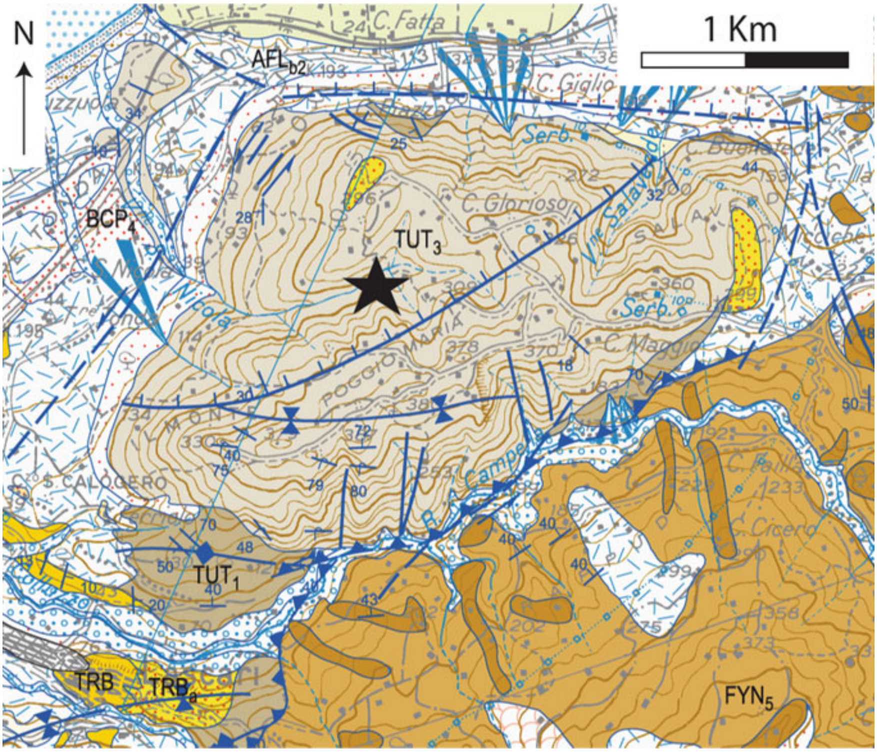


Fig. 2.65 Locatiion of the paratype section of the Tusa tuffites (TUT) at Poggio Maria (Capo Plaia). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

Fig. 2.66 Alternation of mudshale (**b**), micaceous sandstones (**a**) and volcanoclastic layers (**c**) of the Tusa tuffites (Halesa section, Castel di Tusa)

form the siltitic-clay member and further upwards become coarse volcanoclastic sandstones alternating with siltitic calcareous whitish marls and greyish mudstone with planktonic foraminifers containing intercalations of resedimented calcarenites with large benthic foraminifers, molluscs, gastropods, bryozoans and algae fragments (sandstone member). The thick-bedded (1–3 m) fine to medium-grained volcanoclastic graded sandstones shift with transitional contact to the intercalated whitish marls and contain fragments of andesitic plagioclase, quartz, carbonate clasts and abundant muscovite, whose crystals are arranged with the longitudinal axes parallel to the bedding. Wezel and Guerrera (1973) recognised 16 volcanoclastic layers reaching 10–14 m in thickness.

Paleontological content: Planktonic foraminifers (*Globigerina euapertura* Jenkins, *Globigerina venezuelana* Hedberg, *Globigerina woodi* Jenkyns, *Catapsidrax unicaves* (Cushman & Bermudez), *Globorotalia opima nana* Bolli, *Globoquadrina dehiscens* Blow & Banner). Nummulitids, Alveolinids, Discocyclinids and *Lepidocyclina* sp.

Chronostratigraphic attribution: On the basis of the distribution of the planktonic foraminifers N3 and N4 biozones (biozonation scheme of Blow 1969), these deposits were attributed to the Upper Chattian–Aquitanian (Wezel and Guerrera 1973). The occurrence of *Cyclammina acutidorsata* (Hantken), *Haplophragmoides obliquecarinatum* Marks, *Ammobaculites humbolish* (Reuss) in the lowermost beds has permitted their age to be extended to the Upper Oligocene-Lower Miocene (Montanari 1967b). De Capoa et al. (2002) dated the sandstone member to the Burdigalian.

Stratigraphic relationships: The lower boundary is a transitional contact with the varicoloured clays, as is well observable in the Rocca d'Armi-Casa Tita and Cozzo Difesa outcrops (W Nebrodi Mountains). Locally, it is a thrust surface with the Numidian flysch and Tavernola formation deposits. The upper boundary is an unconformity surface with the clastic deposits of the Reitano formation (Madonie Mountains, Grasso et al. 1978).

Depositional environment: The occurrence of deep-water fauna ("*Rhabdammina-Bathysiphon*" Brouwer), in association with the rare benthic foraminifers, fish teeth and spherical radiolarians, suggests a deep paleobathymetry (Wezel and Guerrera 1973). Sandstones display turbiditic sedimentological features, whose paleocurrents are oriented towards the present-day WNW (Wezel and Guerrera 1973).

Regional aspects: These deposits outcrop frequently in Eastern Sicily, particularly in the Nebrodi Mountains (Castel di Tusa, Mistretta, San Teodoro, Bronte, Cesarò). Minor outcrops are recognised in the Lascari and Cefalù areas (Eastern Madonie Mountains).

Carg abbreviation: TUT

2.3.6 Reitano Formation

General remarks: The unit was described as "Reitano flysch" (Ogniben 1960; Dueé 1969; Broquet 1968) and "Pettineo and Caronia formations" (Ceretti and Ciabatti 1965).

Lithology and thickness: Regular alternations of thin to thick-bedded (20–40 cm up to 2 m) yellowish graded and laminated coarse arkose sandstones and greenish lithic arkoses (Fig. 2.67a, b), blackish clays and nodular marly clays; calcisiltites and conglomerates occur at the base and top of the succession. Average outcropping thickness is 500–600 m, with peak values reaching 800 m (Nebrodi Mountains). Thicknesses of 200–300 m are measured in Madonie Mountain sections (Grasso et al. 1978). Cassola et al. (1992, 1996) and De Capoa et al. (2000) have differentiated three main lithological intervals in the field: (i) metres-thick channelized coarse conglomerates with erosional boundary and sandstone with incomplete turbiditic Bouma sequence, represented mainly by graded coarse sandstones (Ta), convolute laminated sandstones (Tb) and pelites (Te); (ii) pelites with intercalations of thin fine-grained sandstones; (iii) coarse sandstones organized in facies sequences thickening and coarsening upwards. Petrographic analysis highlights that sandstones are greywackes with coarse quartz grains, mica, feldspars, carbonates with ankerite, phyllade and andesite fragments, with large benthic foraminifers and *Lithotamnium* sp. (Puglisi 1979, 1987, 1992; Loiacono and Puglisi 1984; Costa et al. 1992). In the Pettineo area, the occurrence of groove casts has suggested a present-day NE-SW transport direction. In the Caronia region, Dueé (1969) described a 200 m-thick conglomerate with black micaceous granite, pegmatite, gneiss, phyllite and quartz elements (up to 30 cm in diameter) deriving from the dismantling of the Peloritani crystalline metamorphic basement, and with white pebbly oolitic calcarenite deriving from the erosion of the Mesozoic carbonates covering the crystalline basement. These conglomerates facies disappear in

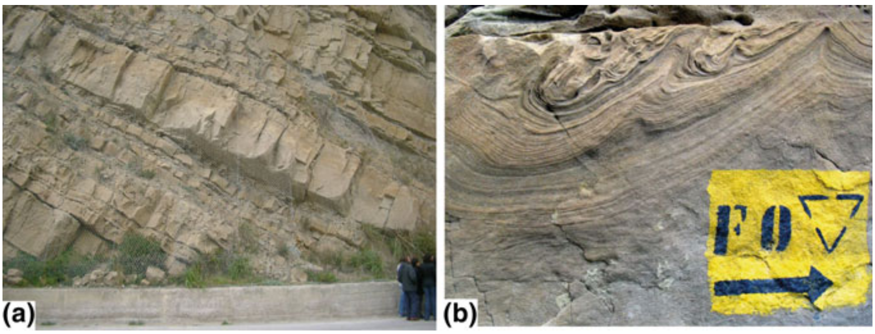


Fig. 2.67 Turbiditic sandstones of the Reitano formation, characterised by alternations of thick beds of yellowish arkosic sandstones and grey clays (**a**). In **b** detail of sandstone beds with oblique and convolute laminations (western side of the relief of the town of Reitano)

westward outcrops where the unit is formed mainly by alternating fine sandstone and marls.

Paleontological content: Arenaceous and planktonic foraminifers (*Orbulina universa* d'Orbigny, *Globigerina praebulloides* Blow, *Globigerinoides sacculifer* (Brady), *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia scitula ventricosa* (Ogniben), *Globorotalia obesa* Bolli, *Paragloborotalia siakensis* Roy, *Catapsydrax unicaves* Bolli, Loeblich & Tappan). Large benthic foraminifers and *Lithotamnium* sp. have been recovered in the reworked calcareous beds.

Chronostratigraphic attribution: On the basis of planktonic fauna, the unit was recently attributed to the Burdigalian–Langhian time interval by De Capoa et al. (2000) and up to the Serravallian by Lentini et al. (1991). Cassola et al. (1992, 1996) dated the lower portion of the unit to the Lower Oligocene and the upper one to the Lower Miocene.

Stratigraphic relationships: The lower boundary, which frequently displays tectonic disharmony, is a paraconformity surface with the Tusa tuffites and with the Polizzi and Troina formations, as can be clearly observed in the Cerami and Troina sections (Nebrodi Mountains). In the area outcropping in the Madonie Mountains, marly limestone with conchoidal fracture at the base of the succession can be seen. The upper boundary, when present, is a thrust surface with older units.

Regional aspects: These deposits frequently outcrop in the Nebrodi Mountains (Castel di Tusa, Mistretta, Capizzi-Rocca d'Ancipa and Cerami-Troina regions). Well-exposed sections are those outcropping along the sinistral side of the Torrente di Tusa and in Contrada Stranghi, in the towns of Reitano and Capizzi (Serre della Castagna). They also occur, though with a limited extension, in the Cefalù and Capo Plaia regions (Madonie Mountains).

Carg abbreviation: REI

2.4 Tertiary Clastic Units

These units comprise the Oligo-Miocene turbiditic successions, unconformably deposited on the Mesozoic carbonate units during the deformation of the Sicilian continental margin.

2.4.1 Numidian Flysch

General remarks: This unit comprises the terrigenous deposits, mostly clays and quartz-sandstones, which were deposited during the Oligo-Miocene in a large area of the Central Mediterranean in a complex and still-debated tectonic setting (Ogniben 1960, 1963a; Wezel 1970; Broquet 1968; Duèe 1969; Giunta 1985). The so-called 'Numidian Basin' (Giunta 1985) is believed to have developed, according to many Authors, above an oceanic crust, inherited from the Mesozoic Tethys, and

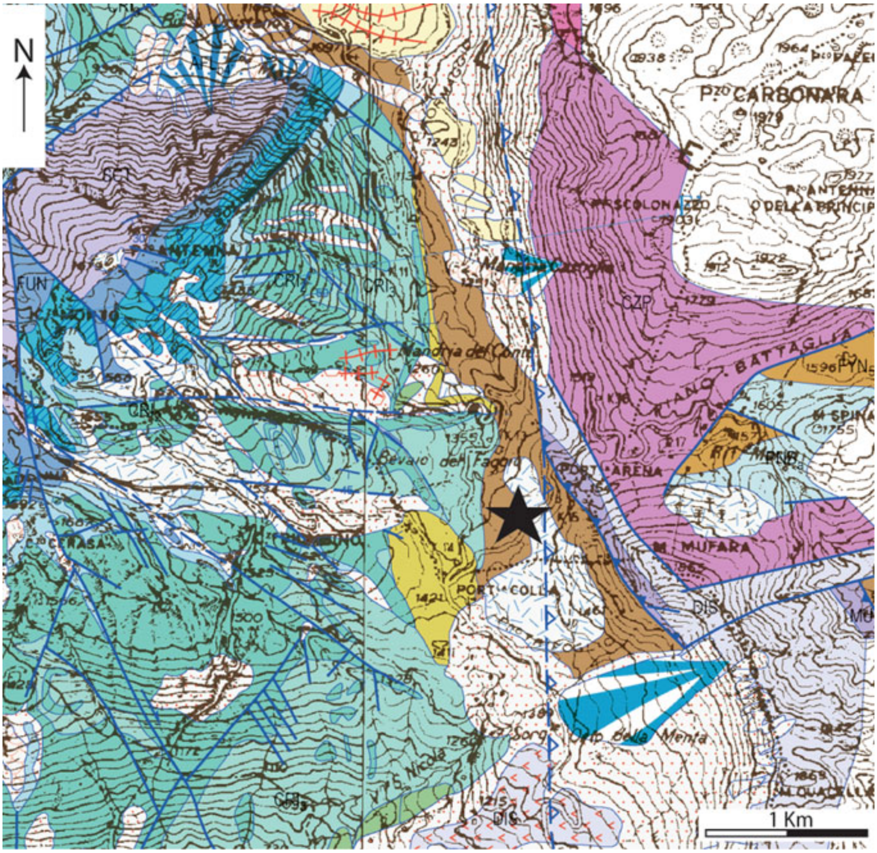


Fig. 2.68 Location of the type section of the Portella Colla member of the Numidian flysch formation (FYN_2) at Piano Battaglia, Madonie Mountains. The map was extracted from the geological Sheets n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map, Catalano et al. 2011b)

on the African continental crust. The term Numidian flysch, or Numidia, comes from the geological literature of North Africa, where these deposits outcrop widely, from Tunisia to southern Spain, through Morocco. The strong similarities of these African deposits with those outcropping in Sicily were highlighted by Caire (1960, 1962), Caire and Mattauer (1960), Caire et al. (1960), which first proposed their correlation. Ogniben (1960) recognised a different lithological portion in the Sicilian outcropping successions and proposed their subdivision into a lower Portella Colla and an upper Geraci Siculo[3] member. The description of the lower

[3] In the Author's meaning, the Geraci Siculo member, considered as a "meso-autochthonous complex", was separated from the previous member by the emplacement of the Panormide nappe on which it rested stratigraphically.

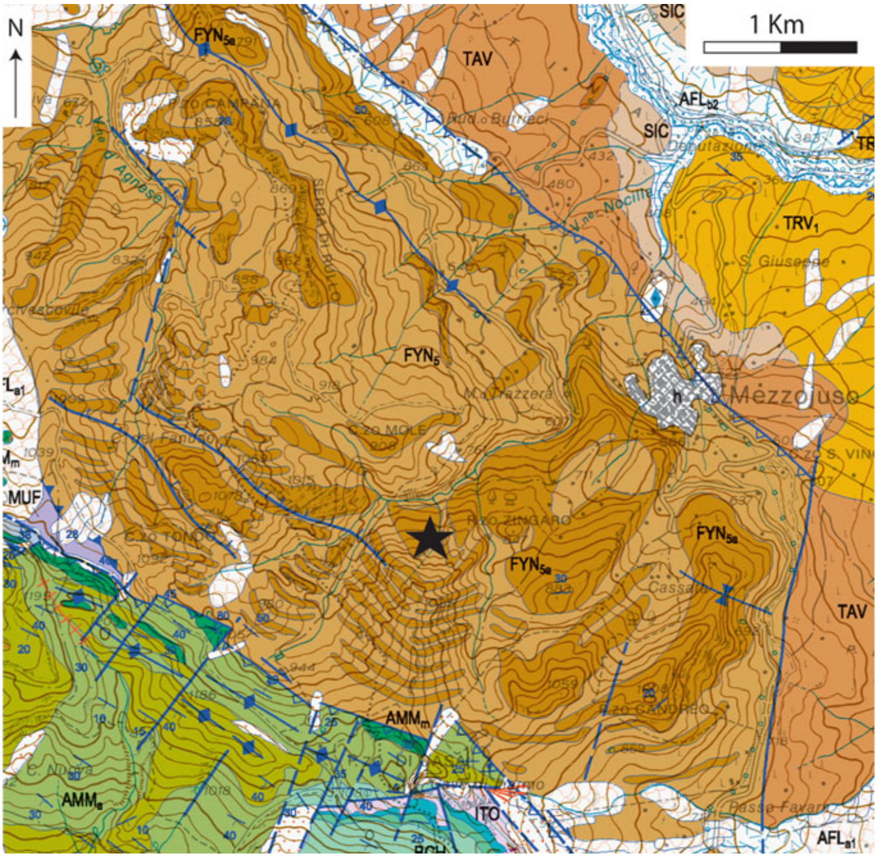


Fig. 2.69 Location of the Mezzojuso-Pizzo Candreo paratype section of the Geraci Siculo member of the Numidian flysch formation (FYN_5). The map was extracted from the geological Sheet n. 608 "Caccamo" (1:50,000 scale map, Catalano et al. 2010b)

member is based on the study of the Portella Colla type section (Madonie Mountains, Fig. 2.68), reconstructed in detail by Wezel (1966). Ogniben (1960) indicates the Geraci Siculo region (Madonie Mountains) as the type area of the upper member of the unit. The Cozzo San Giorgio-Pizzo Ogliastro section, reconstructed by Ogniben (1963b) along the Vallone Pintorna display the upper boundary with the Tavernola formation. Other supported sections are those of Vallone della Lisca-Montemaggiore Belsito (Pescatore et al. 1987), Castelbuono (Johansonn et al. 1998), Mezzojuso-Pizzo Candreo (Figs. 2.69 and 2.70, Basilone 2011a).

Synonyms and priority: This unit has been variously described as "scaly clays and brown sandstones with rounded quartz grains" (Baldacci 1886), "Oligocene" (Marchesini 1937; Coggi and Bruschi 1955), "marly-arenaceous formation" (Jacobacci 1953), "Alia formation" (Marchetti 1956; Flores 1959) and "Geraci

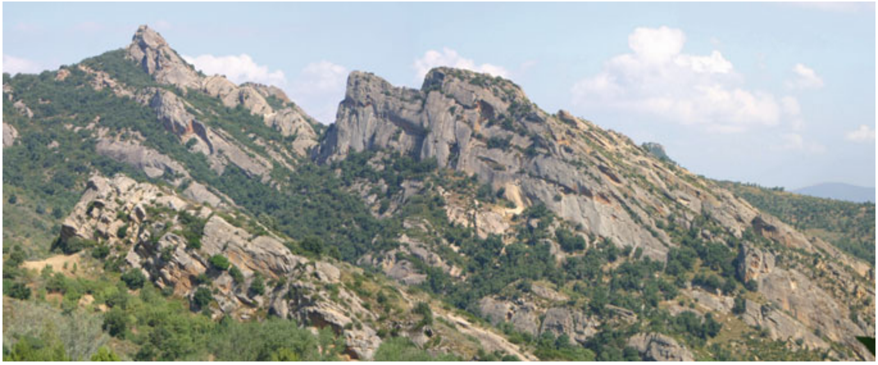


Fig. 2.70 Turbiditic megabeds of quartz-sandstones, alternated with thin layers of brown clays of the Geraci Siculo member of the Numidian flysch formation (Cozzo Tondo, north of Rocca Busambra ridge, see Fig. 2.69 for location)

formation" (Accordi 1958, 1959; Colacicchi 1958, 1960; Campisi 1958, 1960). These latter Authors, describing the successions outcropping in the Nebrodi Mountains, had already differentiated in the field a lower portion dominated by pelites and an upper portion dominated by sandstones. The unit was also called "clayey-arenaceous unit" (Schmidt di Friedberg 1959), "Collesano formation[4]" (Schmidt di Friedberg et al. 1960), "*Numidien*[5]" (Caire and Mattauer 1960; Broquet 1970; Caire et al. 1960; Rangin 1973, 1975). The term *Numidien*, proposed by Ficheur (1890) to define a chronostratigraphic age, was revised in its stratigraphic significance and rejected by Flandrin (1948).

Lithology and thickness: The Numidian flysch is largely characterized by clay and sandstone sequences. The arenaceous content prevails in the upper portion of the unit, which, in addition, includes ten-of-metres-thick conglomerates with chaotic fabric, graded and laminated quartz-sandstones and thin pelitic intercalations. The outcropping thicknesses exceed 2000 m. Sedimentological studies (Pescatore et al. 1987; Johansson et al. 1998; Catalano et al. 2010a, b) enabled the identification of additional lithofacies: (i) chaotic clays and minor quartz-sandstone intercalations; (ii) calcareous megabreccias whose elements, deriving from erosion and the dismantling of a carbonate platform succession, are merged in a siliceous siltitic-sand matrix; (iii) thick-bedded graded quartz-sandstone alternating with thin

[4]The Collesano formation was not used in the Sicilian geological literature both for priority reasons regarding the Numidian flysch and for conceptual reasons, as it includes some of the distinct terms used in reference to the Numidian flysch, and the incompletesess of both lithologies (Schmidt of Friedberg 1962) and stratigraphic boundaries (see Ogniben 1963a, b) of the proposed type section, located at Vallone della Mora (Collesano, Madonie Mountains).

[5]The Numidian flysch has been subdivided by French authors (Duée 1969; Broquet 1968) into three major units called inner, intermediate and outer Numidien; of this division remains the concept of an inner flysch deposited on the Sicilide nappe and an outer flysch deposited on the carbonate units of the continental margin (Imerese Basin, Panormide Platform).

brown pelites and, locally, with lens of grain-supported pebble conglomerates, made up of well-rounded translucent quartz grains.

2.4.1.1 Portella Colla Member

Lithology and thickness: Brown silty clays and planar laminated pelites with manganesiferous nodules (Fig. 2 of Plate 28) alternating with fine-grained quartz sandstones (Fig. 3 of Plate 28). Clay ironstones and iron-manganese inclusions are diagnostic features of the unit (Calderone and Leone 1967). XRD analysis has pointed out that the principal minerals occurring in the pelitic layers are, from more to less abundant: kaolinite, illite-montmorillonite mixed layers, illite, chlorite. In the ironstones, siderite is abundant (40–75%) and pyrite, quartz and chlorite also occur (Calderone and Leone 1967). Calcimetric values are low. In the quartz-sandstone, heavy minerals such as zircon, tourmaline, rutile are found. The sandstones display greater mineralogical maturity compared to those found in the same lithologies of the upper Geraci Siculo member. Graded and laminated breccias with lenticular geometry rich in *Nummulites* sp. and *Lepidocyclina* sp. are present in the lower third of the succession. A 100–200 m-thick interval of thick-bedded sandstones and conglomerates alternating with thin clays follows upwards. A thick level of calcareous breccias with siliceous cements (megabreccias of San Salvatore[6]) is interlayered at the top of the succession. It consists of polygenic megabreccias and megaconglomerates alternating with cm-thick yellowish laminated siltstones. The elements of the megabreccia derive principally from erosion and the dismantling of the Mesozoic shallow-water carbonates. In the breccia megabeds (1–10 m thick), the arenaceous elements decrease in size upward and the carbonate clasts increase; the latter, which are less rounded, give rise to monogenic carbonate breccias. Thickness ranges between 250 and 500 m.

Paleontological content: The most abundant microfossils association is represented by agglutinated foraminifers (*Ammodiscus tenuis* Brady, *Cyclammina acutidorsata* (Hantken), *Hyperammina* sp., *Trochammina* spp.), frequently broken and poorly preserved, which represent diagnostic facies fossils for this unit. Rare planktonic foraminifers and nannofossils. The calcareous breccias are rich in large benthic foraminifers [*Nummulites fichteli* Michelotti, *Lepydociclina morgani* Leni & Deuville, *Lepydociclina marginata* Michelotti, *Lepydociclina tournoueri* Leni & Deuville, *Operculina complanata* (De Francia)].

Chronostratigraphic attribution: The occurrence of the planktonic foraminifers of *Globigerina ampliapertura*, *Globorotalia opima opima*, *Globigerina ciperoensis ciperoensis* biozones and the calcareous nannofossils of NP 24 and NP 25 biozones date the unit to the upper Rupelian–Chattian. The markers of the *Globoquadrina dehiscens dehiscens*-*Catapsydrax dissimilis* biozone and of the MNN 1b subzone

[6]The carbonate megabreccias, outcropping widely in the Madonie Mountains, are also defined by Ogniben (1960) as “wildflysch of Monte San Salvatore”.

date the upper portion of the unit to the Lower Aquitanian. The carbonate breccias with large benthic foraminifers are dated to the Middle-Upper Oligocene (Coggi and Bruschi 1955). Careful dating of the clays in which these calcareous megabreccias are intercalated in the outcropping site along the Jato Valley (Palermo Mountains) suggest a Late Oligocene-Early Aquitanian age (Catalano et al. 2010a).

Carg abbreviation: FYN_2

2.4.1.2 Geraci Siculo Member

Lithology and thickness: Tens-of-metres-thick-bedded yellow and reddish quartz sandstones (megacycles, Fig. 2.70), with subordinate conglomerates and micaceous pelites containing arenaceous and planktonic foraminifers (Figs. 4–6 of Plate 28). The turbiditic sandstones frequently display the entire Bouma sequence (Ta-e, Fig. 1 of Plate 28), bioturbations and intercalations of dm-thick levels of large and rounded crystalline quartz pebbly grains. At times, plurimetric intercalations of blackish pebbly conglomerates cemented by a siliceous matrix occur (Mezzojuso section, Ficuzza, Basilone 2011a). Outcropping thickness is greater than 1000 m. About 700 m-thick of medium-fine grain-sized quartz-arenites alternating with laminated claystone and siltstones have been measured in the succession outcropping north of Rocca Busambra.

Paleontological content: The rare fossil content collected in the pelitic layers comprises radiolarians, calcareous nannofossils, sponge spiculae, arenaceous and benthic foraminifers (*Ammodiscus tenuis* Brady, *Cyclammina acutidorsata* (Hantken), *Trochammina* spp., *Haplophragmoides obliquecarinatus* Marks, *Bolivina* sp.) and planktonic foraminifers (*Globigerinoides trilobus* Reuss, *Globigerinoides sicanus* De Stefani, *Globoquadrina praedehiscens* (Blow and Banner), *Globorotalia acrostoma* Wezel).

Chronostratigraphic attribution: Based on the fossil content, the member has been dated to the Upper Aquitanian–Burdigalian.

Carg abbreviation: FYN_5

Stratigraphic relationships: The lower boundary of the unit, as observed in the type section, is a conformity surface marked by transitional contact with the marly limestone of the Caltavuturo formation. It can also be considered an unconformity and a paraconformity with older units (e.g., the Crisanti formation). The boundary between the two members, frequently characterized by tectonic disharmony (detachment surface), is a paraconformity, marked by the lithological change towards prevalent quartz-sandstones of the Geraci Siculo member. At the Pizzo Candreo section (Mezzojuso), this boundary is marked by the occurrence of a thick conglomerate bed, consisting of coarse-grained pebbles of translucid quartz, which upwards rapidly give way to the quartz sandstone megabeds sequence. In the Portella della Ginestra section (Piana degli Albanesi, Palermo Mountains), the boundary is marked by the occurrence of thick calcareous megabreccias which give way upwards to the thick quartz sandstones sequence. The upper boundary of the formation is an unconformity surface with the marly-sandstone of the Tavernola formation showing downlap stratal terminations. Locally, it is marked by transitional contact that is highlighted by a sharp increase upwards in the calcimetric values and the large glauconite content in the quartz-sandstones.

Depositional environment: These deposits were formed in a slope to base-of-slope dominated by gravity flows producing thick and aerial extended turbiditic systems (Pescatore et al. 1987; Johansson et al. 1998). The conglomerates were interpreted as the product of infilling of an erosional channel (Pescatore et al. 1987). The calcareous megabreccias, derived from the dismantling of the Mesozoic carbonate platform uplifted during the orogenic event[7] (Catalano and D'Argenio 1978; Abate et al. 1982c), display channelized geometries and erosional contacts, suggesting a base of slope depositional environment, where they were deposited through debris flow processes.

Regional aspects: These deposits are diffused in central and western Sicily. Extensive outcrops are found in the Madonie and Nebrodi Mountains and the Caltanissetta region, where they display great thicknesses, mostly related to the tectonic stack of several units doubling parts of or the whole stratigraphic sequence. They also outcrop extensively in the Godrano-Mezzojuso-Campofelice di Fitalia region, in the area surrounding Rocca Busambra and in the region comprised between the towns of Caccamo and Trabia. This unit outcrops with reduced thicknesses, approximately some tens metres, in the Palermo Mountains, where it unconformably covers the Mesozoic shallow-water carbonate deposits (Catalano et al. 1997, 2013a). These deposits have become an important exploration target with regard to the gas reserves, even if the very complex tectonic setting and the variable size of the reservoir geometries make the achievement of the desired goal uncertain.

Carg abbreviation: FYN

2.4.2 Tavernola Formation

General remarks: The unit was proposed by Marchetti (1956) while studying the section located along the Tavernola River (SE of Valledolmo, Caltanissetta), where the unit displays the greatest outcropping thicknesses.

Synonyms and priority: This unit was described as "Garbata formation" by Ogniben (1960). It can be considered equivalent to the "Castelbuono marls" mapped by Grasso et al. (2010).

[7] Ogniben (1960, 1963a, b) and Grasso et al. (1978) describe this level of carbonate breccias as "wildflysch". It is believed to have formed by means of a tectonic mechanism, consisting in the insertion of the Panormide nappe in the lower third of the Numidian flysch succession. Broquet et al. (1966) consider the contact between "Panormide breccias" and Numidian flysch as a tectonic boundary, marked by angular unconformity.

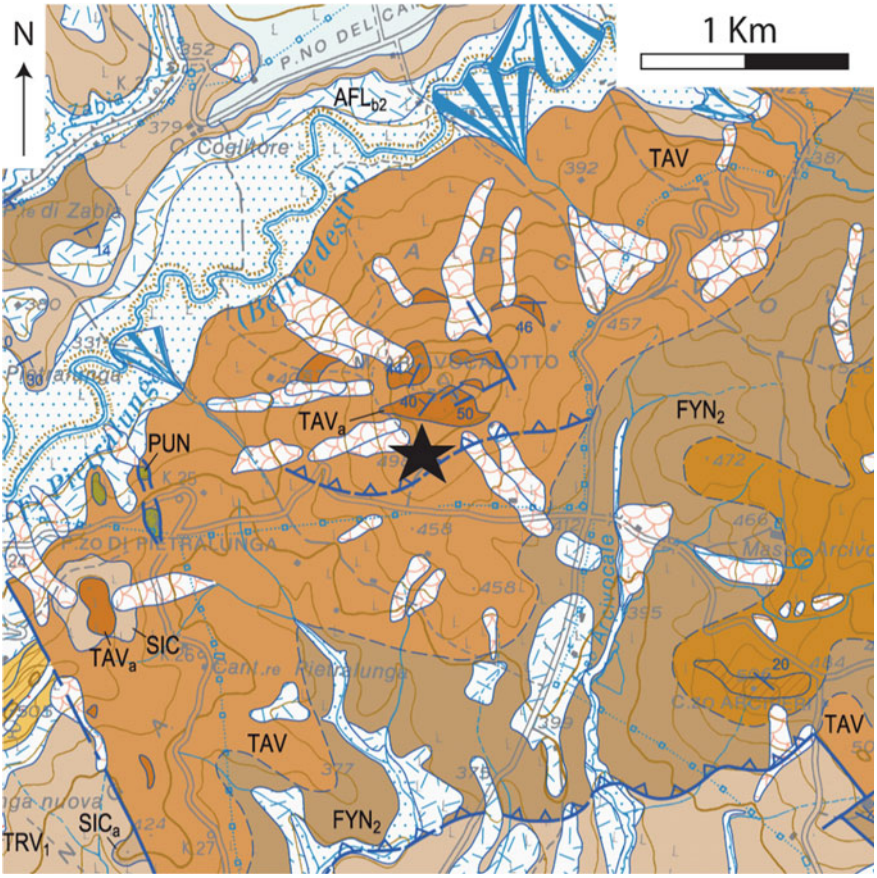


Fig. 2.71 Location of the type section of the Arcivocalotto sandstone (TAV_a). The map was extracted from the geological Sheet n. 607 "Corleone" (1:50,000 map scale), performed by Catalano et al. (2010a)

Lithology and thickness: Marls, pelitic-sandy marls, grey-greenish pelites and cm-thick whitish sandstone alternating with tens-of-metres-thick-bedded yellowish and greenish fine-grained graded and laminated quartz and glauconitic sandstones and yellow sandy marls (Arcivocalotto sandstones, Fig. 2.71, Catalano et al. 2010a). The glauconitic fraction is a diagnostic trait for the recognition of these deposits. In the pelites, the $CaCO_3$ percentage is significantly higher than in those of the Portella Colla member. The sandstones, mostly yellowish with reddish patches due to the presence of iron minerals, are poorly cemented; the medium to fine sand grains are well classed and well rounded; the glauconite grains are greenish, angular and occur with rare blackish coarse lithoclasts. In the sandstone beds, turbiditic sedimentary structures are well-expressed with erosional basal boundary, normal gradation, planar-to-cross (ripples) lamination, bioturbation with ellipsoidal and convoluted patterns (traces of creeping and pasturing, Fig. 8 of Plate 28). Locally, plurimetric-thick fossiliferous floatstone-rudstone with lenticular geometry and rich in bivalve shells (*Lucina* sp.), filled by graded sands, occur (Fig. 7 of Plate 28). Called "*Lucina* limestone" (Baldacci 1886; Di Stefano 1903), they are frequently characterised by an erosional lower boundary and are interlayered in the marly clays. Outcropping thicknesses range between 80 and 200 m; they reach 650 m in the Valledolmo 1 well (central Sicily).

Paleontological content: Radiolarians, sponge spiculae, arenaceous and planktonic foraminifers (*Globigerinoides trilobus* Reuss, *Globigerinoides subquadratus* Brönnimann, *Globorotalia continuosa* Blow, *Globorotalia praescitula* Blow, *Paragloborotalia siakensis* Roy, *Praeorbulina* sp.), calcareous nannofossils (*Discoaster ruggii, Sphenolithus disbelemnos* Fornaciari and Rio, *Sphenolithus heteromorphus* (Deflandre), *Helicosphaera euphratis* Haq, *Helicosphaera ampiaperta* (Bramlette & Wilcoxon), *Helicosphaera mediterranea* Müller, *Helicosphaera carteri* Wallich, *Helicosphaera walbersdorfensis* Muller).

Chronostratigraphic attribution: The unit has been dated to the Burdigalian-Langhian time interval on the basis of planktonic foraminifers (*Globoquadrina dehiscens dehiscens-Cataspydrax dissimilis* biozone of lower Burdigalian, *Globigerinoides trilobus* biozone of upper Burdigalian, and *Praeorbulina glomerosa* s.l. biozone of lower Langhian) and calcareous nannofossils (MNN 1c-d, MNN 4a biozones, middle-upper Burdigalian to lowermost Langhian and MNN 5a biozone, middle Langhian). The planktonic foraminifers (*Globigerinoides trilobus, Globigerinoides subquadratus, Globorotalia continuosa, Globorotalia praescitula, Paragloborotalia siakensis*) collected in the *Lucina* limestone permit the attribution of these deposits to the upper Burdigalian.

Stratigraphic relationships: The lower boundary is an unconformity with discordance with the underlying Geraci Siculo member of the Numidian flysch formation. It can be clearly observed in the outcrop region north of Roccapalumba and Vicari. The upper boundary is an erosional unconformity with the conglomerates and sandstones of the Castellana Sicula and Terravecchia formations. It frequently appears as a tectonic contact (thrust) with the Numidian tectonic stack, Sicilidi and Mesozoic carbonate tectonic units.

Depositional environment: Turbiditic system deposited in a very deep-water basin. The *Lucina* limestone is generally considered to have been deposited in deep-water environments (more than 1000 m of bathymetry) and is associated with fluid escape (methane and sulphides) phenomena (Paull et al. 1984; Brooks et al. 1987; Aharon et al. 1994; Ricci Lucchi and Vai 1994; Taviani 1994).

Regional aspects: The formation outcrops widely in the Madonie Mountains (Gangi, Gagliano-Casteferrato, Nicosia regions) and in the Alia region. The *Lucina* limestone was first indicated by Capellini (1880–1881) at Roccapalumba and Regalgioffoli (Portella district) and by Baldacci (1886) at Ficuzza Wood (north of Rocca Busambra).

Carg abbreviation: TAV

2.5 Miocene Units

This group of lithostratigraphic units includes the clastic sequences filling the wedge-top and foreland basins that developed during the Sicilian FTB build-up (Roure et al. 1990; Catalano et al. 1996, 2010b; Gugliotta 2011a, b). The infilling sedimentary successions were accommodated on top of the accreted Sicilide and Numidian flysch nappes, on the inner Meso-Cenozoic deep-water, Imerese and Sicanian thrust units and, in the outer sector of the FTB, covering the tectonic stack of the Gela thrust system. These basins partially cover the deformed chain inherited from compressional Miocene tectonics and were involved in the Late Pliocene tectonic phase (Gasparo Morticelli et al. 2015 and reference therein). The tectono-sedimentary evolution of the syn-tectonic basins was controlled by the progressive deepening of the structural levels, which were active during the growing of the FTB (Gasparo Morticelli et al. 2015).

The Gela nappe (Beneo 1958; Ogniben 1960; Catalano and D'Argenio 1982a) is a complex structure, comprising several wedge-top basins and located in the southern sector of the Sicilian FTB. It is characterised by a stack of tectonic units, inclusive of the Mio-Pliocene sequences that are detached from their substrate and that were progressively deformed since the end of the Pliocene, as highlighted by their syntectonic structures (Argnani et al. 1987; Butler et al. 1995; Grasso et al. 1990, 1995, 1998; Vitale 1996, 1998; Lickorish et al. 1999; Catalano et al. 1993, 2011b; Gugliotta and Agate 2010).

The siliciclastic and clastic-carbonate deposits of the Upper Serravallian-Lower Messinian time interval (i.e., the pre-evaporitic deposits) unconformably rest above the Sicilide and Numidian flysch units and on the more external Sicanian units, as recently mapped in the Corleone region (Catalano et al. 2010a; Basilone 2011a). These deposits are described as Castellana Sicula and Terravecchia formations and represent the product of deltaic and turbiditic sedimentation due to the dismantling and erosion of the under-construction chain during the Serravallian-Tortonian. The Licata Formation, which is chrono-equivalent to the previous ones, outcrop extensively in the southernmost basins of Sicily and is represented by a deep-water pelitic succession. Above these units, with lateral discontinuity, follow the Upper Tortonian–Lower Messinian *Porites* sp. reef limestone (Baucina formation) and the "bituminous limestone" of Tripoli that marks the beginning of the closing phase of the Mediterranean and the consequent evaporitic sedimentation. The Messinian Salinity Crisis (MSC) ends at the end of the Messinian, when pelagic sedimentation of the "Trubi Formation" begins.

The biostratigraphic and lithostratigraphic scheme of Fig. 2.72 displays the temporal distribution and the stratigraphic relationships of these units. This scheme was constructed by considering the biostratigraphic schemes of Sprovieri et al. (1996a, b) for the upper part of the Tortonian-lower Messinian, and the biozones of Fornaciari and Rio (1996) and Fornaciari et al. (1996), partly amended by Sprovieri et al. (2002), for the remaining portion of the Miocene.

2.5.1 *Castellana Sicula Formation**

General remarks: This newly proposed formation (Catalano et al. 2010a, b, 2011b) is based on the outcropping sections in the Castellana Sicula region (Madonie Mountains), where a thick succession of clays and intercalated sandstones occur. Previously, these deposits were classified with the similar lithologies of the Terravecchia formation (Flores 1959; Schmidt di Friedberg 1964–1965). In these areas, Ruggieri et al. (1969) and Ruggieri and Torre (1982, 1984, 1987) highlighted lithological differences without formalizing any subdivision. Catalano and D'Argenio (1990) described the whole clastic succession as deposits of piggy-back basin growing on the geometrical, higher Sicilidi and Numidian flysch units, postdating the time of deformation.

Lithology and thickness: Grey-green, blue-grey and yellowish pelites and sandy pelites with rare benthic and planktonic foraminifers and sandstone with lenticular geometry, quartz-micaceous sands and well-cemented conglomerates intercalations (SIC_a). These lenses are up to a few tens of metres thick and their aerial extension ranges from a few hundred metres up to 2 km. The cm-m-thick arenaceous beds consist of quartz sandstones, whose elements derived from the "cannibalization" of sandstones of the Numidian flysch. The calcareous sandstones are graded and channelized. Resedimented varicoloured clays are locally intercalated with the sandy clays characterising the lower portion of the succession (Montanari 1966). Thickness ranges between 20 and 250 m.

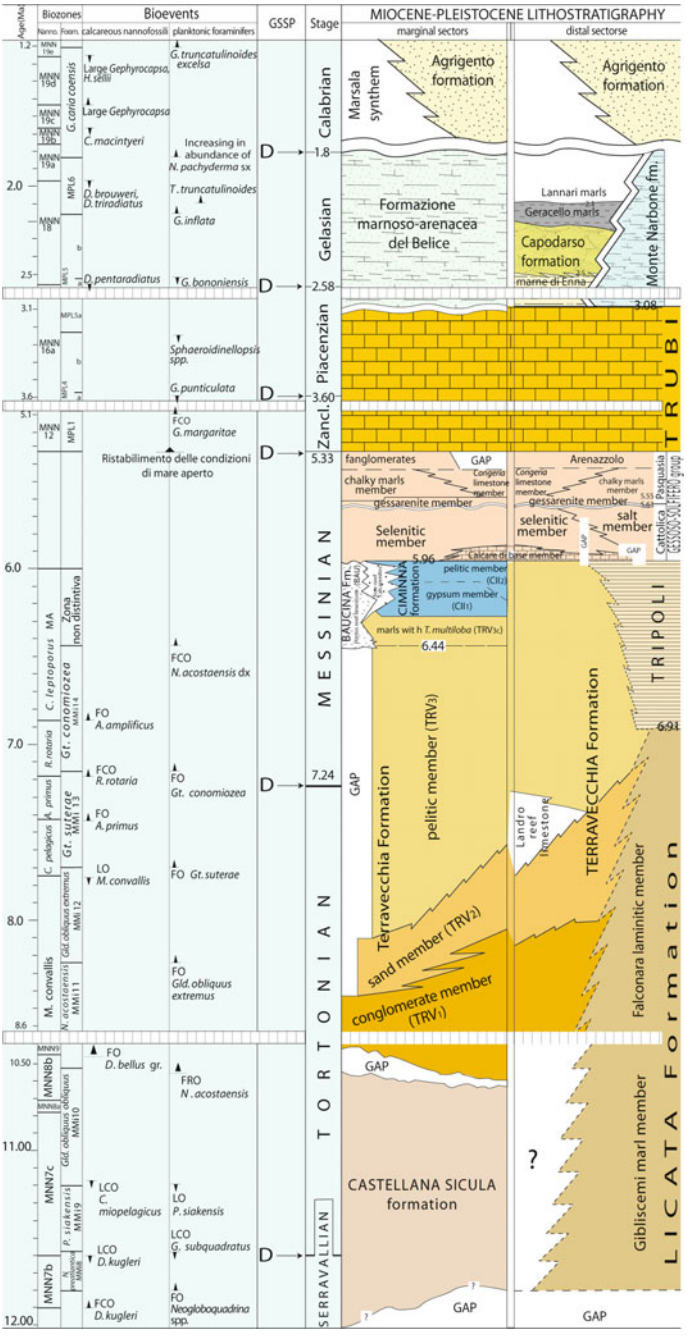
Paleontological content: Fossils are poorly preserved and characterised by low species diversity, consisting of planktonic foraminifers [*Orbulina universa* d'Orbigny, *Globorotolia menardii* (Parker, Jones & Brady), *Globigerina praebulloides* d'Orbigny, *Globigerinoides obliquus obliquus* Bolli, *Neogloboquadrina acostaensis* dx (Blow)] and calcareous nannofossils (*Helicosphaera walbersdorfensis* Muller, *Helicosphaera stalis* (Theodoridis), *Coccolithus pelagicus* Schiller, *Calcidiscus macintyrei* Loeblich & Tappan). Benthic foraminifers, such as *Ammonia beccarii* (Linneo), *Elphidium* sp., *Bolivina dilatata* Reuss and *Lenticulina rotulata* Lamarck., frequently occur in the sandy lenses.

Chronostratigraphic attribution: On the basis of the fossil content (MMi 7-*Paragloborotalia partimlabiata*, MMi 9-*Paragloborotalia siakensis*, MMi 10-*Globigerinoides obliquus obliquus* planktonic foraminifers biozones), the unit is dated to the Serravallian–lower Tortonian time interval (Fig. 2.72).

Stratigraphic relationships: The lower boundary is an unconformity surface with the varicoloured clays (Sicilide complex) and the Numidian flysch deposits (Fig. 2.73) or a paraconformity with the Serravallian–Tortonian hemipelagic clays of the San Cipirello marls (Sicanian succession, Catalano et al. 2010a; Basilone 2011a). The upper boundary is an erosional unconformity with the conglomerates and sandstones of the Terravecchia formation.

Depositional environment: Outer continental platform to slope, where the hemipelagic sedimentation alternated with the intervening gravity-type currents, permitting the sedimentation of turbiditic sandstones.

Carg abbreviation: SIC


MIOCENE-PLEISTOCENE LITHOSTRATIGRAPHY
marginal sectors
distal sectorse
Biozones
Bioevents
calcareous nannofossili
planktonic foraminifers
GSSP
Stage
Calabrian
Gelasian
Piacenzian
Zancl.
MESSINIAN
TORTONIAN
SERRAVALLIAN
Marsala synthem
Agrigento formation
Formazione marnoso-arenacea del Belice
Lannari marls
Geracello marls
Capodarso formation
marne di Enna
Monte Narbone fm.
TRUBI
fanglomerates
GAP
Arenazzolo
chalky marls member
gessarenite member
Selenitic member
selenitic member
salt member
Calcare di base member
pelitic member (CII2)
gypsum member (CII1)
CIMINNA formation
BAUCINA Fm.
marls with T. multiloba (TRV3c)
TRIPOLI
pelitic member (TRV3)
Terravecchia Formation
TERRAVECCHIA Formation
Landro reef limestone
sand member (TRV2)
conglomerate member (TRV1)
Falconara laminitic member
CASTELLANA SICULA formation
Gibliscemi marl member
LICATA Formation
Ristabilimento delle condizioni di mare aperto
1.8
2.58
3.08
3.60
5.33
5.96
6.44
6.91
7.24

◂**Fig. 2.72** Synoptic diagram of lithostratigraphy and cronostratigraphy of the Miocene-Pleistocene successions outcropping in Sicily. Nannofossil and planktonic foraminifer biozonations were taken respectively by Rio et al. (1990) and Cita (1975a) amended by Sprovieri (1993), Di Stefano (1998) and Di Stefano E et al. for the Plio-Pleistocene interval; Sprovieri et al. (1996a, b) and Sprovieri et al. (2002) for the Serravallian-Messinian interval. The middle and upper Miocene bioevents (calcareous nannofossils and planktonic foraminifers) were extrapolated from Sprovieri et al. (1996a, 2002). In the central column, the approved GSSP (D) are shown. The vertical stroke white areas indicate a jump in the time scale. The two different lithostratigraphic columns refer respectively to the more marginal and sectors of the original wedge-top basins, where different stratigraphic successions are present

2.5.2 Terravecchia Formation°

General remarks: The unit was introduced by Schmidt di Friedberg (1962) and then formalised (Schmidt di Friedberg 1964–1965) on the basis of the description of Flores (1959) in his study of the greately deformed Cozzo Terravecchia section (Madonie Mountains). It has recently been amended and revised in its lithologic and chronostratigraphic content in the frame of the geological maps of the CARG project using the proposed Scillato type section (Figs. 2.73 and 2.74, Monte Riparato, Madonie Mountains), where several sedimentological studies have been conducted by Catalano and D'Argenio (1990), Abate et al. (1999), Gugliotta (2011b, c).

Lithology and thickness: The formation consists of a predominantly terrigenous sequence (300–1200 m thick) of conglomerate, sands and clays with abrupt lateral facies variations. The new description subdivided the unit into three members (conglomerate, sandstone and pelitic members). Locally, calcareous rocks

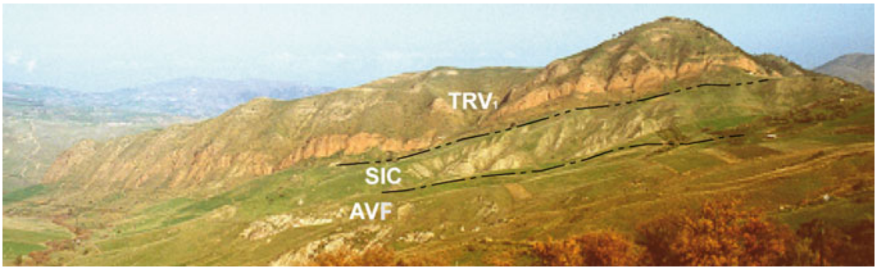


Fig. 2.73 Stratigraphic framework of the Miocene Scillato basin (Madonie Mountains). The photo displays the erosional unconformity boundary surface between the red conglomerate member of the Terravecchia formation (TRV_1) and the underlying sandy clays and marls of the Castellana Sicula formation (SIC) that unconformably rests above the varycoloured clays (AVF) of the Sicilide complex

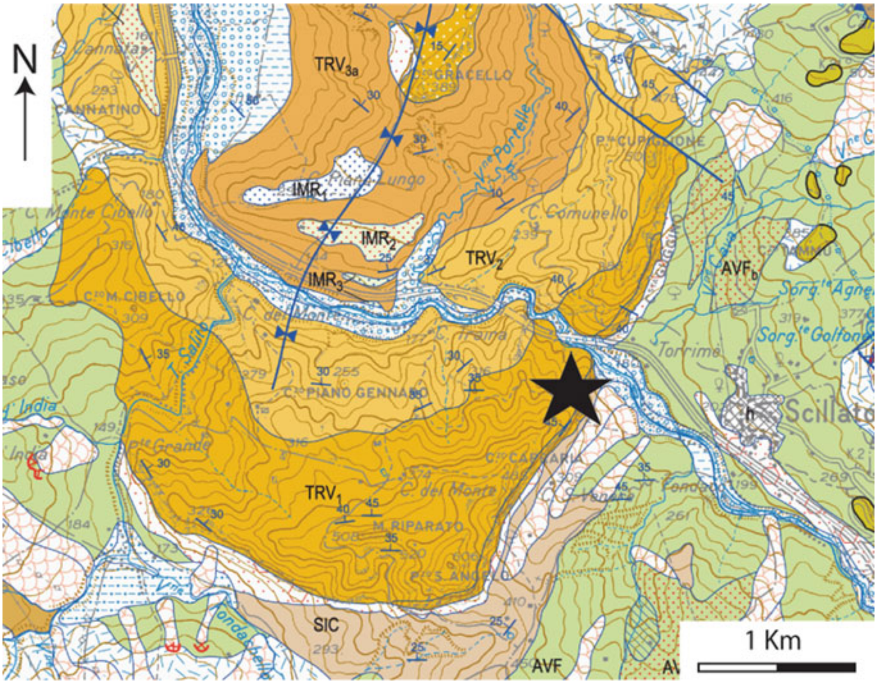


Fig. 2.74 Location of the amended paratype section of the Terravecchia formation (TRV). The map was extracted from the geological Sheet n. 596–609 "Termini Imerese-Capo Plaia" (1:50,000 scale map), performed by Catalano et al. (2011b)

consisting of boundstone alternated with bioclastic calcarenites occur (Landro reef limestone); the bioconstructed framestone consists mostly of corals, where *Tarbellastrea siciliae* (Chevalier), *Paleoplesiastrea columnaeformis* Chevalier and *Porites calabricae* Chevalier are the main components, molluscs and bryozoans. This limestone was previously studied by Chevalier (1961), Daina (1965b), and Catalano (1979).

Conglomerate member: Reddish and yellowish massive conglomerates, with heterometric elements including pebbles of carbonates, siliceous and crystalline rocks, such as granite and dacitic-andesitic porphyrites (Ferla and Alaimo 1975), merged in a reddish sandy matrix; maximum thickness 200 m. The pebbles derive from the erosion of older rocks of the Numidian flysch, Sicilide complex, Mesozoic Imerese rock succession and Peloritani crystalline basement. The clasts of the conglomerate are poorly sorted, can reach 70 cm in diameter and are usually imbricated (Fig. 1 of Plate 29). Locally, greyish and brown-red silty clays, with fresh-water to slightly brackish faunas, including the *Chara* sp. and *Cyprideis* sp. (Ruggieri in Crimi 1984), occur at the top of the succession.

Carg abbreviation: TRV_1

Sandstone member: Micaceous sandstones becoming clayey sands upwards, with thicknesses up to 250–350 m, follow unconformably. The well-cemented yellowish sandstones display planar to cross stratification, ripples lamination (Fig. 2 of Plate 29) and large-scale erosional channels filled by crossed strata. Graded conglomerate intercalations diminish upwards where a few small conglomerate lenses occur.

Carg abbreviation: TRV_2

Pelitic member (TRV_3): Grey-blue clays, marly and sandy clays, sandy marls with molluscs and abundant microfossils that display, upwards, a brackish fauna [*Turborotalita multiloba* (Romeo)]. Outcropping thicknesses range from 100 to 300 m.

Paleontological content: In the massive conglomerates a rich mollusc fauna was collected by Ruggieri and Torre (1984); it shows the presence of large specimens of *Omphaloclathrum miocenicum* (Michelotti), *Glycymeris glycymeris* (Linneo), *Arca syracusensis* (Mayer), *Ostrea gingensis* Schlotheim, *Hinnites brussonii* De Serres, *Ringicardium hians* Brocchi. In the pelitic member, the microfossils comprise planktonic (*Neogloboquadrina acostaensis* Blow, *Globigerina nepenthes* Todd, *Turborotalita multiloba* Romeo) and benthic (*Uvigerina rutila* Cushman & Todd, *Uvigerina auberiana* d'Orbigny, *Uvigerina longistriata* Perconig, *Bulimina aculeata minima* Tedeschi & Zanmatti, *Bolivina punctata* d'Orbigny) foraminifers. *Ammonia beccari* (Linneo) is considered as a facies fossil recognised only in this unit. In the Landro reef limestone, the coral content comprises the *Montastraea, Tarbellastraea, Plesioastrea and Porites* genus. Chevalier (1961) described several species, including *Tarbellastraea reussiana* Milne Edwards & Haime, *Tarbellastrea siciliae* (Chevalier), *Heliastraea* sp., *Coelonia siciliae* Chevalier, *Paleoplesiastrea desmoulinsi* Milne Edwards & Haime, *Paleoplesiastrea columnaeformis* Chevalier, *Siderastrea crenulata* Blainville, *Porites calabricae, Porites* cf. *lobatosaepta*.

Chronostratigraphic attribution: On the basis of the planktonic fossil content, the unit is dated to the upper Tortonian (*Globigerinoides obliquus extremus* and *Globorotalia suterae* planktonic foraminifer biozones and *Minylitha convallis* calcareous nannofossils biozone)—Lower Messinian (*Globorotalia conomiozea* biozone and *Amaurolithus primus* and *Reticulofenestra rotaria* biozones). The coral content dates the reef limestone to the upper Tortonian (Chevalier 1961; Catalano 1979). On the basis of fossils distribution, the conglomerate and sandstone members are dated to the upper Tortonian, while the uppermost pelitic member is dated to the Lower Messinian.

Stratigraphic relationships: The lower boundary is a regional unconformity—marked by erosional truncation—with the sandstones and clays of the Castellana Sicula formation or with older deposits, such as the varicoloured clays of the Sicilide complex and the clastic deposits of the Numidian flysch. The upper boundary is a paraconformity with the reef limestone of the Baucina Formation, the diatomite marly limestone of the Tripoli formation and the evaporites of the Gessoso-Solfifero Group.

Depositional environment: The several facies associations recognised, comprising filling erosional channel, levee deposits, channel fluvial bars, suggest an overall braided fluvial depositional environment changing upwards to deltaic and marine conditions (Gugliotta 2011a, b, c). The data collected from paleocurrents analysis indicate the main provenance of the clastic materials as the present-day North sector, where a large emerged area appears to have occurred (Catalano and D'Argenio 1990; Gugliotta and Gasparo Morticelli 2011). The clays of the pelitic member are characterised by oligotypic fauna, suggesting variability in the salinity conditions, and by the brackish environments in the uppermost clays containing *Turborotalita multiloba*.

Regional aspects: These deposits outcrop widely along the Sicily FTB, from the Catania area to the Egadi islands. In the Scillato basin (Madonie Mountains), they display a thicker sequence and an extension of approximately 30 km^2. Landro reef limestone has been reported by Seguenza (1873), Baldacci and Mazzetti (1880), Chevalier (1961) in the outcropping sites of Monforte, Rocca Serro, Rometta (Peloritani Mountains), from the Portella del Landro-Villadoro section (Chevalier 1961), Capodarso section (Enna) and Grotte region (Agrigento, Daina 1965b).

Carg abbreviation: TRV

2.5.3 Licata Formation

General remarks: This pre-evaporitic unit was called "Globigerinids marls" by Behrman (1938), Colalongo et al. (1979). Its lithological and biostratigraphic features were described by Sprovieri et al. (1996a), which proposed its subdivision into two main sub-units: the Gibliscemi laminitic member, characterising the lower portion of the succession and defined in a study of the Monte Gibliscemi type section (Gela, S Sicily), and the Falconara marly member, defined in the Falconara type section (southern slope of Mount Cantigaglione) and located about 30 km from Monte Gibliscemi.

Lithology and thickness: The lower member (82 m thick in the Monte Gibliscemi section) consists of a cyclical alternation of light-grey marls and reddish laminites, generally covered by manganesiferous crusts (Fig. 2.75). Each lithological cycle, reaching a maximum thickness of 1 m, is represented in its lower half by laminites and in the upper half by marls. The marls, 5–30 cm thick, display bioturbation in their lowermost portion and its blackish colour is due to the high content of organic matter. The succession, locally, displays internal angular unconformity highlighting a synsedimentary tectonic event (Fig. 2.75). The upper member (31 m thick in the Falconara section) consists of prevailing grey marls and minor marl/reddish laminate couplets. The laminites, 10–30 cm thick, are not regularly distributed along the succession. In the uppermost section, a laminated sandstone bed (turbidite) occurs, locally. The unit thickness ranges between 71 and 115 m. A cyclostratigraphy study and the analysis on the relative distribution of the planktonic foraminifers highlighted the occurrence of 130 cycles and a cyclical

Fig. 2.75 Clays with sapropelitic layers of the Licata formation; the angular unconformity surface within the succession is due to a synsedimentary tectonic event (Palma di Montechiaro, southern Sicily)

fluctuation of the abundance of *Globigerinoides* spp., whose peaks in the lower half cycle correspond to the laminites sedimentation (Sprovieri et al. 1996a, b).

Paleontological content: Benthic [*Cibicidoides pachyderma* (Rzehak)] and planktonic foraminifers and a rich association of calcareous nannofossils (see Sprovieri et al. 1996a).

Chronostratigraphic attribution: The planktonic foraminifers of the *Neogloboquadrina acostaensis, Globigerinoides obliquus extremus-Globigerinoides bulloides*, *Globorotalia suterae* and *Globorotalia conomiozea* biozones and the calcareous nannofossils of the *Discoaster bellus*, *Minylitha convallis*, *Coccolithus pelagicus*, *Amaurolithus primus* and *Reticulofenestra rotaria* biozones dating these deposits to the Tortonian–Lower Messinian time interval.

Stratigraphic relationships: The lower boundary is an unconformity with the deformed deposits of the Sicilide complex and Numidian flysch tectonic units. The upper boundary is a sharp surface with the diatomaceous laminites of the Tripoli formation or an unconformity—marked by erosion and discordance—with the Messinian evaporites.

Depositional environment: The occurrence of benthic foraminifers, as the rare *Parrelloides robertsonianus* (Brady) and *Siphonina reticulata* Lehnert, Stone & Heimler, suggests bathyal environments with 1000–1300 m of paleo-depth, in accordance with the studies on the paleo-bathymetric distribution of benthic fauna in the Mediterranean basin (Wright 1978; Hasegawa et al. 1990; De Rijk et al. 2000).

Regional aspects: These deposits outcrop mostly in central and southern Sicily.

Carg abbreviation: LCT

2.5.4 Baucina Formation

General remarks: The unit was proposed by Aruta and Buccheri (1971), while studying the Cozzo San Pantaleo section (Baucina, Palermo).

Lithology and thickness: Boundstone with *Porites* sp. (lithofacies of the *Porites* reef limestone) cyclically alternated with marls and bioclastic limestone (forereef lithofacies). The reef-wall is represented by columnar *Porites* colonies (Fig. 2.76). Upwards and laterally (heteropic), the reef lithofacies changes to an alternation of yellowish bioclastic cross-bedded coarse calcarenites with coral, pectinid and red algae fragments and sandy marls with ostracods and benthic foraminifers. Oolitic limestone with large-scale cross-lamination (wave laminations), rich fauna of molluscs and benthic foraminifers and bioturbations are intercalated. Outcropping thickness is 76 m in the Baucina type section, where two bodies of these reef limestone have been mapped (Catalano et al. 2010b) separated one from the other by grey-yellowish marls (Lo Cicero et al. 1997). Up to 40 m thick in the outcropping site of Calatafimi (W Sicily, Catalano 1979).

Paleontological content: Corals (*Porites* sp., *Tarbellastrea* sp., *Siderastrea* sp.), gastropods, pelecypods (*Pecten aduncus* Eichwald, *Pecten vigolenensis* Simonelli, *Arca fichteli* Sacco, *Comarmondia* cfr. *reyvevali crassior* (Pantanelli), *Ostrea* (*Ostrea*) *edulis* Linneo, *Chlamys* (*Chlamys*) *multistrata* (Poli), *Chlamys* (*Chlamys*) *tauroperstriata* Sacco, *Modiolus intermedius* (Foresti), *Modiolus adriaticus* Lamark), echinoid spines, bryozoans, benthic foraminifers, ostracods (*Aurila* sp.), anellids.

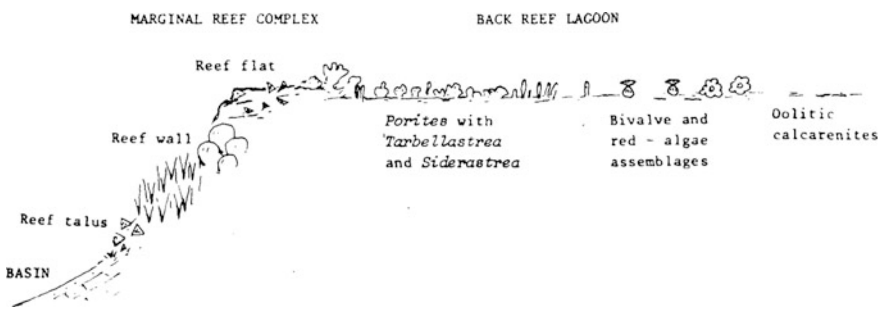


Fig. 2.76 Messinian coral reef depositional model in the Mediterranean, proposed by Esteban (1978)

Chronostratigraphic attribution: On the basis of the malacofauna and ostracods (*Olimfalunia sicula* biozone), the unit is dated to the Lower Messinian (Aruta 1966; Aruta and Buccheri 1971, 1976). The lower boundary was dated to 6.41–6.44 Ma on the basis of the occurrence of *Neogloboquadrina acostaensis* dx in the marl intercalations (Fig. 2.72, Lo Cicero et al. 1997).

Stratigraphic relationships: The lower boundary is an erosional unconformity with the pelitic and/or the sandstone members of the Terravecchia formation, often marked by polygenic pebbles and by decreases in detrital quartz content. The upper boundary is a truncational erosion unconformity surface on which rest the selenite gypsum of the Cattolica formation or the marly-limestone member of the Pasquasia formation (i.e., the "carbonate terminal complex" of Esteban 1978).

Depositional environment: Carbonate platform reef margin (Fig. 2.76), laterally becoming back-reef lagoon (landward) and forereef/upper slope (seaward) depositional environments (Catalano and Esteban 1978; Esteban 1978; Catalano 1979; Esteban et al. 1982; Grasso and Pedley 1989; Pedley et al. 1994).

Regional aspects: The unit outcrops with reduced extension and thickness, but it is quite widespread in Sicily. It outcrops in the Castelvetrano, Salemi (Monte Rose section), Marsala, Mazara del Vallo (Contrada Grieni section), Calatafimi (Monte Tre Croci section), Vita (Monte Calemici section) and in the Baucina, Ciminna and Ventimiglia regions. Sporadic outcrops are seen in the coastal belt of Termini Imerese (Buonfornello), north of Cattolica Eraclea (Agrigento) and in the Maddalena peninsula (Siracusa). The *Porites* limestone outcrops widely in the peri-Mediterranean area, and particularly in Spain (Esteban 1978).

Carg abbreviation: BAU

2.5.5 Tripoli°

General remarks: "Tripoli" is a historical name already used by Mottura (1871, 1910) and Baldacci (1886) to describe the Messinian diatomite marls widely outcropping in Sicily, Calabria and North Africa. They were described as the lowermost deposits of the "gessoso-solfifera sequence" (Ogniben 1960). Schmidt di Friedberg (1964–1965) includes them as a member of the Solfifera formation (now no longer considered a valid formation). In the recent classification of the Messinian evaporitic lithostratigraphic units in the frame of the geological maps of the Carg project, the Tripoli formation was considered as separated by the evaporitic units (Basilone et al. 2001). It is included in the Traditional Units of the Italian Formations Catalogue (Cita et al. 2007b). The formation outcrops widely in the Caltanissetta Basin, where the more complete Monte Falconara section, also proposed as the stratotype of the Tortonian-Messinian boundary (Colalongo et al. 1979), was studied in depth with modern stratigraphic methods, including integrated biostratigraphy, magnetostratigraphy, isotopic stratigraphy and cyclostratigraphy (Sprovieri et al. 1996a, b; Langereis and Dekker 1992; McKenzie et al. 1980; Hilgen 1991; Blanc-Valleron et al. 2002). Other supported successions are the Capodarso section (Selli 1960; Roda 1967a, b; Sprovieri et al. 1996b), Contrada Gaspa section (Grasso et al. 1990; Pedley and Grasso 1993; Sprovieri et al. 1996b) and Monte Gibliscemi section (Sprovieri et al. 1996a).

Lithology and thickness: Rhythmic alternations of white diatomaceous laminites and grey to reddish marls rich in organic matter (sapropels, Figs. 3 and 4 of Plate 29). Each lithological cycle ranges between 20 and 170 cm and consists of three different lithologies: (i) dark-grey clays, (ii) brown-reddish calcareous laminites rich in organic matter (sapropels) and (iii) white laminated diatomite with fish rests. Microcrystalline gypsum and evaporitic carbonates are locally intercalated (McKenzie et al. 1980). Based on the lithological alternations and on the relative abundance of fossils, several cycles have been recognised. By the correlation of multiple sections, Hilgen and Krijgsman (1999) have recognised 49 lithological cycles, 41 in the Falconara section (Sprovieri et al. 1996a), referring them to the periodicity of the orbital precession cycles (21 ka). Cyclicity was also related to sea level oscillations induced by tectonics that, through ephemeral cut-off, interrupted exchanges with the open sea (Grasso et al. 1990; Pedley and Grasso 1993). Measured outcropping thicknesses are 27 m in the Falconara section, 25 m in the Capodarso section, 60 m in the Contrada Gaspa section. Reduced thicknesses are evaluated from sections that are believed to have developed along the marginal sectors of the depositional basin.

Paleontological content: Mostly represented by oligotypic fauna. The rich ichtyofauna (*Bregmaceros* sp., *Myctophum* sp., *Syngnathus* sp.) was described in detail by Arambourg (1925). The microfauna comprise abundant diatoms and radiolarians, mostly occurring in the laminites; they are rare in the marls where, in contrast, are abundant benthic (*Bulimina echinata* d'Orbigny, *Bulimina aculeata* d'Orbigny, *Brizalina dentellata* Tavani) and planktonic [*Globigerinoides* spp., *Neogloboquadrina atlantica* (Berggren), *Neogloboquadrina acostaensis* dx (Blow), *Turborotalita multiloba* Romeo, *Turborotalita quinqueloba* (Natland)] foraminifers and calcareous nannofossils (*Amaurolithus amplificus* (Bukry & Percival), *Amaurolithus delicatus* Gartner and Bukry, *Reticulofenestra rotaria* Theodoridis, *Helicosphaera* spp., *Coccolithus pelagicus* (Wallich), *Calcidiscus* spp., *Discoaster pentaradiatus* (Tan), *Sphenolithus abies* Deflandre).

Chronostratigraphic attribution: On the basis of the *Globorotalia conomiozea*, *Reticulofenestra rotaria* and *Calcidiscus leptoporus* biozones, the Tripoli formation is dated to the Lower Messinian (6.90–6.00 Ma BP).

Stratigraphic relationships: The lower boundary is a sharp continuity surface with the clays of the Terravecchia formation, or paraconformably with the Licata formation. The upper boundary is a transitional contact with the calcare di base member of the Cattolica formation, marked by an alternation of diatomaceous marls and calcareous beds whose thickness increases upwards. This boundary is represented by a rock interval ranging from some metres up to 40 m-thick (Ogniben 1957).

Depositional environment: Low depth and closed basin with restricted circulation, characterised by euxinic conditions, where salinity variations (McKenzie et al. 1980; Bellanca et al. 2001) and diatomite "*blooms*" (Gersonde 1980), periodically occurred. The presence of gypsum and halite pseudo-morphs has suggested hypersalinity environmental conditions (Bellanca et al. 2001).

Regional aspects: The unit outcrops widely in Sicily, Calabria, Emilia Romagna and in North Africa. It is well-exposed in the "Caltanissetta Basin", but laterally it is absent and replaced by grey-darkish marls and limestone intercalations (Madonie Mountains), whitish marls with small bivalves (Cattolica Eraclea section) and limestone/bituminous clays couplets (i.e., the Costa Raia gypsum of the Ciminna formation, Poggioreale, Catalano et al. 2010a). A study by Broquet et al. (1984b), including the analysis of 68 stratigraphic sections distributed in Central Sicily, made it possible to redefine the paleogeographic setting of the "Caltanissetta Basin". These authors assume that the oil potential of the formation may reach several billion tons of hydrocarbons. This rock, rich in organic matter, began to be used to power steam trains in 1886 (year of construction of the narrow-gauge railway in Sicily).

Carg abbreviation: TPL

2.6 Messinian Evaporites

The Messinian evaporites originated from the salinity crisis that affected the entire Mediterranean area (Hsu et al. 1973, 1977, 1978; Ryan et al. 1973; Montadert et al. 1978; Ryan and Cita 1978; Krijgsman et al. 1999). The Messinian salinity crisis (MSC) enabled the development of hundreds of metres of evaporites widespread in much of the Mediterranean basin (Fig. 2.77). Most of our knowledge about the evaporites of the Mediterranean basin was acquired during the oceanographic

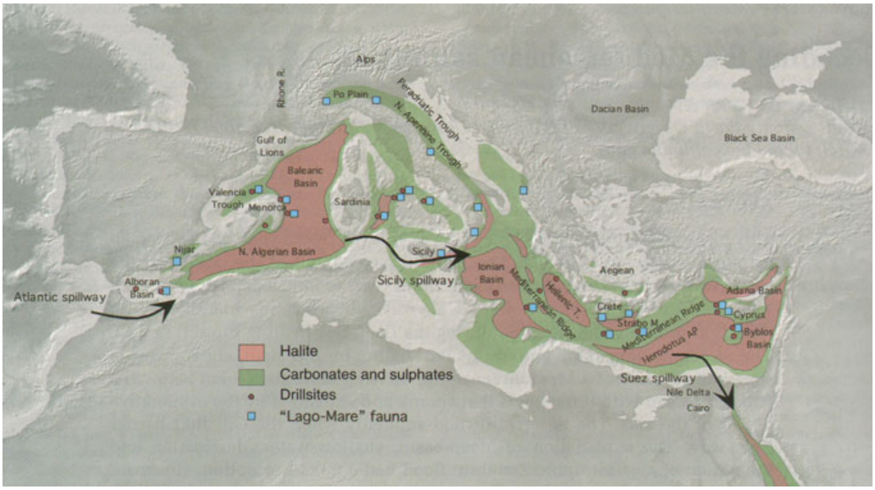


Fig. 2.77 Distribution of evaporites in the Mediterranean Sea (after Ryan 2009)

cruises of Glomar Challenger (1973–1975); several core samples have permitted scientists to conclude that in the Mediterranean, during the Late Miocene, evaporite deposits developed in an area more than 2,200,000 km^2 (Ryan et al. 1973; Hsu et al. 1978).

The genesis of the evaporites has been reported in several models including that of Hsu et al. (1973), which hypothesized the formation of the thick evaporite successions in dried deep-water basins, of Nesteroff (1973) and Nesteroff et al. (1973), which postulated the idea of small basins with low initial depth ranging between −300 and −500 m, and the ocean model of Selli (1960).

The issue of the "salinity crisis" in the Mediterranean has been the subject of numerous seminars, including those held in Erice (Sicily) in 1975 (Catalano et al. (eds) 1976), Cargnano (northern Italy) in 1976 (Cita and Ryan 1978), Malaga (Spain) in 1977, Rome in 1978 (Cita and Wright 1979), Paphos (Cyprus) in 1979 (Orszag-Sperber and Rouchy 1980), a book that includes the contributions of various scholars (McKenzie et al. 2009; Fischer and Garrison 2009; Fischer et al. 2009; Ryan 2009) and a recent Cost-AnrMedsalt symposium helded in Palermo (Sicily) in 2016 (Caruso et al. 2016). These offer an interesting starting point for historical and scientific reconstruction of the Mediterranean salinity crisis. In general, researchers agree that the evaporite basin of the Mediterranean corresponds to a mosaic of ponds of various sizes, separated by structural high areas. Currently, the scientific community is still uncertain about the original extent, the thickness and the nature of the evaporite deposits.

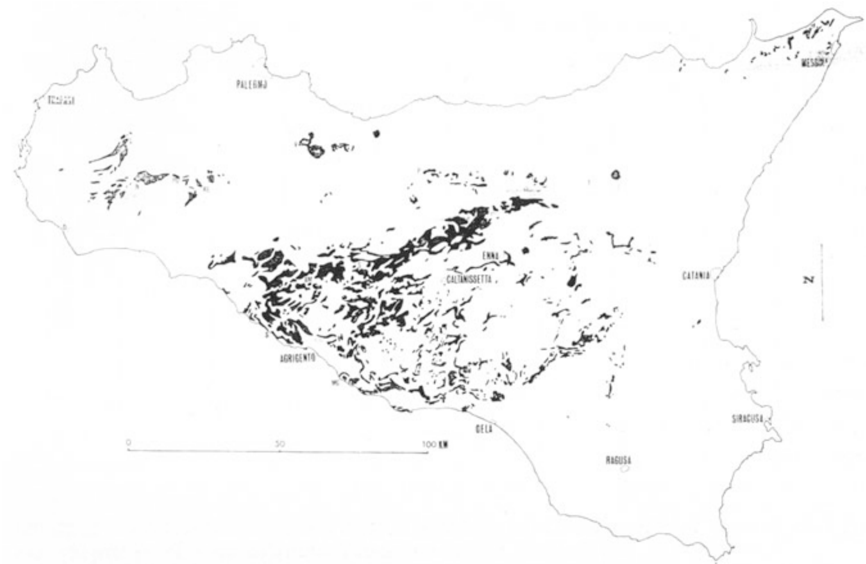


Fig. 2.78 Distribution of the evaporites in Sicily (after Broquet 1968)

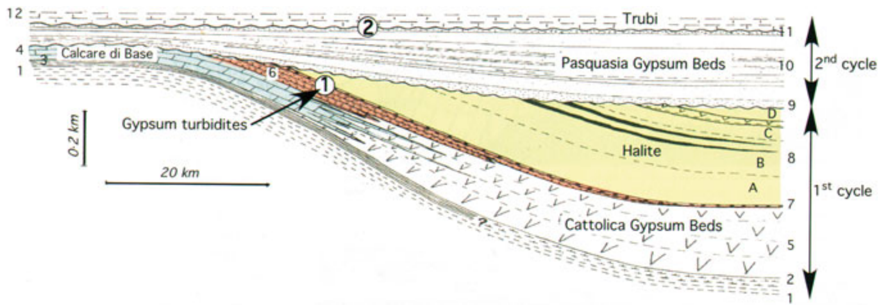


Fig. 2.79 Depositional model of the gessoso-solfifera succession, outcropping in Sicily as viewed by Decima and Wezel (1971)

Evaporite deposits are widespread in Sicily (Fig. 2.78) and are distributed in the two major mining areas of Caltanissetta-Enna and Agrigento. Smaller basins are those of Ciminna, Gibellina-Salaparuta, Troina and Messina.

The Sicilian evaporites have been extensively studied at the spectacular outcrops of the Pasquasia and Capodarso sections (Enna) and the Cattolica Eraclea section (Agrigento) (Baldacci and Mazzetti 1880; Behrmann 1938; Beneo 1950, 1956; Ogniben 1957–1960; Selli 1960; Ente Zolfi Italiani 1962; Mezzadri 1962–1963; Roda 1966–1971; Di Geronimo 1969; Casale 1969; Mascle and Mascle 1972; Mascle 1979; Schreiber et al. 1976).

Genetic models of the evaporite sequence outcropping in Sicily (and generally, throughout the Mediterranean) provide an explanation of the occurrence of proximal and distal basins (Fig. 2.79), as well-defined by Decima and Wezel (1971, 1973). The same Authors proposed the subdivision of the stratigraphic sequence into a “lower evaporitic cycle” and an “upper evaporitic cycle”, separated by an unconformity surface (angular unconformity) caused by an intra-messinian tectonic event. They recognized a facies distribution featuring a proximal and distal sedimentation sectors with respect to the original coastline. The distribution of the evaporites in Sicily has been illustrated with various stratigraphic models similar to each other (Butler et al. 1995; Garcia-Veigas et al. 1996; Clauzon et al. 1996; Krijgsman et al. 1999; Rouchy and Caruso 2006) that are not much different from the one originally proposed by Decima and Wezel (1971, see Fig. 2.79). Some of these sketches provided the precise location of the evaporite deposits and their lateral distribution along the depositional profile, correlating sequences of distal and marginal sectors using the intra-messinian submarine to subaerial erosional surface as a marker.

Some Authors (Roveri et al. 2008a, b) give a different interpretation of the source of some of the selenitic gypsum beds, suggesting gravitational-type processes (i.e., giant landslides).

The evaporitic event, represented by the gypsum body outcropping in the “Ciminna Basin” (Villafrati-Baucina region, Bommarito and Catalano 1973), is interpreted by Lo Cicero et al. (1997) and Catalano et al. (2011b) as a previous evaporitic event of the well-known Messinian salinity crisis. These deposits, here described as the Ciminna formation, are separated from the overlying evaporites (i.e., the Cattolica formation) by about 80 m of marls with *Turborotalita multiloba* (Romeo) whose fossil content justifies predating this event with respect to the onset of the evaporite sedimentation in the Mediterranean that occurred at 5.96 Ma. These data confirm that a previous evaporite phase existed, starting in local basins such as those of Ciminna and Gibellina, which may have occupied marginal areas of the evaporite basin. This event was coeval with the sedimentation of the upper portion of the Tripoli formation.

*2.6.1 Ciminna Formation**

General remarks: This unit comprises the gypsum, forming the lowermost portion of the evaporite sequence of the "Ciminna basin" (Fig. 2.80), which was studied in detail by Lo Cicero et al. (1997). Recently, in the frame of the geological maps of the Carg project (Catalano et al. 2010a, b; Di Stefano et al. 2013), the unit was subdivided into two well-differentiated members in the field. They are the gypsum and the pelitic members that, being characterised by high lateral (heteropic) and vertical internal facies variability, are described with differentiated lithofacies.

Lithology and thickness: The formation is comprised in a gypsum body that appears in the form of a sedimentary wedge intercalated between clays and marls (Fig. 2.80). At the bottom, the gypsum member displays massive selenites with algal filaments and laminated carbonates, cyclically arranged stromatolitic gypsum and a thick wedge of yellow-reddish resedimented gessorudites, gessoarenites and gessopelities (gypsum turbidites, Bommarito and Catalano 1973; Catalano et al. 1976; Lo Cicero et al. 1997). The pelitic member is represented by the sandy marls

Fig. 2.80 At "Le Serre di Ciminna" the gypsum member of the Ciminna formation (CII_1) is inserted between marls and pelites (TRV_{3c} and CII_2) with *Turborotalita multiloba*. Follow, upwards, the selenitic gypsum body of the Cattolica formation (GTL) (after Catalano et al. 2010b)

with *Neogloboquadrina acostaensis* Blow, *Turborotalita multiloba* (Romeo). Geochemical analysis carried out on these marls reveals an increase in the salinity of the waters in the upper part of the succession (Coradossi and Corazza 1978). The fossil content indicates shallow-marine sedimentary environments passing upwards to brackish water conditions (Di Stefano and Catalano 1976). Total outcropping thickness ranges between 60 and 200 m. The Costa Raia gypsum, which is a differentiated lithofacies outcropping along the Poggioreale-Gibellina ridge (Belice valley), consists of alternating layers of thin-bedded white-greyish diatomitic marls with traces of hydrocarbons, marly limestones and selenitic gypsum, upwards becoming chalky and calcareous breccias and laminated gessoarenites (gypsum turbidites, Catalano et al. 2010a). This lithofacies displays thicknesses ranging between 80 and 100 m.

Chronostratigrafic attribution: The evaporites body of the Ciminna formation is inserted between the marls with *Turborotalita multiloba*, which allow us to date these deposits to the lower Messinian, no younger than 6.08 Ma (LO of *Turborotalita multiloba*, Di Stefano and Catalano 1976). The fossil content of the pelitic member dates this formation to the 6.44–6.08 Ma age interval.

Stratigraphic relationships: The gypsum of the Ciminna formation appears in the form of a sedimentary wedge inserted between the *Turborotalita multiloba* marls (Fig. 2.80). The lower boundary of the unit is a sharp surface with the marls of the underlying pelitic member of the Terravecchia formation. The upper boundary is an unconformity surface with the evaporites of the Cattolica formation.

Regional aspects: These deposits outcrop exclusively in the Ciminna basin, where they extend for several km^2, and in the Poggioreale-Gibellina ridge (Costa Raia section).

Carg abbreviation: CII

2.7 Gessoso-Solfifero Group

The "Gessoso-Solfifera" (Ogniben 1957) is a sequence composed predominantly of evaporites, comprised between the underlying Tripoli, Terravecchia, or Licata formations and, upward, the marly limestone of the Trubi Formation. The evaporites were previously thought to begin with the diatomite deposits of the Tripoli formation, which, with clear characteristics of impoverishment of fauna, was believed to mark the beginning of the closure of the basins (Selli 1960). The end of the evaporitic sedimentation is believed to coincide with the onset of new open sea conditions, revealed by the deposition of the pelagic marly limestone of the Trubi formation.

Following the demands of the new Italian Formations Catalogue and the geological map of the Carg project, a new classification of the Sicilian evaporite sequence was proposed (Basilone et al. 2001). This classification amended the original Gessoso-Solfifera Formation (Schmidt di Friedberg 1964–1965), elevating it to the rank of lithostratigraphic group. The "Gessoso-Solfifero" Group comprises two main formational units reflecting the original differentiation of the two evaporite cycles (Decima and Wezel 1971, 1973, Fig. 2.79). The Cattolica formation represents the lower evaporite cycle, the Pasquasia formation the upper one. These formations consist of a number of subunits, in the rank of members, and these differ from the various outcropping sections in their minor facies lateral variations reflecting the different depositional zones (marginal to distal) of the original evaporitic basin. In detail, the Caltanissetta-Enna successions are thought to represent the marginal sectors of the evaporitic basin, while those outcropping in the Agrigento area, well-observable in the Cattolica Eraclea section, represent the deposits formed in the distal sectors. The Monte Capodarso-Monte Pasquasia (Central Sicily) and Cattolica Eraclea (Southern Sicily) sections have historically been considered the type sections of the various units of this lithostratigraphic group.

Carg abbreviation: GS

2.7.1 Cattolica Formation°

General remarks: This unit comprises the evaporites, consisting of sulphur limestone, selenitic gypsum and potassium salts, described by Decima and Wezel (1971) as the "lower evaporite cycle".

Lithology and thickness: Upwards, from the bottom, the following members are distinguished:

2.7.1.1 "Calcare di Base" Member

This well-known unit term was introduced in the geological literature by Ogniben (1957) and Selli (1960) to describe the limestone located at the base of the Messinian evaporite sequence. It is also known as sulphur limestone (Guide excursion SGI 1953) as in outcrop it frequently displays the typical yellow colour of mineralized porous limestone. The member was included in the Traditional Units of the Italian Formations Catalogue (Cita et al. 2007b). These deposits consist of thick-bedded grey-yellowish limestone separated by pelitic joints (Fig. 2.81, the so-called "compartments" of the miners). The limestone beds, characterised by the local presence of halite pseudo-morphs (Decima et al. 1988; Ogniben 1957; Pedley and Grasso 1993), display rhythmic lamination and brecciated limestone with intraclasts. Locally, impregnations of bitumen, are recognised. With thickness ranging between 3 and 10 m, the unit is laterally discontinuous. It rests above the diatomites of the Tripoli formation along a sharp surface, locally marked by transitional contact highlighted by an increase in thickness of the limestone beds. The lower boundary is also an unconformity surface—marked by stratal discordance—with the clays of the Terravecchia and Licata formations. The upper boundary is a

Fig. 2.81 In the outcrop near the town of Comitini, the "Calcare di base" member consists of alternations of marls and thin-bedded limestones, involved in soft sedimentary deformation structures (slumping), which are interlayered between two massive beds showing lower erosional boundaries

sharp surface with the overlying Selenitic member or, through an erosional surface and stratal discordance, directly with the Gessoarenites member of the Pasquasia formation.

These evaporitic deposits, which are the result of concentration of brines (Usiglio 1849) during their development, appear to have been subjected to periodic influxes of freshwater discharged in a continental and restricted environment subjected to desiccation (McKenzie et al. 1980). Some isotopic values seem to suggest a formation linked to bacterial reduction of sulphates (Decima et al. 1988). The very poor fossil content consists of benthic foraminifers, the remains of fishes, continental plant fragments and algal stromatolites. Spectacular outcrops of this unit are observed in the Marianopoli, Casteltermini, Riesi and Favara section, forming part of the Caltanissetta basin. At Pietraperzia, intercalations of lenticular levels of celestine ($SrSO_4$) are observable.

Carg abbreviation: GTL_1

Fig. 2.82 Thin-bedded selenitic gypsum (estuary of the Platani river)

2.7.1.2 Selenitic Member

Selenitic gypsum with large crystals vertically grown more than 50 cm (Fig. 5 of Plate 29), nodular and massive to stratified (Fig. 2.82) selenites, reworked gypsum, laminated algal gypsum, whitish chalky marls and limestone and chalky clay intercalations with lenticular geometry. The individual selenite beds, reaching 1.5–3 m in thickness, are alternate regularly with thin marls evidencing the development of 6–7 cycles during the Messinian. Outcropping thicknesses reach 150 m.

Carg abbreviation: GTL_2

2.7.1.3 Salt Member

This evaporite unit is well represented by the salt deposits of Realmonte (AG) and Italkali (Petralia, Madonie Mountains) mines. The rock consists of the direct precipitation of sodium chlorides (halite), potassium and magnesium salts (Fig. 2.83). It is characterized by crystalline texture, with the typical cubic morphology of NaCl crystals sometimes characterised by sulphurous impregnations. Locally, anhydrite (1–10 cm) and red clays are intercalated (Realmonte mine). The magnesium and potassium salts, mainly consisting of kainite minerals, are diffused in the

Fig. 2.83 Spectacular view of salt in defomed structure as shown inside the Realmonte mine

middle-upper portion of succession and display thicknesses of several metres. In the halite, the bromine content decreases upwards, indicating a salt recycle by rainwater (Decima 1975). In the salts of Realmonte mine, which reach thicknesses of 600–700 m (Lugli 1997), a subaerial exposure surface separates the salt body into two subunits: the lower body is characterised by accumulations of halite crystals with cubic morphology and with minor amounts of kainite; the upper one displays accumulations of salt crystals with irregular “hopper” morphology, in which the corners have grown faster than the centre of the faces of the crystals. These differences suggest an initial precipitation from stratified hypersaline waters and a subsequent precipitation from brackish waters of shallow-water environments such as salt lakes, after a subaerial emerging phase (Schreiber et al. 1976; Lugli and Schreiber 1997; Lugli et al. 1999). The cyclical alternations of black salts and clays are thought to have formed due to precipitation/dissolution processes related to temperature changes (up to 10°), as suggested by the fluid inclusions analysis of the Realmonte salts (Lugli and Lowenstein 1997). The salt deposits are considered as a most basinal facies respect to the selenites (Decima and Wezel 1971, 1973; Lugli and Schreiber 1997; Lugli 1999; Lugli et al. 1999).

Carg abbreviation: GTL_3

Stratigraphic relationships: The lower boundary of the Cattolica formation is a sharp surface, with local transitional contact with the diatomites of the Tripoli formation. It is also an unconformity surface—marked by stratal discordance—with the clayey member of the underlying Terravecchia and Licata formations. At the Monte Casalotto section (Roccamena), this gypsum, 50–100 m-thick, rests unconformably with stratal discordance on the Castellana Sicula formation and, with erosion and large hiatus, on the Corleone glauconitic calcarenites. The upper boundary is an erosional unconformity with the resedimented gypsum of the gessarenites member of the Pasquasia formation.

Carg abbreviation: GTL

2.7.2 Pasquasia Formation°

General remarks: This formation contains the evaporites, consisting of the gessarenite, chalky marl, *Congeria* limestone, fanglomerate and Arenazzolo members, described as forming the "upper evaporite cycle" (Decima and Wezel 1971).

Lithology and thickness: Upwards, from the bottom, the following members are distinguished:

2.7.2.1 Gessarenites Member

Graded and laminated gessoarenites and gessopelites with gypsum, carbonates, quartz and glauconitic grains and organic matter (Fig. 2.84). Poorly-graded

Fig. 2.84 The m-thick massive gessoarenite beds display gradation and lamination structures and are interlayered with thin levels of gypsum marls (gessoarenite member, town of Grotte near Agrigento)

conglomerates and breccias, chalky-clayey, cross-laminated (ripple) sands with erosional base and lenticular geometries, showing the entire Bouma sequence, occur locally; red planar laminated gessopelites are also present (Fig. 6 of Plate 29). Outcropping thicknesses reach 150 m. These deposits are considered the product of turbiditic and debris flows in a slope-basin environment (Catalano et al. 1976).

Carg abbreviation: GPQ_1

2.7.2.2 Chalky Marls Member

Clayey marls, locally silty and sandy marls alternate with massive selenitic gypsum and laminated gypsum, arranged in several sedimentary cycles. In the Eraclea Minoa section at least 6–7 cycles can be recognised. Each cycle, with variable thickness ranging between 5 and 15 m, shows an evolution from sandy and marly lithologies to laminated and selenitic gypsum, reflecting an increase in salinity. The lower boundary is a sharp surface with the underlying gessoarenites member (Eraclea Minoa section). The upper boundary, with the *Congeria* limestone member, is marked by a transitional contact represented by alternations with limestone beds rich in ostracods and molluscs brackish water fauna. Outcropping thickness ranges between 50 and 300 m.

Carg abbreviation: GPQ_2

2.7.2.3 Congeria Limestone Member

Described as "*Congeria* beds" (Baldacci 1886), "Zone with *Congeria*" (Ogniben 1957), they are stratigraphically located above the chalky-marl member and below the Arenazzolo member. They can be observed well in the Casteltermini and Marianopoli outcropping sites (Caltanissetta). The unit consists of well-cemented yellowish limestone, bioclastic and sometimes pseudo-oolitic limestone and sandy marls with quartz detrital grains. Thickness ranges from a few centimetres to 1 m. The fossil content comprises abundant brackish water fauna such as large shells (up to 10 cm) of bivalves (*Congeria* sp., *Cardium* sp., *Dreissenia* sp., *Melanoides* sp.), gastropods (*Bithynia* sp.) and planktonic foraminifers (*Globigerina* spp.). These deposits are attributed to the "Lago-Mare" facies (Ruggieri 1967a), representing the final sedimentation events of the Messinian salinity crisis (Ruggieri and Sprovieri 1974, 1976a). This "lumachella" limestone is believed to be in situ accumulation, deposited in a lagoon environment and marking the gradual transition to open sea conditions, established with the sedimentation of the marly limestone of the Trubi formation (Ogniben 1957). Other environmental and sedimentological features are reported in several specific papers (see Ryan 2009 and references therein).

Carg abbreviation: GPQ_3

2.7.2.4 Fanglomerates Member

These deposits were first described by Ruggieri and Torre (1987), which, on the basis of their stratigraphic position, dated them to the Upper Messinian. The unit consists of gessarenites and gessopelites, clays and grey to red-brown marls with brackish ostracods (*Cyprideis pannonica* MEHES); upwards, reddish reverse graded polygenic conglomerates with abundant gypsum fragments are intercalated. Outcropping thicknesses reach 100 m. The lower boundary is an erosional unconformity—marked by stratal discordance—with the gypsum beds of the Cattolica formation. The upper boundary, no younger than 5.33 Ma, is an angular unconformity with the Trubi formation. The member represents the lateral facies of the Arenazzolo member occurring in the marginal evaporite basins.

Carg abbreviation: GPQ_4

2.7.2.5 Arenazzolo Member

The term derived from the Sicilian word "*rinazzolu*", pet form of *rina* (lat. arena), which means "sand". It was used for the first time in a scientific paper by Mottura (1871, 1910) to indicate a poorly cemented quartz-micaceous sandstone. The Arenazzolo was included in the Traditional Units of the Italian Formations Catalogue (Cita et al. 2007b). It is yellow-brown cros-laminated sandstone and locally white-greenish coarse calcarenites with angular quartz grains, feldspars, mica, abundant fragments of carbonate and crystalline rocks often aligned and arranged parallel to the bedding, representing small-scale tractive structures (Fig. 2.85). Flaser stratification have suggested high-energy conditions in littoral environments at the edge of a lake or a delta lobe (Brolsma 1978). Generally, these deposits occur in massive layers with lateral continuity and thickness varying from

Fig. 2.85 Cross- and planar-laminated fine-to-coarse sandstone of the Arenazzolo member (Cattolica section)

1 to 40 m. The fossil content includes oligotypic faunal associations, including abundant *Ammonia beccarii* (Linneo), *Ammonia beccarii tepida* (Cushman), ostracods (*Cyprideis pannonica* var. *agrigentina* Decima). The lower stratigraphic boundary is a sharp surface—with local erosion—with the underlying *Congeria* limestone and the chalky marls members; the upper boundary is a sharp conformity with the marly limestone of the Trubi formation.

Carg abbreviation: GPQ_5

Stratigraphic relationships: The lower boundary of the Pasquasia formation is an erosional unconformity with the gypsum beds of the Cattolica formation. The upper boundary of the unit is an unconformity surface—locally marked by onlap stratal terminations—with the marly limestone of Trubi.

Carg abbreviation: GPQ

2.8 Trubi Formation°

General remarks: Trubi is a name that comes from the term in Sicilian dialect *trubbu* (pl. *trubba*), which means "whitish rocks" (Fig. 2.86). It has been used extensively in the Sicilian geological literature and was included in the Traditional Units of the Italian Formations Catalogue (Cita et al. 2007b). The Capo Rossello section (Agrigento), which represents the stratotype of the Zanclean Stage (Cita and Gartner 1973), was study in detail in its lithological, chronostratigraphic,

Fig. 2.86 Lower Pliocene white pelagic limestone and marl successions, pertain to the Trubi formation, in the outcrop of the turistic site of Cattolica Eraclea (Agrigento). Look at the cyclic organization of the set of strata

cyclostratigraphic and palaeomagnetic features (Hilgen and Langereis 1988; Zachariasse et al. 1989, 1990; Hilgen 1991; Sprovieri 1992, 1993; Sprovieri et al. 1996a). Thus, it can be taken as the type section to study of the marly limestone of the Trubi formation. Based on these studies, the bottom and the top of the unit were regionally dated at 5.33 and 3.08 Ma, respectively. Detailed biostratigraphic analysis (Cita 1973, 1975a, b; Rio et al. 1984) conducted at the Eraclea Minoa section (Agrigento) helped to define the GSSP of the Miocene-Pliocene boundary, astronomically dated at 5.33 Ma (Lourens et al. 1996; Van Couvering et al. 2000). It is located at the base of the formation, along its lower stratigraphic boundary with the underlying Arenazzolo member. In the Punta Piccola section (Agrigento), the outcropping succession of the Trubi formation was studied to define the lower portion of the Piacentian stratotype (Castradori et al. 1998). In the supported Buonfornello and Lascari sections (N Sicily), the lithostratigraphic characteristics of the resedimented limestone of the Lascari member are well observable (Cipolla 1926a; Moroni and Torre 1966; Avellone et al. 2011).

Synonyms and priority: The unit was described by Mottura (1871, 1910) and Baldacci (1886) as a formation deposited in an open sea environment marking the end of the Messinian salinity crises.

Lithology and thickness: Cyclical alternations of white thin-bedded (5–30 cm) marly limestone, marls and sandy-marls, rich in planktonic fauna (Figs. 2.86 and 2.87). Locally, at the bottom of the succession, resedimented conglomerates are present, whose elements derive from erosion of the upper evaporite unit.

Fig. 2.87 Lower Pliocene white marly limestones of the Trubi; the succession displays regular stratification in thick and thin beds (Punta Bianca, Palma di Montechiaro)

Fig. 2.88 Thick clastic intercalation within the pelagic limestone of Trubi, consisting of calcarenites with *Amphisteginae* and planar to cross laminations of the Lascari member (Lascari, Madonie Mountains)

A 50 m-thick layer of grey to yellowish thin to thick-bedded (10–40 cm) biocalcarenites with reworked large benthic foraminifers (*Amphistegina* sp.) is intercalated in the lower portion of the N Sicily supported sections (Fig. 2.88, Lascari member). Locally, large boulders of resedimented carbonates (isolated blocks) are embedded in the formation. Outcropping thicknesses range from 60 to 150 m.

Paleontological content: Planktonic foraminifers (*Globorotalia puncticulata* (Deshayes), *Globorotalia margaritae* Bolli & Bermudez, *Orbulina universa* d'Orbigny, *Sphaerodinellopsis* spp., *Globigerinoides obliquus extremus* Bolli & Bermudez, *Globigerinoides quadrilobatus* Banner & Blow), calcareous nannofossils (*Discoaster tamalis* (Kamptner), *Discoaster asymmetricus* (Gartner), *Reticulofenestra pseudoumbilicus* (Gartner) and *Helicosphaera sellii* (Bukry & Bremlette). In the Lascari member, there are echinoid spines, tooth fish, bivalves, gastropods and, locally, oyster shells (*Pycnodonta navicularis* Brocchi) in life position on the Mesozoic carbonate substrate (Ruggieri 1973a).

Chronostratigraphic attribution: On the basis of MPL1-4a, b planktonic foraminifer biozones (Cita 1973, 1975a, b) and MNN12-MNN16 calcareous nannofossil biozones (Rio et al. 1984, 1990), the unit has been dated to the Zanclean-Lower Piacentian.

Stratigraphic relationships: The lower boundary is a paraconformity or unconformity surface with the Messinian evaporites and the clastic deposits of the Terravecchia formation or directly with the Mesozoic carbonates. The upper boundary is a paraconformity surface with the Monte Narbone formation or with the Enna marls. It can be considered an unconformity surface—marked by erosion, stratal discordance and long hiatus—with the clastics of the Belice formation.

Depositional environment: Sedimentological and paleoecological features suggest deep-water depositional environments. Paleo-bathymetric evaluations, based on the benthos *versus* plankton fauna content, suggest an average paleo-depth around −700 m (Sprovieri 1982), although some fossil specimens, currently living up to −2000 m in depth, are also present.

Regional aspects: The unit outcrops both in Sicily and Calabria. It is widely outcropping in the S Sicily coastal belt, from the Agrigento and Eraclea Minoa type area to Gela. The marly limestone gives way laterally and vertically to grey marls, mostly in some outcropping areas of the Peloritani and Nebrodi Mountains and Calabria (Sprovieri, personal communication). On the basis of the cyclical limestone-marl couplets of the Capo Rossello section, a correlation has been proposed between the cyclic variation of $CaCO_3$ content and the astronomical records and with the planktonic foraminifers of hot and cold climate peak abundance fluctuations (Hilgen 1991; Sprovieri 1993; Sprovieri et al. 1996a). Catalano et al. (1998) recognised some glacio-eustatic 4th order cycles (400 ka) and attributed them to orbital eccentricity (astronomical cycles of Milankovitch 1920, 1941).

Carg abbreviation: TRB

2.9 Plio-Pleistocene Units

The Upper Pliocene-Pleistocene deposits consist of clastic and clastic-carbonate units chrono-equivalent to each other and outcropping in the Belice Valley, Enna-Caltanissetta, Gela, Agrigento regions and with minor extensions in the Termini Imerese-Trabia area. Their distribution and lithological differences indicate that different sedimentation basins occurred in Sicily during the Late Pliocene (Fig. 2.89). In the Belice basin (W Sicily), the turbidite sequence that follows the Trubi marly limestone is known as pertaining to the Belice marly-arenaceous formation (Ruggieri and Torre 1973). The Enna-Caltannissetta Basin (Central Sicily) is an E-W oriented basin, about 200 km^2 in size, bordered by antiforms (Vitale 1996). The recognised lithostratigraphic units, which develop above the Trubi, comprise clastic carbonates and marly clays, included in the Enna marls, Capodarso formation and Geracello marls (Roda 1967a, b). In the area between Gela and Agrigento (S Sicily), the marly clays of the Monte Narbone formation and the unconformably fossiliferous calcarenites of the Agrigento formation, both belonging to the Ribera Group amended here, characterise the sedimentary sequence developing above the Lower Pliocene marly limestone of Trubi. This sedimentary sequence is characterised by a complex tectono-sedimentary setting, related both to the progressive deformation of the Gela nappe and eustatic sea-level oscillations (Catalano et al. 1992b, c; 1993, 1998; Vitale 1990, 1996, 1997b, 1998; Grasso et al. 1995; Butler et al. 1995; Agate et al. 2011; Gasparo Morticelli et al. 2015).

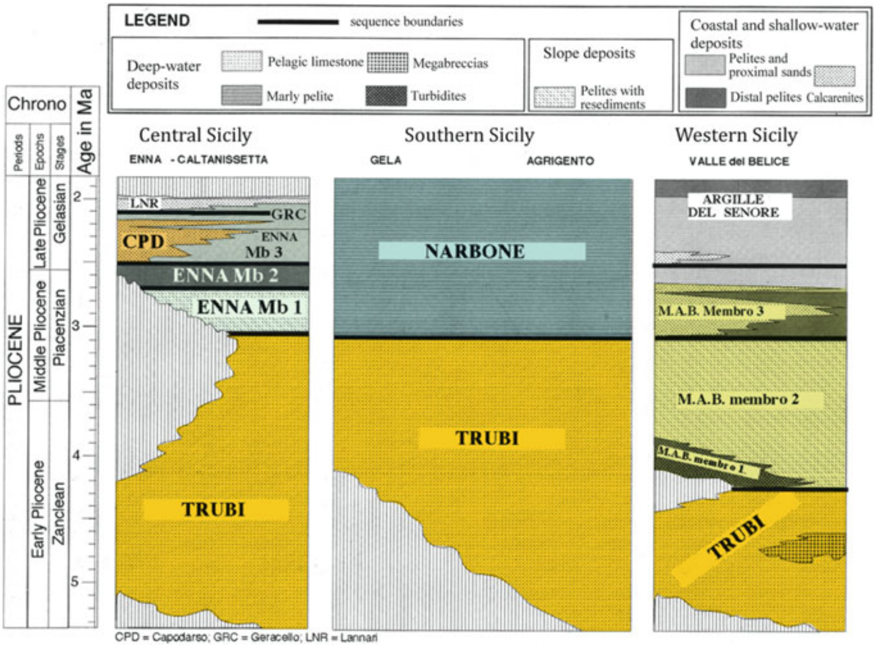


Fig. 2.89 Chronostratigraphic correlation between the Plio-Pleistocene lithostratigraphic units, outcropping in central-western and southern Sicily (after Vitale 1996)

2.9.1 Marly-Arenaceous Formation of Belice

General remarks: Consisting of a clastic to clastic-carbonate succession, the unit was subdivided into members on the basis of the Pizzo di Gallo and Cozzo di Felice type sections (Poggioreale, Ruggieri and Torre 1973; Vitale 1990, 1997a). It represents the Upper Pliocene-Lower Pleistocene sedimentary sequence filling the so-called Belice basin.

Lithology and thickness: Alternations of turbiditic quartz sandstones and mudstone, followed by resedimented shallow-water calcarenites. Outcropping thicknesses reach 600–700 m. The lower arenaceous member consists of fine-grained quartz arenites, showing turbiditic structures and rounded quartz grains, alternating with clays. Locally, lens of resedimented biocalcarenites. Upwards, and laterally with interfinger relationships, clays, blue-grey marly and silty clays with planktonic foraminifers and rare molluscs and cross-laminated sand intercalations compose the clay member. The calcarenite member, occurring at the top of the succession, consists of thick resedimented biocalcarenites; it follows unconformably the underlying deposits.

Paleontological content: Planktonic foraminifers (*Globorotalia puncticulata* (Deshayes), *Globorotalia margaritae* Bolli & Bermudez), calcareous nannofossils (*Discoaster tamalis* biozone), large benthic foraminifers (*Amphisteginae*).

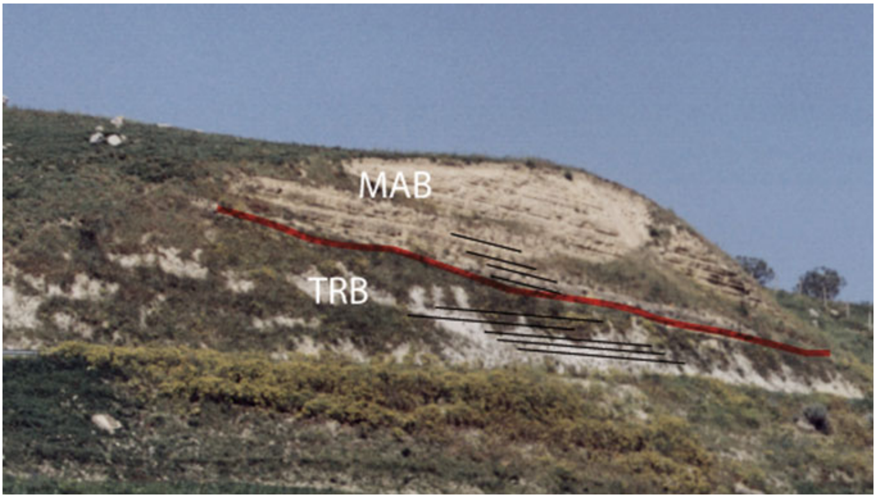


Fig. 2.90 Unconformity boundary between the yellow calcarenites of the marly-arenaceous Formation of Belice (MAB) and the white pelagic limestones of the Trubi (TRB) (Poggioreale-Gibellina ridge, near Corleone)

Chronostratigraphic attribution: Piacenzian (MPL4b biozone)—Gelasian (MPL5 and MPL6 biozones).

Stratigraphic relationships: The lower boundary is an unconformity marked by hiatus with the Trubi formation (Fig. 2.90). The upper boundary, generally represented by the topographic surface, is marked locally by clays and marls (Senore marls, Vitale 1990).

Depositional environment: A deltaic to turbiditic system that evolves upwards to a carbonate ramp depositional environment. Thickness variations along the Belice basin, with thinning southwards, have suggested a synsedimentary tectonic control (Vitale 1990, 1998).

Regional aspects: These deposits outcrop diffusely in the Belice Valley (SW Sicily) and in the S Sicily offshore, where they have been drilled by several deep boreholes (Agip). They are mapped in NW Sicily where outcrop with few extension (Catalano et al. 2011a, b).

Carg abbreviation: BLC

2.10 Caltanissetta Group

General remarks: In this informal group, we include the formational units, known as the Enna marls, the Capodarso formation and the Geracello marls, which characterised the sedimentary sequence filling the so-called Caltanissetta basin. The description of the units is based on the results of several studies, first that of Roda

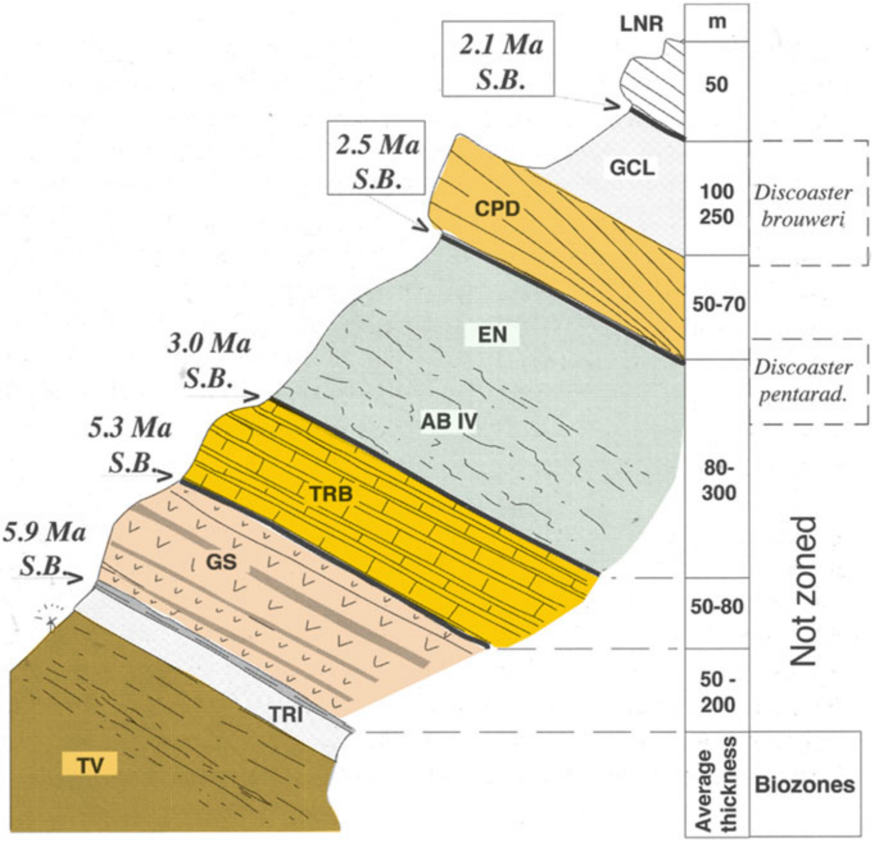


Fig. 2.91 Monte Capodarso section (after Vitale 1996), where the original lithostratigraphic units recognized by Roda (1967a, b), the sequence boundaries and the biozones (Catalano et al. 1993, 1998) are shown

(1967a, b, 1971) and then those of several authors (Grasso and Butler 1993; Butler and Grasso 1993; Vitale 1996, 1998; Catalano et al. 1993, 1998; Maniscalco et al. 2010), which studied the Capodarso type section (Enna, Figs. 2.91 and 2.92). The Monte Capodarso sequence has been interpreted as the filling of a growth syncline, about 10 km^2 wide and enclosed between two major anticlines (fault-propagation anticlines, Catalano et al. 1993; Lickorish and Butler 1996; Vitale 1996). Sequence stratigraphy and sedimentological studies have highlighted the cyclical organization of the sequence with a number of depositional sequences, systems tracts and parasequences (Catalano et al. 1997, 1998; Vitale 1996, 1997b). Supported sections for these formational units are described in the area of Enna (Casale 1969; Maniscalco et al. 2010), Valguarnera and Regalbuto (Ogniben 1955), Monte Navone-Piazza Armerina (Di Geronimo 1969), Aidone (Wezel 1966), Agrigento and Centuripe (Butler and Grasso 1993; Butler et al. 1995). The Caltanissetta basin

Fig. 2.92 Panoramic view of the Capodarso Mount (Enna); the outcropping Miocene-Pliocene succession displays, from the bottom: grey-bluish clays of the pelitic member of the Terravecchia formation (TRV_3), Messinian evaporitic deposits of the gessoso-solfifero group (GS), Lower Pliocene white pelagic limestones of Trubi (TRB), Upper Pliocene marly clays of the Enna marls (ENN), Upper Pliocene Capodarso calcarenites (CPD) with progradational geometries

deposits have been mapped in the Caltanissetta geological map (1:100,000 scale-map, Mezzadri and Francaviglia 1951) and, recently, in the Caltanissetta n. 631 geological map of the CARG project (1:50,000 scale-map, Tortorici et al. 2010). In this frame, some descriptive terms have been discarded, such as "brecciated clays" of Roda (1967b) and the AB IV level of Ogniben (1955), which he included with the Enna marls (see also Catalano et al. 1992b, c).

2.10.1 Enna Marls

Lithology and thickness: Grey marls (about 40 m thick) change gradually upwards to green clayey-marls and marly-clays with benthic foraminifers and molluscs (Fig. 7 of Plate 29) and to grey silty clays (70 m). 6 m-thick breccias, whose elements included mud chips, sandstone fragments and lenses of the underlying Trubi marly limestone, characterise the base of the unit. Outcropping thickness varies from 250 to 280 m.

Paleontological content: These lithologies are dominated by benthic (*Robulus curviseptus* (SEGUENZA), *Marginulina coarctata* SILVESTRI, *Nodosaria pentecostata* COSTA, *Planularia auriscymba* D'ORBIGNY, *Lenticulina peregrina* (SCHWAGER), *Plecto frondicularia inaequalis* COSTA, *Orthomorphina bassanii* (FORNASINI), *Bolivina antiqua* D'ORBIGNY, *Bolivina arta* MACFADYEN, *Bolivina leonardii* ACCORDI & SELMI, *Bolivina placentina* ZANMATTI, *Siphonodosaria vertebralis* (BATSCH), *Baggina gibba* CUSHMAN & TODD, *Anomalina helicina* COSTA) and planktonic (*Globorotalia bononiensis* DONDI, *Globorotalia crassaformis* GALLOWAY & WISSLER) foraminifers.

Chronostratigraphic attribution: On the basis of the *Globorotalia punticulata* biozone, these deposits have been dated to the lower part of the Late Pliocene.

Stratigraphic relationships: The lower boundary is a transitional contact or a paraconformity with the marly-limestone of the Trubi formation; it also can be considered an unconformity—marked by long hiatus—with the Messinian evaporites or with the clastic deposits of the Terravecchia formation. The upper boundary is an erosional unconformity with the Capodarso formation.

Depositional environment: Outer continental shelf.

Carg abbreviation: ENN

2.10.2 Capodarso Formation

Lithology and thickness: Yellowish biocalcarenites with large-scale cross-bedding and clinoforms alternating with greyish siltstones (Fig. 8 of Plate 29); fine sands and sandstones and sandy-clay for a total thickness of 50–90 m. The calcarenites display clinoforms, heights up to 27 m and a length of 2.1 km, measured along the direction of progradational geometries (Agate et al. 2011). The rhythmic calcarenite-sand alternations, related to paleo-bathymetric oscillations (Roda 1971), are considered forming parasequences that in turn are included in a larger depositional sequence. Their vertical and lateral (heteropic) lithological variations and the internal stacking patterns (geometries, facies trends and thickness) were both attributed to eustatic oscillations and to the synsedimentary growth of large-scale folds (Catalano et al. 1993, 1998; Vitale 1996, 1997b, 1998).

Paleontological content: Rodoficean algae, echinoids and molluscs (*Pecten* sp., *Venus* sp. and *Lucina* sp.).

Chronostratigraphic attribution: Lower Pleistocene (Figs. 2.72 and 2.89, Gelasian Italian Marine Stage, see Cohen and Gibbard 2016).

Stratigraphic relationships: The lower boundary is an unconformity—marked by downlap stratal termination and offlap geometries—with the Enna marls.

Depositional environment: The sedimentary structures and ichnofacies suggest coastal with ramp geometry (distally steepened, Agate et al. 2011), adjacent to continental sectors (northwards) and, southwards, a deep-water sector (Vitale 1998).

Carg abbreviation: CPD

2.10.3 Geracello Marls

Lithology and thickness: Carbonate breccias a few cm thick changing upwards to grey-bluish marly- and silty-clays and yellowish clayey sands. The sands display poorly-sorted gravel-sized quartz and carbonate rock fragments and an abundant fraction of micaceous clays with rests of plants. The uppermost 200 m-thick sequence is characterised by yellowish sands with intercalations of well-cemented bioclastic calcarenites and lenses of conglomerates (Fig. 2.91, Lannari sands, Roda 1971).

Paleontological content: The poorly-preserved fossil content is dominated by benthic (*Ammonia inflata* (Seguenza), *Bulimina elegans* d'Orbigny, *Bulimina marginata* d'Orbigny, *Reussella spinulosa* (Reuss), *Cassidulina levigata* d'Orbigny, *Cassidulina carinata* Silvestri) and planktonic [*Neogloboquadrina pachyderma* dx Ehrenberg, *Globigerinoides ruber* d'Orbigny, *Globorotalia inflata* (d'Orbigny)] foraminifers, bivalves (*Cardium* sp., *Venus* sp.), gastropods (*Turritella* sp., *Natica* sp.).

Chronostratigraphic attribution: Gelasian (Italian Marine Stage, Cohen and Gibbard 2016).

Stratigraphic relationships: The lower boundary is an unconformity with the Capodarso formation, linked to a transgressive phase (Behrmann 1938; Trevisan 1943) or with older deposits, including the marly limestone of the Trubi formation, Messinian evaporites and the clastic deposits of the Terravecchia formation.

Depositional environment: Continental shelf.

Carg abbreviation: GER

2.11 Ribera Group

General remarks: In the original definition of the Ribera formation, Marchetti (1956, 1960) included the younger deposits of the Southern-Central Sicily stratigraphic column. The members included were named Arenazzolo, Trubi, Narbone and Agrigento. The Agrigento unit was also described as Butera formation by Baldacci (1886). The new classification proposed here separates the Trubi formation into independent units, considers the Arenazzolo as a member of the Pasquasia formation and raises the Ribera formation to the rank of group, including in it the Monte Narbone and Agrigento formations. The following description is based on the Monte Narbone and Agrigento type sections (Fig. 2.93), recently studied in their biostratigraphic, lithological and sequence-stratigraphy features by Sprovieri et al. (1996a, b) and Catalano et al. (1997, 1998).

2.11.1 Monte Narbone Formation

Lithology and thickness: Cyclic alternations of bioturbated grey clays and white calcilutites or sandy silt, changing topwards, with transitional contact, to well-cemented coarse calcareous sandstone (Monte Narbone section). This latter lithology is laterally represented by *lumachella* limestone (Agrigento section, Fig. 2.93). Cyclic alternations of marly clays and silty sands with thick-bedded calcareous sandstone and cross-stratified bioclastic calcarenites characterise the

Fig. 2.93 Plio-Pleistocene Agrigento section, showing from the bottom the brown marls and clays of the Monte Narbone formation, followed upwards by the yellow calcarenites with pectinids of the Agrigento formation

Caltanissetta, Piazza Armerina and Valguarnera outcrops. Sprovieri et al. (1996a) recognised seven upward-shallowing cycles, each around 50 cm thick, bounded by a sharp marine ingression surface. Total thickness ranges between 300 and 400 m.

Paleontological content: Benthic and planktonic foraminifers [*Globorotalia inflata* (d'Orbigny)], calcareous nannofossils, molluscs (*Corbula gibba* Olivi).

Chronostratigraphic attribution: On the basis of *Dictyococcites productus*, *Calcidiscus macintyrei* and *Helicosphaera sellii* calcareous nannofossils biozones, the unit has been dated to the Upper Pliocene (Sprovieri et al. 1996a, b).

Stratigraphic relationships: The lower boundary is a transitional contact with the marly limestone of the Trubi formation (Fig. 2.94); the upper boundary is an unconformity with the bioclastic calcarenites of the Agrigento formation (Fig. 2.93).

Depositional environment: Paleoecological analysis reveals that these hemi-pelagic deposits formed in shallow-water to upper slope (epibathyal) environments.

Regional aspects: The unit outcrops widely in Central-Southern Sicily. In the area between Gela and Ribera (S Sicily), the formation is composed of bluish sapropelitic marl levels. It was drilled to depths ranging from a few tens of metres up to about 200 m for several deep oil exploration wells (Agip), located in the S Sicily offshore.

Carg abbreviation: NAB

Fig. 2.94 Stratigraphic relationships between the white marly limestones of Trubi and the upper brown marls of the Monte Narbone formation (Cattolica Eraclea, Agrigento)

2.11.2 Agrigento Formation

Lithology and thickness: Fossiliferous (mostly Pectinids) yellow sands and well-cemented planar, oblique to cross (ripples) laminated calcarenites with intercalation of biocalcirudites and conglomerates. Brown pelites and quartz-carbonate sands occur laterally and upwards. Thickness ranges between 30 and 90 m.

Paleontological content: Bivalves (*Glycimeris* spp., *Pecten jacobaeus* Linneo, *Chlamys multistriata* Poli, *Chlamys septemradiata* [synonimized name of *Pseudamussium peslutrae* (Linneo)], *Arctica islandica* Linneo, *Ostrea* spp.), gastropods (*Patella* spp.), corals, bryozoans, sponges, algae, vermetids, scaphopods, echinoderms, benthic foraminifers.

Chronostratigraphic attribution: Lower Pleistocene

Stratigraphic relationships: The lower boundary is a sharp erosional unconformity with the Monte Narbone formation (Fig. 2.93), marked by downlap stratal terminations, and, locally, with the Trubi formation, marked by stratal discordance and long hiatus (Fig. 2.95).

Fig. 2.95 Unconformity between Trubi chalk succession and the yellow biocalcarenites of the Agrigento formation (Scala dei Turchi, Agrigento)

Depositional environment: Coastal (beach) depositional environment (foreshore to shoreface).

Regional aspects: The unit outcrops widely along the Southern Sicily coastal belt, from Gela to Marsala. It corresponds to the equivalent deposits of the Marsala synthem, outcropping and mapped in the northern Sicily coastal belt.

Carg abbreviation: AGG

2.12 Quaternary Unconformity-Bounded Stratigraphic Units

Synthem stratigraphy (Chang 1975) is a stratigraphic tool aimed at defining the Unconformity-Bounded Stratigraphic Units (UBSUs) as "bodies of rocks bounded above and below by significant unconformities of regional extent" (Salvador 1987; Murphy and Salvador 1999).

The UBSUs, which are objective units, were promoted by the Italian Geological Survey (Servizio Geologico Nazionale 2001) and the Italian Commission on Stratigraphy (Cita 2007, 2008a, b, c, 2009a, b) for the new geological maps of the Carg project (http://www.isprambiente.gov.it).

In the coastal sector of NW Sicily, the regional correlation of relevant unconformities recognised within the Quaternary sedimentary successions made possible the mapping of seven UBSUs (Fig. 2.96, Di Maggio et al. 2008, 2009; Agate et al. 2017). The regional unconformities are marine or subaerial erosional surfaces, as

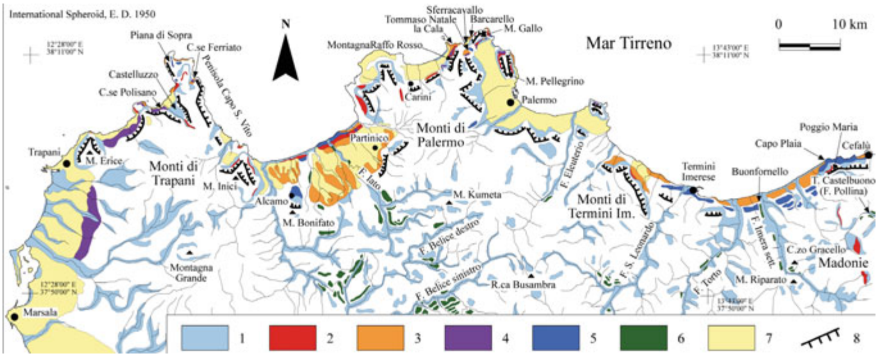


Fig. 2.96 Quaternary synthem map of NW Sicily (after Di Maggio et al. 2009): (1) Capo Plaia synthem; (2) Raffo Rosso synthem; (3) Barcarello synthem; (4) Polisano synthem; (5) Buonfornello synthem; (6) Imera synthem; (7) Marsala synthem; (8) main fault scarps or slopes and fault cliffs or abandoned cliffs

well as non-depositional surfaces, marked locally by paleosoils (Fig. 2.97). The erosional surfaces originated through marine abrasion, surficial overland water/ concentrated flow, river erosion, karst solution, mass movement or wind erosion. The main lithofacies of the Quaternary UBSUs consist of: (a) marine and coastal bioclastic calcarenites, (b) aeolian sandstones, (c) river deposits, (d) colluvial deposits), (e) talus slope deposits, (f) landslide deposits and (g) chemical carbonates.

The correlation among the logged sections (Fig. 2.98) helps us to understand the stratigraphic setting on a regional scale; the sketch in Fig. 2.97 displays the geo-

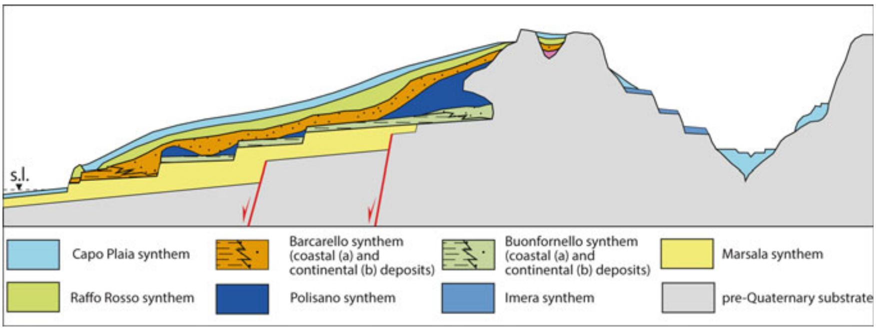


Fig. 2.97 Conceptual sketch showing the geometric relationships among unconformity-bounded stratigraphic units of NW Sicily coastal belt

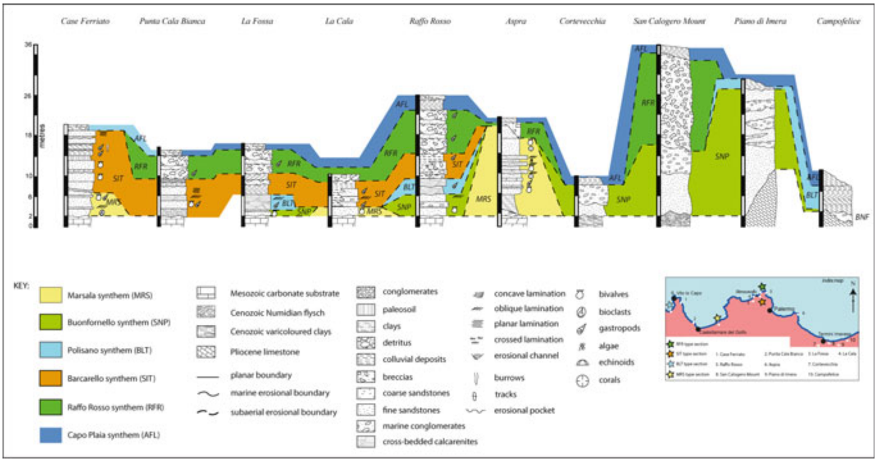


Fig. 2.98 Correlation of the Quaternary stratigraphic sections reconstructed and measured from the NW Sicilian coastal belt (see index map for location)

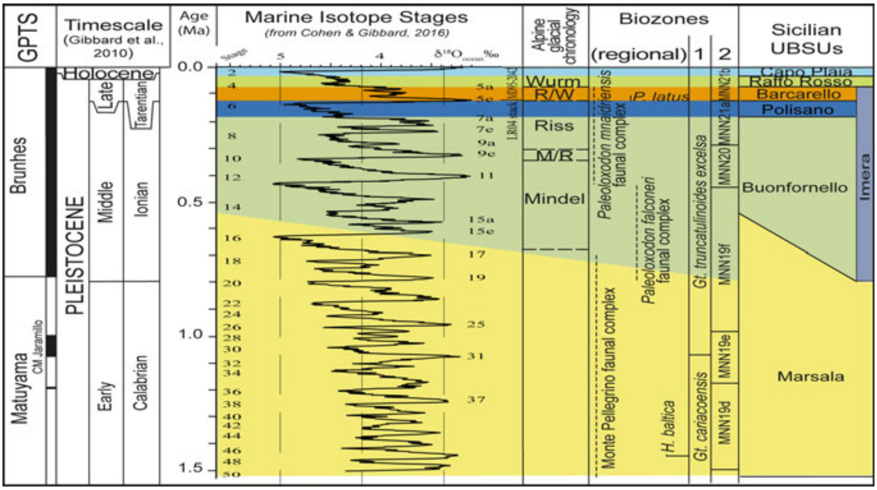


Fig. 2.99 Chronological correlation scheme (after Basilone and Di Maggio 2016; Agate et al. 2017), showing temporal distribution of the Sicilian UBSUs and their correlation with isotopic stage, Alpine glaciations, planktonic foraminifer (1: Cita et al. 2006) and calcareous nannofossil (2: Rio et al. 1990) biozones, mammal faunal complexes distribution (Bonfiglio et al. 2008; Masini et al. 2008)

metric relationships among the synthems. Quaternary deposits were age-constrained by using Pleistocene biozonations (Cita et al. 2006; Rio et al. 1990) and numerical age-dating (Hearty et al. 1986; Mauz et al. 1997) compared with the Oxygen Isotope Stages (OISs) of the $\delta^{18}O$ curve (Fig. 2.99, Shackleton 1995). The global chronostratigraphic units (Gibbard et al. 2010) are integrated here with the terminology of "Italian marine stages" (see Cohen and Gibbard 2016).

The Sicilian Quaternary deposits have been widely investigated (Gignoux 1913, 1926; Fabiani 1941; Tongiorgi and Trevisan 1953; Ottman and Picard 1954; Bonifay and Mars 1959; Buccheri 1966; Ruggieri 1967b, 1971, 1973b, 1978, 1987; Ruggieri and Sprovieri 1977, 1983; Ruggieri et al. 1984). Local and incomplete reconstructions of continental rock successions and their relationship with coastal and marine deposits are reported by Hugonie (1979, 1982), Agnesi et al. (1998), Di Maggio (1997), Buccheri et al. (1998); Cottignoli et al. (2002), Bonfiglio et al. (2004), Contino (2005, 2007). Paleontological studies on the vertebrate fauna of continental deposits (Scinà 1831; De Gregorio 1925; Vaufrey 1929; Brugal 1987; Burgio et al. 1989; Burgio and Fiore 1997) compared with stratigraphic, aminostratigraphic and geomorphologic studies (Belluomini and Bada 1985; Burgio and Cani 1988; Bada et al. 1991; Bonfiglio and Burgio 1992; Di Maggio 1997, 2000; Di Maggio et al. 1999; Bonfiglio et al. 2003) have helped to define the bio-chronological scheme in detail (Fig. 2.99, Basilone and Di Maggio 2016; Agate et al. 2017).

*2.12.1 Barcarello Synthem**

General remarks: This unit comprises the well-known "*Strombus* limestone" (Gignoux 1913; Cipolla 1926b, 1929, 1933, 1949; Fabiani 1941; Tongiorgi and Trevisan 1953; Ottmann and Picard 1954; Coggi 1965; Bonifay and Mars 1959; Ruggieri et al. 1967; Ruggieri and Milone 1974; Hugonie 1979). The main type sections studied are those outcropping at La Cala and Punta di Barcarello (Fig. 2.98; Figs. 1 and 4 of Plate 30, Sferracavallo, Palermo). Detailed fossil lists are provided by Malatesta (1957), Abate et al. (1991b), Mauz et al. (1997). The same deposits, outcropping along the coastal belt of Eastern Sicily, were classified as the Monte Tauro synthem and mapped in the Augusta 1:50,000 scale-map of the CARG project (Carbone et al. 2011).

Lithology and thickness: Red coastal bioclastic calcarenites alternate with parallel and cross-stratified sands and bio-conglomerates consisting of heterometric and polygenic elements (Figs. 2–6 of Plate 30) with shallow-water fauna (Fig. 3 of Plate 30). Laterally, they progress to laminated red silty clay (reworked soils) and calcareous breccias (stone-line structures) merged in a red sand matrix with polmonate gastropods and mammal rests (colluvial deposits, 1–5 m thick). These deposits occur in two orders of marine terraces exposed between 0 and 25 m a.s.l. Outcropping thicknesses range from 1 to 7 m.

Paleontological content: Marine deposits are characterised by the warm-temperate "Senegalensis fauna" (*Ostrea edulis* Linneo, *Hyotissa hyotis* Linneo, *Glycimeris glycimeris* Linneo, *Glycimeris pilosus* Linneo, *Spondylus gaederopus* Linneo), gastropods (*Strombus bubonius* (Lamark), *Patella ferruginea* Gmelin, *Cantharus viverratus* Kiener, *Mitra fusca* Swainson, *Conus testudinarius* Martini, *Conus ventricosus* Gmelin, *Conus mediterraneous* Hwass, *Natica* sp., *Cerithium lividulum lividulum* Risso, *Cerithium vulgatum* Bruguière, *Cantharus viverratus*), vermetids, echinoid, algae, corals. The continental deposits display abundant continental gastropods and mammal rests of the *Elephas mnaidriensis* faunal complex (Burgio and Cani 1988; Burgio et al. 1989; Bonfiglio et al. 2002, 2003).

Chronostratigraphic attribution: Based on the warm-temperate "Senegalensis fauna" (Table 2.7), the lower unconformity is dated to the lowermost Upper Pleistocene (OIS 5.5). Both fossil content and numerical age-dating (Mauz et al. 1997) suggest that the age of the synthem corresponds to the Tyrrhenian "Italian marine stage" (OIS 5, 130–120 ka, Fig. 2.99).

Stratigraphic relationships: Along the coastal areas, the lower unconformity is a marine abrasion (ravinement) surface, above which coastal/marine deposits with *Strombus bubonius* onlap the underlying aeolian sands of the Polisano synthem or older rocks, marked by stratal discordance (Figs. 1 and 4 of Plate 30). Landwards, the unconformity is a subaerial erosional surface produced by surficial water overland/concentrated flow and it is covered by colluvial deposits (reworked soils and breccias) containing fossil mammals (*Elephas mnaidriensis* Faunal Complex). The upper boundary is a subaerial erosional unconformity with both the stratified debris of the Raffo Rosso synthem and the younger deposits of the Capo Plaia synthem (Figs. 1 and 4 of Plate 30). When this boundary is detected along the planar sectors of the coastal belt, where the debris cannot be displaced, it is a non-depositional surface or the present-day topographic surface.

Depositional environment: The fossil content and observed sedimentary structures suggest coastal to marine depositional environments for these deposits. Glacio-eustatic oscillations and tectonic uplift (Antonioli et al. 1999; Di Stefano E et al. 2012a; Sulli et al. 2012) controlled the genesis and evolution of the coastal lower unconformity and deposits; a semi-arid and warm climate were the main factors favouring the development of surficial water overall/concentrated flows and the subsequent production of the subaerial erosional unconformity and colluvial deposits.

Regional aspects: The coastal and continental deposits of the Barcarello synthem discontinuously outcrop along the present-day coastal belt at a maximum altitude of 2–5 m a.s.l. (Figs. 2.96 and 2.97).

Carg abbreviation: SIT

Table 2.7 Synoptic table summarising stratigraphic and sedimentological features, thicknesses, depositional environments, fossil content, and ages of the Quaternary UBSUs

UBSUs	Labels	Texture and lithology	Thick. (m)	Depositional environment	Fossil content	Age	MISs
Unconformity 7: erosional or non-depositional surfaces with RFR or older deposits							
Capo Plaia synthem	AFL	Colluvial deposits, consisting of heterometric clasts (reworked scree) welded in a clayey matrix (reworked soils) with stone line; scree and debris flow; littoral deposits; chemical carbonates (travertines and speleothems)	1–40	Continental to coastal	Continental gastropods and molluscs stranded on the beach; mammal remains	Upper Pleistocene–Holocene	2-1
Unconformity 6: non-depositional surface or subaerial erosional unconformity with SIT or older deposits							
Raffo Rosso synthem	RFR	Stratified slope deposits composed of cemented coarse-to-fine inverse graded clast-supported breccias, involving very angular to sub-rounded carbonate clasts (0.5–50 cm). They, arranged in several well-sorted levels, with a thickness from 0.5 to 2 m, are cyclically alternated with red paleosoils, frequently reworked	Max 10	Talus slope (glacial climatic event)	Continental gastropods, mammal remains of the Castello and Pianetti Sicilian Faunal Complexes	Upper Pleistocene	4-2

(continued)

Table 2.7 (continued)

UBSUs	Labels	Texture and lithology	Thick. (m)	Depositional environment	Fossil content	Age	MISs
Unconformity 5: marine erosional surface or continental erosional unconformity with BLT or older deposits							
Barcarello synthem	SIT	Red coastal bioclastic calcarenites alternated with parallel and cross-stratified sands and bioconglomerates consisting of heterometric and polygenic elements with shallow-water fauna. They laterally pass to laminated red silty clay (reworked soils) and calcareous breccias (stoneline structures) merged in red sand matrix (colluvial deposits, 1–5 m-thick)	1–7	Continental to coastal (warm climatic event)	*Persististrombus latus, Cantharus viverratus, Mitra fusca*, *Conus testudinarius, Hyotissa hyotis, Ostrea edulis*, *Glycimeris glycimeris, Spondylus gaederopus*, *Patella ferruginea, Natica* sp., *Cerithium lividulum lividulum, C. vulgatum*, vermetids, echinoids, algae and corals. Continental gastropods and remains of vertebrates of the "*Elephas mnaidriensis* faunal complex"	Upper Pleistocene	5
Unconformity 4: subaerial erosional or non-depositional surface with SNP or older deposits							
Polisano synthem	BLT	Red to yellow cross-stratified and laminated quartz and carbonate aeolian well sorted fine sands and sandstones; rare angular carbonate clasts and blocks, related to local rock or debris falls, are interlayered	1–9	Aeolian dunes (glacial climatic event)	Continental gastropods, mammal remains of the *Paleoloxodon mnaidriensis* Faunal Complex	Middle Pleistocene	6

(continued)

Table 2.7 (continued)

UBSUs	Labels	Texture and lithology	Thick. (m)	Depositional environment	Fossil content	Age	MISs
Unconformity 3: subaerial erosional surface with BCP or older deposits							
Imera synthem	IMR	Pebbly grains, polygenic conglomerates, fluvial channel sands, sandy silt and clayey silt. Colluvial deposits with vertebrate rest are locally interlayered	20–30	Several order of fluvial terraces	Remains of *Hippopotamus pentlandi* (*Paleoloxodon mnaidriensis* faunistic complex) in the colluvial lithofacies	Upper-Middle Pleistocene	
Unconformity 2: ravinement surface with MRS or older deposits							
Buonfornello synthem	SNP	Marine, paralic and continental deposits represented by: (a) Litho- and bioclastic calcarenites with hummocky cross stratification and sands with cross and parallel laminations, paleocurrent traces and bioturbations, locally algal boundstone, (b) debrites and colluvial deposits, (c) cm-dm sized flatten and rounded well cemented conglomerates, with tempestitic layers and sands; (d) soils with stone line and petrocalcic crusts; (e) travertines	10–25	Coastal (warm climatic event)	Bivalves (*Corbula revoluta, Chlamys multistriata, Ostrea edulis, Pecten jacobaeus, Spondylus* spp., *Glycimeris* spp.), gastropods (*Patella caerulea, Cymatium ficoides, Cantharus viverratus*), corals (*Cladocora caespitosa, Astroides calycularis*), brachiopods (*Megathiris detruncata*), cirripeds, echinoderms (*Arbacia lixula*), fish fragments, and vertebrate remains (*Leithia* sp.), of the "*Elephas falconeri* faunal complex"	Middle Pleistocene	19-7

(continued)

Table 2.7 (continued)

UBSUs	Labels	Texture and lithology	Thick. (m)	Depositional environment	Fossil content	Age	MISs
Unconformity 1: ravinement surface cutting the tectonically deformed Meso-Cenozoic carbonate substrate (angular unconformity)							
Marsala synthem	MRS	Yellowish poorly-cemented fossiliferous carbonate sands with a minor content of clays rich in bioturbations (i.e. *Glossifungites*) alternated with yellow bio- and lithoclastic well-cemented oblique, parallel and cross laminated calcarenites and calcirudites rich in mollusc fragments; minor content in quartz grains and intercalation of conglomerates, 1–2 m-thick, with carbonate and siliceous elements, deriving from the dismantling of the Meso-Cenozoic substrate. Locally at the base clays and silty clays (Ficarazzi clays), with bivalves and planktonic fauna	Max 80	Coastal, foreshore to shoreface	Bivalves (*Glycimeris* spp., *Pecten jacobaeus*, Linneo, *Chlamys multistriata* Ansell, *C. septemradiata* (Müller), *Arctica islandica* Linneo, *Ostrea edulis, Volga rugosa, Loripes latteus, Ceritium creanatus, Zippora* sp., *Rissoa cimex, Bittium reticulatum, Phasinella, Clanculus jussei*), gastropods (*Patella* spp.), corals, bryozoans, sponges, calcareous algae, vermetids, scafopods, echinoderms, benthic foraminifers (*Hyalinea balthica* Merla & Ercoli), ostracods (*Aurila* sp., *Denodocitere prava, Cimbaurilia latisolea*), calcareous nannofossils (*Pseudoemiliana lacunosa, Gephyrocapsa oceanica, Helicosphaera selli, Syracosphaera pulchra*) of the MNN 19d–MNN 21 biozones, rare planktonic foraminifers (*Globorotalia truncatulinoides excelsa* Sprovieri, Ruggieri & Unti)	Calabrian–early Middle Pleistocene	

Main references Ruggieri (1973b), Ruggieri et al. (1984), Di Stefano and Rio (1981), Hearty et al. (1986), Burgio and Fiore (1997), Mauz et al. (1997), Bonfiglio et al. (2003, 2008), Di Maggio et al. (2009), Incarbona et al. (2016)

MIS numerical datings: Mauz et al. (1997), Hearty et al. (1986)

2.12.2 Buonfornello Synthem*

General remarks: This unit comprises marine, paralic and continental deposits belonging to several orders of marine terraces, distributed from about 10 to over 250 m above sea level. Two main subsynthems can be distinguished; they are separated by a marine erosional unconformity dated to the isotopic stage 7 (Mauz et al. 1997; Hearty et al. 1986). Similar deposits, also known as "panchina", were described as the Augusta synthem from Eastern Sicily and mapped in the Augusta 1:50,000 map-scale of the Carg project (Carbone et al. 2011).

Lithology and thickness: Litho- and bioclastic calcarenites with hummocky cross stratification and sands with cross and parallel laminations, paleocurrent traces and bioturbations, and locally, algal boundstone (Figs. 2.100 and 2.101). Cm-dm-sized flattened and rounded well-cemented conglomerates, with tempestite layers and sands, debrites and colluvial deposits, soils with stone line and petrocalcic crusts; travertines. These deposits show a tabular geometry and overlay stepped surfaces of marine terraces (abandoned wave-cut platforms and sea cliffs) occurring at different altitudes (from 10 to 250 m a.s.l.) and frequently marked by red paleosoils. The marine/coastal sediments laterally change to coeval continental deposits (colluvium

Fig. 2.100 Poorly-cemented calcarenites with planar and oblique laminations, erosional surfaces and ripple structures pertain to the marine terraces of the Buonfornello synthem (Buonfornello, Termini Imerese Mountains)

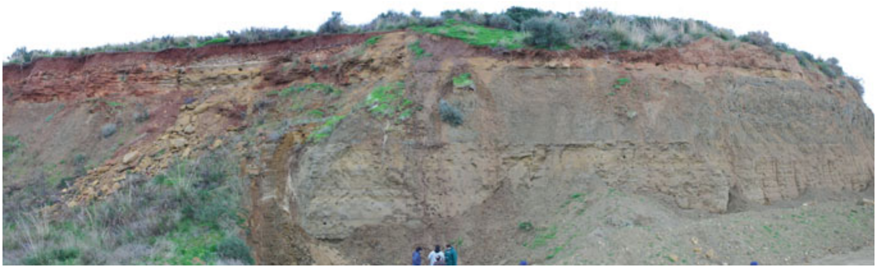


Fig. 2.101 Stratigraphic relationships—marked by subaerial erosional unconformity—between the clayey sands of the marine terraces of the Buonfornello synthem and the overlying continental deposits (colluvium and red soils) of the Capo Plaia synthem (Contrada Pestavecchia, Buonfornello, Termini Imerese Mountains)

and travertines) outcropping mostly in karstic depressions or abandoned sea caves, with vertebrate rests of the *Elephas falconeri* complex. Thickness 10–25 m.

Paleontological content: Bivalves (*Corbula revolute* (Brocchi), *Chlamys multistriata* (Poli), *Ostrea edulis* Linneo, *Pecten jacobaeus* Linneo, *Spondylus* spp., *Glycimeris* spp.), gastropods [*Patella caerulea* Linneo, *Cymatium ficoides* (Reeve), *Cantharus viverratus* (Kiener)], corals [*Cladocora caespitosa* Linneo, *Astroides calycularis* (Pallas)], brachiopods [*Megathiris detruncata* (Gmelin)], cirripeds, echinoderms (*Arbacia lixula* Linneo), fish fragments and vertebrate rests (*Leithia* sp.).

Chronostratigraphic attribution: Numerical age-dating and warm-temperate fauna within the coastal deposits refer them to the Middle Pleistocene sea level highstand phases, corresponding to the OISs 17–13 and 11, 9 and 7 (Fig. 2.99, Mauz et al. 1997). A similar age is confirmed by the fossil content of the heteropic continental deposits belonging to the *Elephas falconeri* Faunal Complex (Bonfiglio et al. 2003). Along the Castellammare plain, radiometric age-dating of travertines covering a marine terrace surface at 250 m a.s.l. suggests an age of 455 $\pm$ 90 ka (Bada et al. 1991; Rhodes 1996). From the above, the age of the lower unconformity is correlatable to the time-interval between OISs 19–11, and the synthem deposit age is between OISs 19–11 and 7 (Fig. 2.99).

Stratigraphic relationships: The lower boundary is an erosional marine surface (ravinement) carved into the Marsala synthem or older rocks. The upper boundary is a non-depositional surface or subaerial erosional unconformity with the aeolian deposits of the Polisano synthem, marked by paleosoils and stratal discordance (Figs. 2.97 and 2.101).

Depositional environment: The interaction between sea-level oscillation (glacio-eustatic cycles) and tectonic uplift is the mechanism generating the unconformities and the marine terrace deposits. Moreover, a favourable climate was responsible for the genesis both of colluvial and chemical deposits.

Regional aspects: Marine terraces and related deposits are discontinuously exposed along the structural lows of the NW Sicily coastal belt (Fig. 2.96), previously filled by the Marsala synthem deposits, which are the result of hundreds of metres of tectonic displacement towards the sea sectors (N-wards). They are also exposed along the structural highs corresponding to the remaining uplifted hanging walls of the high angle extensional faults, where pre-Quaternary rocks crop out. These deposits can be considered related to the chrono-equivalent deposits outcropping in Southern Sicily (i.e., the “grande terrazzo superiore” of Ruggieri and Unti 1974; Ruggieri et al. 1975a).

Carg abbreviation: SNP

2.12.3 Capo Plaia Synthem*

General remarks: This unit includes the most recent continental, coastal and marine deposits, mainly represented by unconsolidated sediments, including fluvial, aeolian sands, marsh, karst, slope and rock debris, poorly cemented colluvial deposits, coastal deposits, storm deposits and concreted deposits (Fig. 2.102), which formed during the last 100–120 ka, after the last glacial climatic event.

Lithology and thickness: The different deposits include: (i) colluvial deposits, consisting of heterometric clasts (reworked scree) welded in a clayey matrix (reworked soils, Fig. 2.103) with stone line (*Carg abbreviation*: AFLb$_2$); (ii) scree and debris flow mainly concentrated along the sides of mountains (*Carg abbreviation*:

Fig. 2.102 Karst deposits consisting of vadose pisoid grains and calcareous crusts and caliche of the Capo Plaia synthem (Monte Gallo, Mondello)

Fig. 2.103 Red paleosoil, partially reworked, covered by slope deposits consisting of coarse debris of the Capo Plaia synthem (Pizzo Sella, Monte Gallo, Mondello)

$AFLa_3$); (iii) littoral deposits, consisting of gravels or sands with a predominance of quartz grains, subjected to coastal marine evolution processes (*Carg abbreviation*: $AFLg_2$); (iv) aeolian deposits, mainly consisting of sands and silty-sands, accumulated in dunes that are distributed along the coastal belt (AFLd); (v) marsh deposits, consisting of blackish clays and sandy-clays rich in organic matter and plant rests with peat soils, often fetid for the presence of hydrogen sulphide emissions (*Carg abbreviation*: $AFLe_3$); (vi) alluvial deposits, consisting of conglomerates, sands and pelites formed in present-day river beds and relative tributaries which have caused the flooding of the valley floor (*Carg abbreviation*: AFLb); (vii) landslides (*Carg abbreviation*: $AFLa_1$); (viii) chemical carbonates (travertines and speleothems) represented by whitish vacuolar limestone (*Carg abbreviation*: $AFLb_1$). Total thicknesses range between 1 and 40 m.

Chronostratigraphic attribution: The lower unconformity is dated to the OIS 2 (Fig. 2.99). The synthem encompasses all the uppermost Pleistocene-Holocene deposits, widely outcropping along the study area, which were formed during the last interglacial climatic event (OISs 2-1).

Stratigraphic relationships: The lower boundary can be a paraconformity surface or a subaerial erosional unconformity surface where the mostly unconsolidated deposits of the Capo Plaia synthem lie above the stratified and cemented screes of the Raffo Rosso synthem or older deposits (Figs. 2.97 and 2.98). The upper boundary is the present-day topographic surface.

Regional aspects: The unit displays various lithologies from coastal to continental facies (Table 2.7) and assumes an important multidisciplinary role for geological mapping works, archaeological investigations and applied sciences (engineers, architecture, geotechnical).

Carg abbreviation: AFL

2.12.4 Imera Synthem

General remarks: These deposits, with tabular geometry, characterise the ancient deposits of most NW Sicily river valleys. They hang on along the valley slopes, lying on various orders of river terrace surfaces elevated from a few metres to one hundred of metres in height with respect to the present-day valley bottom (Fig. 2.96).

Lithology and thickness: Pebbly grains, polygenic conglomerates, fluvial channel sands, sandy silt and clayey silt. Colluvial deposits with vertebrate rests are locally interlayered. Thicknesses range between 20 and 30 m.

Paleontological content: Rests of *Hippopotamus pentlandi* Meyer in the colluvial lithofacies.

Chronostratigraphic attribution: Along the younger river terrace deposits, the presence of some rests of *Hippopotamus pentlandi*, pertaining to the *Elephas mnaidriensis* Faunal Complex (Bonfiglio et al. 2003), dates these deposits to the Upper Pleistocene. Numerical age-dating of the fluvial conglomerates, sampled along a river valley crossing the Castellammare plain, indicates 227 ± 40 ka age (Mauz et al. 1997). The rests of mammals of the *Elephas Falconeri* Faunal Complex (Bonfiglio et al. 2003), found along the older river terrace deposits, suggest a Middle Pleistocene age. Therefore, data analysis suggests a Middle Pleistocene age for the basal unconformity and a Middle-Upper Pleistocene age for synthem deposits (Fig. 2.99).

Stratigraphic relationships: The lower boundary is a river erosional surface carved on Pleistocene (Marsala and Buonfornello synthems) and pre-Quaternary rocks and covered by pebbly grains, polygenic conglomerates, fluvial channel sands, sandy silt and clayey silt forming the fluvial deposits of the Imera synthem (Figs. 2.97 and 2.98). The upper boundary consists of non-depositional surfaces.

Depositional environment: The interaction between alluvial deposition and vertical to lateral river erosion, controlled by climatic changes and by subsequent fluctuations of the river base level and the downward migration trend of the river base level due to tectonic uplifting, are responsible for the genesis of the lower unconformity and Imera synthem deposits.

Carg abbreviation: IMR

2.12.5 Marsala Synthem°

General remarks: The unit, known as "Marsala calcarenite", was described by Ruggieri (1973b) and Ruggieri et al. (1975b), while studying the Marsala type section, where a thick, continuous and widely extended succession outcrops. Widely outcropping along the NW Sicilian coastal belt (Fig. 2.96), these deposits consist of Lower Pleistocene yellow-whitish fossiliferous calcarenites alternating with sandy clays, laterally displaying few lithological changes (Fig. 2.98 and Fig. 1 of Plate 31; Table 2.7). Locally, thick bluish clays are intercalated. These intercalated clays, outcropping at the currently closed Puleo quarry (Palermo) and informally named "Ficarazzi clay" (Seguenza 1873–1877; Brugnone 1877), were drilled by the Ficarazzi 1 borehole, where a detailed study made it possible to define the biostratigraphy of the Sicilian time interval (Ruggieri and Sprovieri 1975, 1976b; Di Stefano and Rio 1981; Buccheri 1984). The same deposits were described as the Lentini synthem from Eastern Sicily and mapped in the Augusta 1:50,000 map-scale of the Carg project (Carbone et al. 2011).

Lithology and thickness: Yellowish and whitish bioclastic calcarenites and sands very rich in mollusc fauna, mostly gastropods and bivalves, corals alternate with mostly carbonate marls and sandy-marls with minor quartz components and intercalations of thin pebbly conglomerate horizons (Fig. 2.105 and Figs. 2–4 of Plate 31). The conglomerate consists of well-rounded poorly classed and heterogenic elements; the pebbles are often flattened, indicating a mechanical action of waves in a foreshore environment (Fig. 2.104). Calcarenites and sands display planar, oblique and cross (ripples) lamination and stratification. Locally, chaotic stratification reveals the occurrence of soft sedimentary deformational structures. The calcareous beds display variable degrees of cementation that display primary (microcrystalline calcite) and secondary (spathic calcite) diagenetic features. A 1–2-m-thick coarse-grained conglomerate, followed by bio-lithoclastic calcarenites and sands, occurs at the base of the succession, as observed in the supported Punta Raisi section (Fig. 5 of Plate 31). This horizon, laterally discontinuous in relation to the paleo-morphologic settings and sedimentary dynamics of the basin, consists of carbonate and quartz-arenite clasts, deriving from erosion and the dismantling of the Mesozoic carbonate units and Cenozoic Numidian flysch deposits. In the Palermo area, this unit is represented by whitish calcarenites and sands that locally display clays a few metres thick and intercalations of silty-clays with planktonic foraminifers (Ficarazzi clays; see Incarbona et al. 2016). Thicknesses range between a few metres (in the inner sector of the coastal belt) and 30–40 or 80–90 m in seaward sectors.

Paleontological content: The fossil content (Table 2.7) characterising the calcarenites consists of gastropods (*Patella* spp.), bivalves (*Glycimeris* spp., *Pecten jacobaeus* LINNEO, *Chlamys multistriata* ANSELL, *Chlamys septemradiata,* (MÜLLER), *Arctica islandica* LINNEO, *Ostrea* spp.), corals, bryozoans, spongid, algae, vermetids, scaphopods, echinoids, ostracods, benthic foraminifers (*Hyalinea baltica* MERLA & ERCOLI); nannofossils of the small *Gephirocapsa* biozone and rare

Fig. 2.104 Calcirudites and coarse calcarenites of the Marsala synthem. The breccia displays elements deriving from the dismantling of the Mesozoic carbonate substrate; the rock is well cemented and rich in shell fragments, as molluscs, crinoids, anellids, corals (Punta Raisi, Palermo)

planktonic foraminifers (*Globorotalia truncatulinoides excelsa* Sprovieri, Ruggieri & Unti) in the clayey lithologies.

Chronostratigraphic attribution: On the basis of the fossil content (Ruggieri and Cicala 1962; Ruggieri and Romeo 1971; Ruggieri 1973a, b), the age of the synthem is dated to the Early Pleistocene, corresponding to the Emilian and Sicilian "Italian marine stages" (Calabrian superstage, about 1.5–0.8 My, Cita et al. 2008); numerical age-dating indicate these deposits are older than the OIS 19 (Fig. 2.99). Collected data show that the basal unconformity age is the early Emilian "Italian marine stage" (about 1.5 My).

Stratigraphic relationships: The lower boundary is a sharp marine erosional (ravinement) unconformity surface cutting the Pliocene sandy marls (Belice and Trubi formations, see Fig. 2.98) and the tectonically deformed Meso-Cenozoic carbonates and clastic rocks (Fig. 5 of Plate 31). Above this surface, in some place marked by incised channels some metres wide, the Lower Pleistocene marine/coastal deposits of the Marsala synthem lie with onlap (more towards the land sectors) and downlap (towards the sea) stratal terminations, with a maximum inclination of about 10°. The upper boundary is an erosional unconformity (historically referred to the "Roman Regression" of Boucart 1938) with the marine terraces of the Buonfornello synthem.

Fig. 2.105 Colonial corals found in the calcarenites of the Marsala synthem (Punta Raisi, Palermo)

Depositional environment: Fossil fauna and sedimentary structures suggest a coastal depositional environment (foreshore to shoreface). As suggested by the nature of the lower unconformity and the facies of the overlying deposits, tectonics and eustatism drove the formation of the synthem. The lowermost Pleistocene extensional tectonics produced a differential subsidence, which formed steeped fault blocks where the shallow-water sediments, arranged in high frequency (glacio-eustatic) cycles, accumulated.

Regional aspects: These deposits outcrop extensively along the whole coastal belt of NW Sicily, from Marsala to Trabia flat coastal areas (Fig. 2.96), occupying a marginal sector of a Plio-Pleistocene South Tyrrhenian basin (Agate et al. 1993). In the Marsala and Castellammare del Golfo outcropping areas, these deposits, 80 m thick, fill tectonic depressions opening to the sea, and inland, they are bordered by wide tectonically controlled abandoned sea cliffs (former fault scarps). In the Palermo plain, they reach 40–50 m in thickness and consist mainly of bluish clays at the bottom, followed upwards by white to yellow calcarenites. Colluvial deposits and reworked soils with vertebrate rests of the lower Pleistocene Monte Pellegrino Faunal Complex (Burgio and Fiore 1997; Bonfiglio et al. 2002; Masini et al. 2008) are found in a karstic cave at Mount Pellegrino.

Carg abbreviation: MRS

2.12.6 Polisano Synthem*

General remarks: We include in this synthem the Aeolian deposits, forming both coastal and climbing dunes, generally outcropping along the foot of the northwards sides of the carbonate massifs bordering the N Sicilian coastal belt (Fig. 2.98 and Figs. 1, 2 of Plate 32).

Lithologies and thickness: Red to yellow cross-stratified and cross-laminated quartz and carbonate aeolian well-sorted fine sands and sandstones; rare angular carbonate clasts and blocks, related to local rock or debris falls, are interlayered (Figs. 3–6 of Plate 32). Coeval colluvial deposits consisting of breccias and reworked soils, with stone-line structures and mammal rests (*Elephas mnaidriensis* Faunal Complex), occur locally. Thickness 1–9 m.

Paleontological content: Continental gastropods, mammal rests.

Chronostratigraphic attribution: On the basis of the small and weak diagnostic fossil content, this unit is dated mostly by stratigraphic relationships (Fig. 2.97). Being encompassed between the Buonfornello synthem (OIS 7) and the marine deposits of the Barcarello synthem (OIS 5), the continental deposits of the Polisano synthem are dated to the Middle Pleistocene (OIS 6), corresponding to the Ionian "Italian marine stage" (Fig. 2.99).

Stratigraphic relationships: The lower unconformity is partly a subaerial erosional surface and partly a non-depositional surface topping the younger marine terrace deposits of the Buonfornello synthem, as well as older rocks (Fig. 2.98; Table 2.7 and Fig. 2 of Plate 32). The upper boundary is an erosional (subaerial or marine) unconformity capped by the deposits of the Barcarello synthem.

Depositional environment: The formation of the subaerial erosional unconformity and the non-depositional surfaces occurred both during sea level fall and the subsequent lowstand stage. Due to an arid cold climate, rare but intense surficial water processes (overland or concentrated flows) produced erosion surfaces and colluvial deposits. The wind flows transported large quantities of sand from the surfacing continental platform and discharged them along the coastal areas (forming coastal dunes) up to the foot of the adjoining slopes (forming climbing dunes, Fig. 3 of Plate 32).

Regional aspects: The Polisano synthem is exposed along the flat coastal areas and at the foot of the bordering slopes. They have been subject to intensive quarry extraction for ornamental purposes.

Carg abbreviation: BLT

2.12.7 Raffo Rosso Synthem*

General remarks: The proposed type section for this synthem is located along the northern slope of Monte Gallo, near Punta Barcarello (Figs. 1 and 2 of Plate 33, Sferracavallo, Palermo). Here, a thick succession of stratified and cemented debris

Fig. 2.106 Well-cemented coarse debris of the Raffo Rosso synthem, with sharp carbonate elements, deriving from the dismantling adjacent carbonate reliefs, welded in a red carbonate matrix (northern slope of Monte Gallo, Mondello)

resting on the deposits of the Barcarello synthem outcrops clearly and is easily accessible.

Lithology and thickness: Stratified slope deposits (Fig. 1 of Plate 33) composed of cemented coarse-to-fine inverse graded clast-supported breccias, involving very angular to sub-rounded carbonate clasts (0.5–50 cm, Fig. 2.106). Arranged in several well-sorted levels, with a thickness from 0.5 to 2 m, they alternate cyclically with red paleosoils, frequently reworked (Figs. 3–5 of Plate 33). Maximum thicknesses are 10 m.

Paleontological content: Continental gastropods, mammal rests (Table 2.7).

Chronostratigraphic attribution: Numerical age-dating (Mauz et al. 1997) constrains these deposits to the OISs 4–2 (Fig. 2.99, Upper Pleistocene, Tarantian "Italian standard super-stage").

Stratigraphic relationships: The lower unconformity is a subaerial erosional surface marked by paleosoils and/or caliche crusts, where both stratified slope deposits variously cemented and aeolian sands (Raffo Rosso synthem) downlap the marine lithofacies of the Barcarello synthem or older deposits (Figs. 2.97, 2.98 and Fig. 2 of Plate 33). The upper boundary is a subaerial erosional unconformity with the deposits of the Capo Plaia synthem.

Depositional environment: The genesis of the lower unconformity is related to the sea level lowstand caused by the acme of the last glacial climatic event ("Wurm", OISs 4–2). During this event, a semi-arid and cold climate promoted strong physical weathering of the rocks, producing slope deposits that were rapidly cemented due to the abundant vadose water circulation. Wind processes created Aeolian dune deposits.

Regional aspects: The stratified slope deposits outcrop along the flanks and at the foot of the high dipping carbonate rock slopes. Seawards, crossed stratified quartz and calcareous aeolian sandstones (coastal or climbing dunes), 1–2 m-thick, outcrop along the flat coastal areas (Fig. 2.96); landwards, 1–7 m thick colluvial deposits with fossil mammals (Pianetti and Castello Sicilian Faunal Complex, Bonfiglio et al. 2003), dated to the late Upper Pleistocene (Burgio and Fiore 1997), outcrop both in karstic caves and at the foot of the coastal relief.

Carg abbreviation: RFR

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Chapter 3
Illustrative Plates

Abstract This chapter contains several illustrative plates that accompanied the worksheets. The illustrations show the main lithological, textural and paleontological characteristics of the rock units from outcrop and microscope observations. Plates 1–4 illustrate the lithological characteristics and typical facies of some of the Permo-Triassic units, as observed from outcrop and well data. Plates 5–27 illustrate the lithological characteristics and typical facies of some of the Meso-Cenozoic carbonate shallow- and deep-water units. Plate 28 illustrates the lithological characteristics and typical facies of the Oligo-Miocene shales and sandstones of the Numidian flysch. Plate 29 illustrates the lithological characteristics and typical facies of some of the Miocene-Pliocene terrigenous, clastic, carbonate and evaporite units. Plates 30–33 illustrate the lithological characteristics and typical facies of the Quaternary continental and marine Unconformity-Bounded Stratigraphic Units (UBSUs).

L. Basilone, *Lithostratigraphy of Sicily*, UNIPA Springer Series,
https://doi.org/10.1007/978-3-319-73942-7_3

Plate 1. Characteristic microfacies of the Ladinian—Upper Carnian Daonella limestone (DAO): (1) wackestone with radiolarians and pelagic pelecypods (core 26, 2979, 1–2981.5 m, Platani 2 well, scale bar 1 mm); (2) wackestone with pelagic pelecypods (core 26, 2979.1–2981.5 m, Platani 2 well, scale bar 1 mm); (3) mudstone with intercalation of siltstone-wackestone with radiolarians (core 25, 2882–2884 m, Platani 2 well, scale bar 2 mm); (4) grey laminated mudstone with radiolarians, dark grey and greenish clay and recrystallized mm-layers rich in radiolarians (core 27, 3052–3056 m, Platani 2 well, scale bar 2 mm); (5) packstone-grainstone (calcareous turbidites) with ammonites, radiolarians, pelagic pelecypods and peloids (core 26, 2979.1–2981.5 m, Platani 2 well, scale bar 2 mm); (6) fine packstone/grainstone with ooids, intraclasts and bioclasts (core 26, 2979.1–2981.5 m, Platani 2 well, scale bar 1 mm).

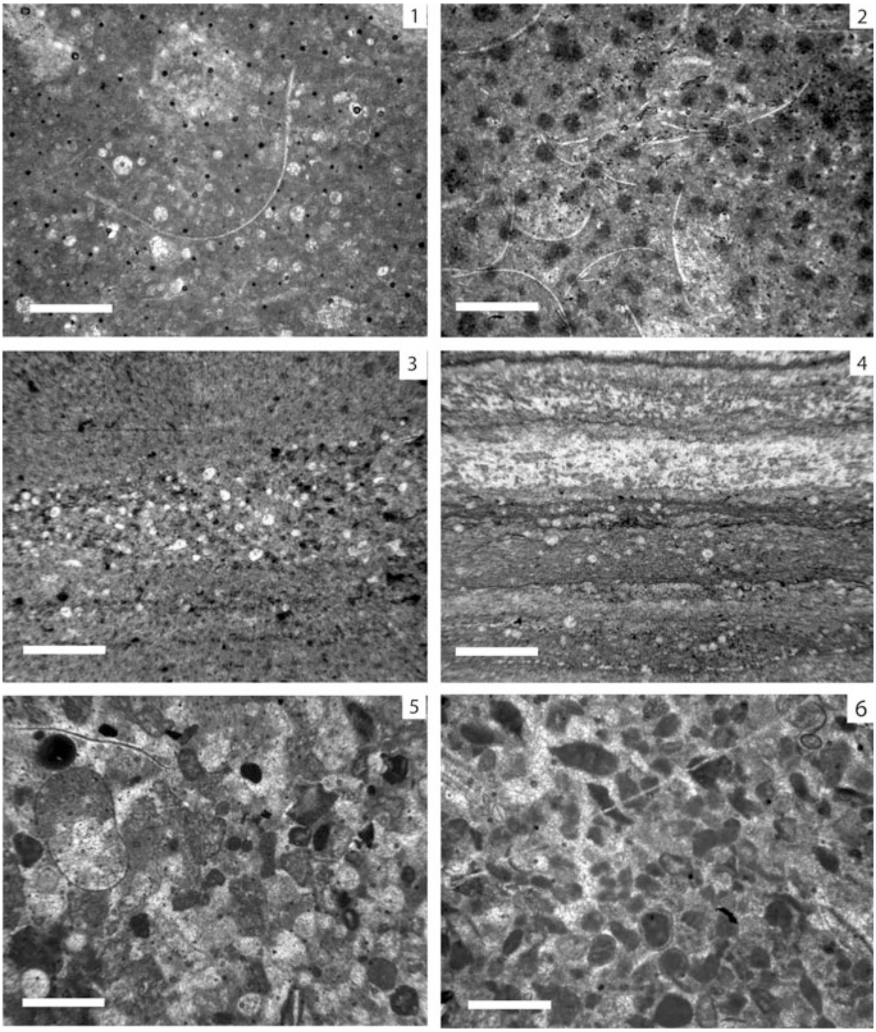
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Plate 2. Characteristic microfacies of the Lower Triassic Manganaro clayey limestone (MNG): (1) wackestone-packstone with pelagic pelecypods (core 14, 2336–2339, 7 m, Roccapalumba 1 well, scale bar 1 mm); (2) red clays with pelagic pelecypods (cutting: 2402–2405 m, Roccapalumba 1 well, scale bar 0.4 mm); (3) laminated quartzitic sandstone (core 6: 1635, 5–1637, 5 m, Roccapalumba 1 well, PPL, scale bar 2 mm); (4) red mudstone with siliceous sandstone and white shallow-water carbonate clasts (core 16, 2427, 6–2431, 2 m, Roccapalumba 1 well, macroscopic sample, scale bar 1 cm); (5) calcareous breccia (rudstone) with shallow-water derived clasts (core 8: 1724–1727 m, Roccapalumba 1 well, macroscopic sample, scale bar 0.5 cm); (6) grainstone/packstone with surficial oolites, pelecypods fragments and coated grains (core 8: 1724–1727 m, Roccapalumba 1 well, scale bar 1 mm).

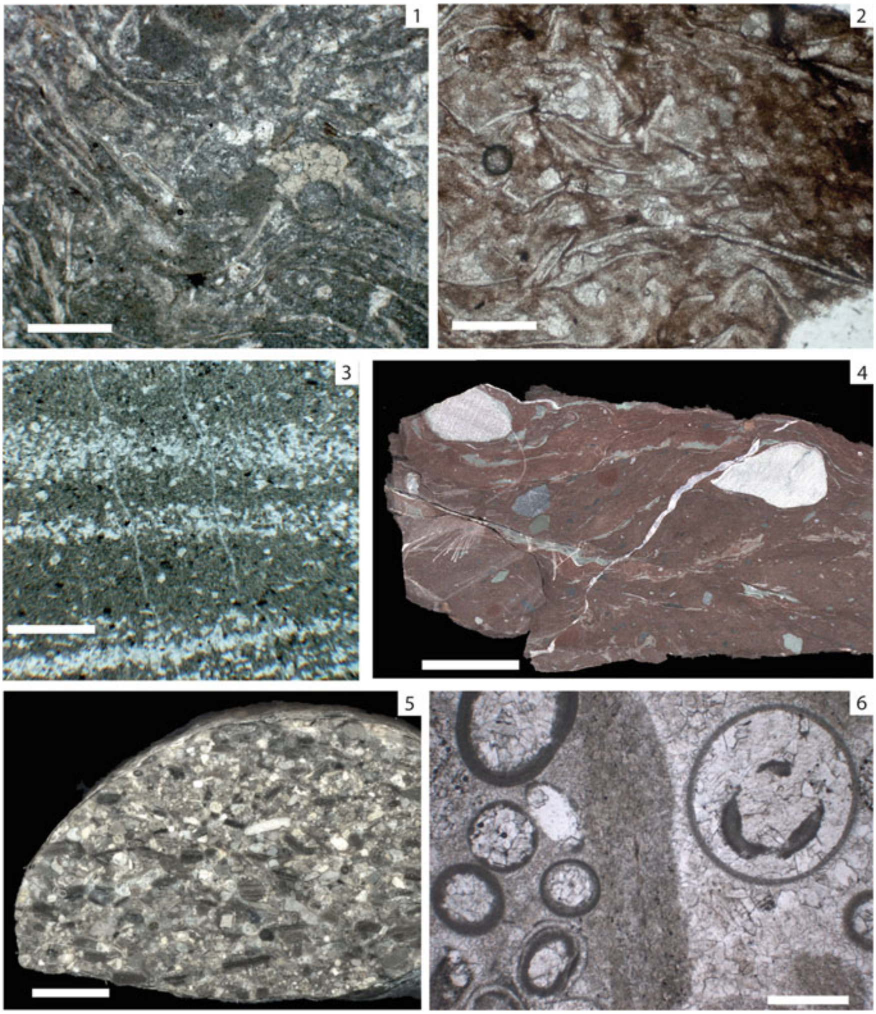
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Plate 3. Characteristic microfacies of the Late Permian Roccapalumba clay and sandstone (RCS): (1) red brown planar laminated clay fine sandstone with cm-thick layers of greenish to light-grey crossed laminated (ripples) fine sandstone and siltitic mudstone intercalations (core 2, 708–711 m, Roccapalumba 1 well, macroscopic sample, photograph field about 10 cm); (2) thin layer of coarse siltstone with quartz, feldspar, mica, glauconitic and phosphate fragments interlayered into red siltitic clays (core 1, 484.6–485.9 m, Lercara 1 (Agip) well, crossed polarized light (XPL), scale bar 0.4 mm); (3) grey to dark greenish altered basaltic rock with calcite veins (cutting 68–72 m, Roccapalumba 1 well, PPL, scale bar 1 mm); (4) siltstone/fine sandstone with quartz, feldspar, glauconitic and phosphate fragments (cutting 231–234 m, Roccapalumba 1 well, plane polarized light (PPL), scale bar 0.4 mm); (5) calcareous breccias with reef-derived fragments (cutting 64–67 m Lercara Friddi 1 well, scale bar 1 mm); (6) reworked bioclastic packstone showing benthic foraminifers, algae, encrusting organisms (core 5, 915–916 m, Lercara 1 (Agip) well, scale bar 1 mm); (7, 8) carbonate breccias with shallow-water derived fragments rich in bioclasts (gastropods, bivalves). The samples, coming from Lercara region outcrops, pertain to the resedimented calcareous beds intercalated in the pelitic succession of the Roccapalumba clay and sandstone.

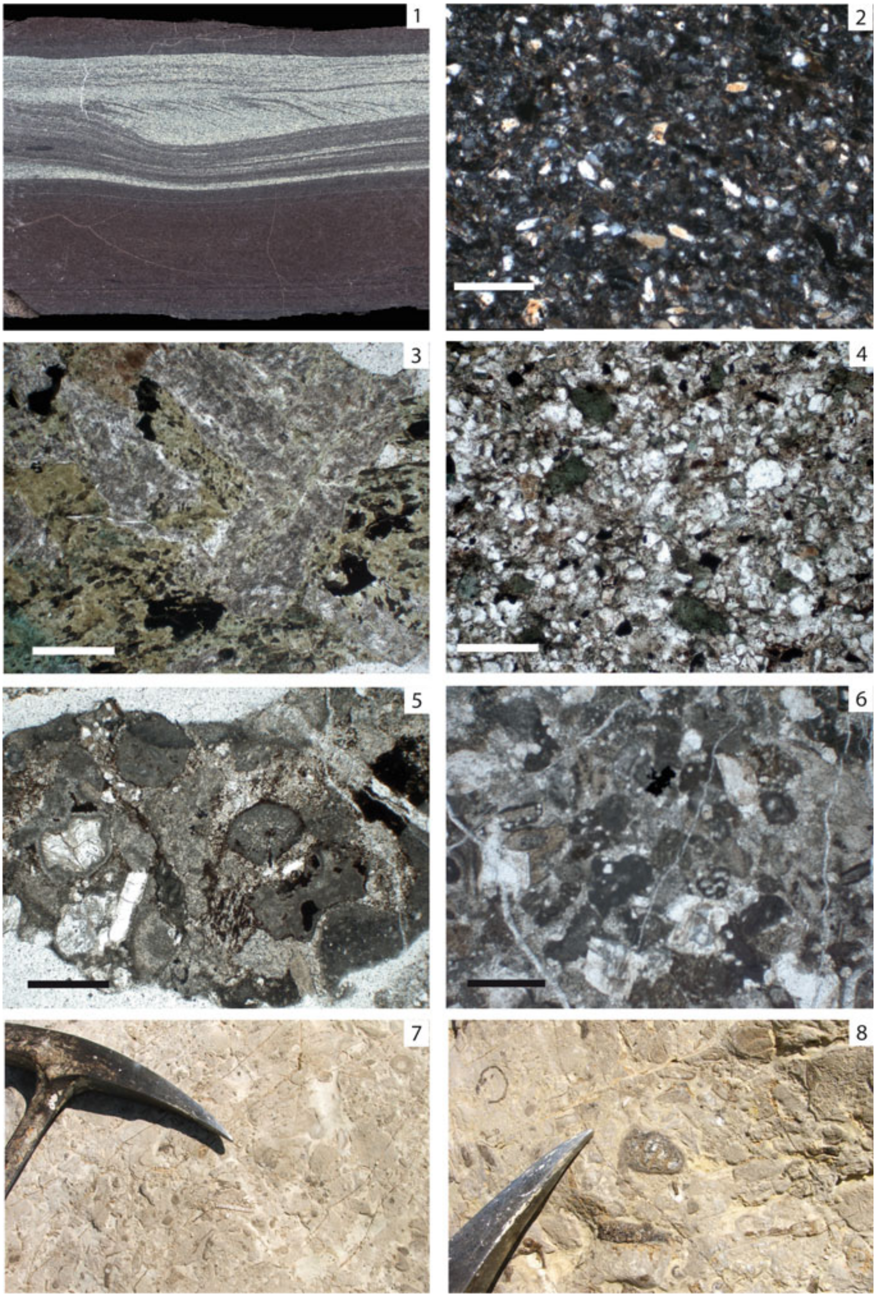
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Plate 4. Typical facies of the Upper Cretaceous-Eocene carbonate deep-water deposits of the Amerillo formation: (1) Paleogene deep-water succession of Cala Rossa (Terrasini, Panormide succession). The succession is characterized by internal deformations (due to the Miocene compressional tectonics) with chevron folds and inverse faults, but slumping structures are also present; (2) graded and laminated calcarenites (packstone-grainstone), forming incomplete turbidite sequences, interlayered in the Paleogene pelagic succession of Cala Rossa; (3) Upper Cretaceous carbonate megabreccias with white angular elements derived from the fragmentation of the Upper Triassic-Lower Liassic peritidal limestones of the Inici and Sciacca Formations, welded in the pink pelagic limestones with globotruncanids of the Amerillo formation (Trapanese pelagic-platform succession of Rocca Busambra, Corleone); (4) breccias and megabreccias with reef-derived elements (coral, rudistid and mollusc fragments), inserted in the Eocene pelagic succession of the Amerillo formation, pertaining the Panormide succession of Monte Sparagio (San Vito Lo Capo Mountains); (5) reddish wackestone with Eocene planktonic foraminifers assemblage of the Amerillo formation inserted in the Trapanese succession of Rocca Busambra (scale bar 1 mm); (6) wackestone with globotruncanids and intraclasts, recollected in the Upper Cretaceous pelagic limestones of the Piano Pilato succession (Rocca Busambra, scale bar 1 mm); (7) rudstone–floatstone of the megabreccias member of the Amerillo formation with Lower Liassic peritidal limestones and pelagic Rosso Ammonitico (Buccheri formation) elements, welded in the Upper Cretaceous globotruncanids wackestone (Trapanese succession of Rocca Busambra ridge, scale bar 1 mm); (8) wackestone-packstone with Middle–Late Eocene planktonic foraminifera assemblage (with specimen of *Globigerinatheka* sp.). The sample has been recollected from the pelagic limestones of the Amerillo formation inserted in the neptunian dykes cutting the Lower Liassic Inici Formation (Rocca Argenteria, Rocca Busambra ridge, scale bar 1 mm).

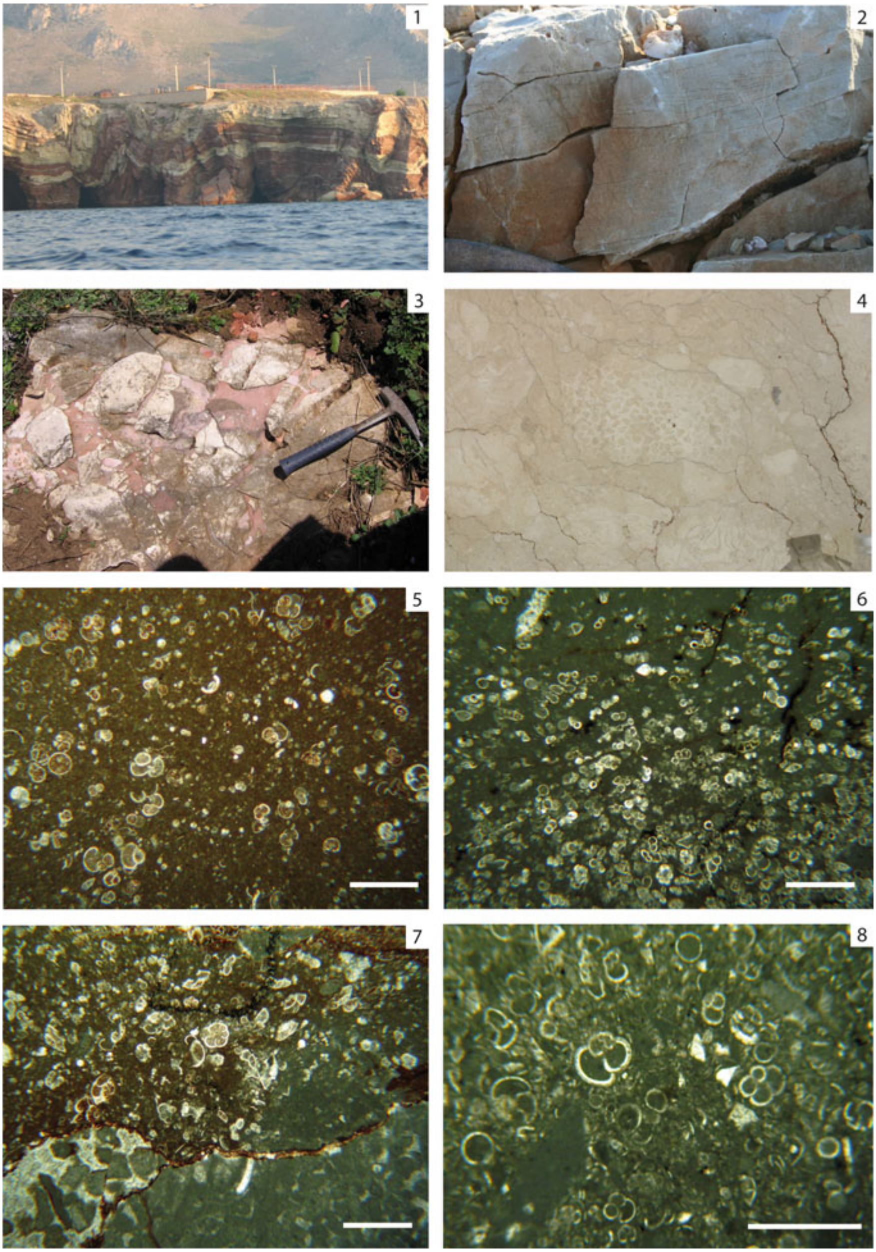
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Plate 5. Characteristics facies of the Gastropod limestones (GAS): (1, 2) reddish and grey bioclastic wackestone-packstone with small gastropods; (3, 4) reddish wackestone with dasycladacean algae (*Salpingoporella* sp.) and small gastropods (scale bar 1 mm), Spinasanta quarry (Monte Gallo, Palermo Mountains). Characteristics facies of the Brachiopods limestone (CDR): (5) packstone with aligned brachiopod shells (scale bar 1 mm, Pecoraro section, Palermo Mountains); (6) cm-thick Fe–Mn crust (hardground), inserted between the shallow-water limestone of the Upper Triassic Capo Rama formation and the Lower Jurassic pelagic deposits of the brachiopod limestone (Pecoraro section, Palermo Mountains). Characteristic microfacies of the breccias of Prizzi: (7) and (8) packstone with small oncolites, crinod fragments, undeterminable bioclasts and intraclasts.

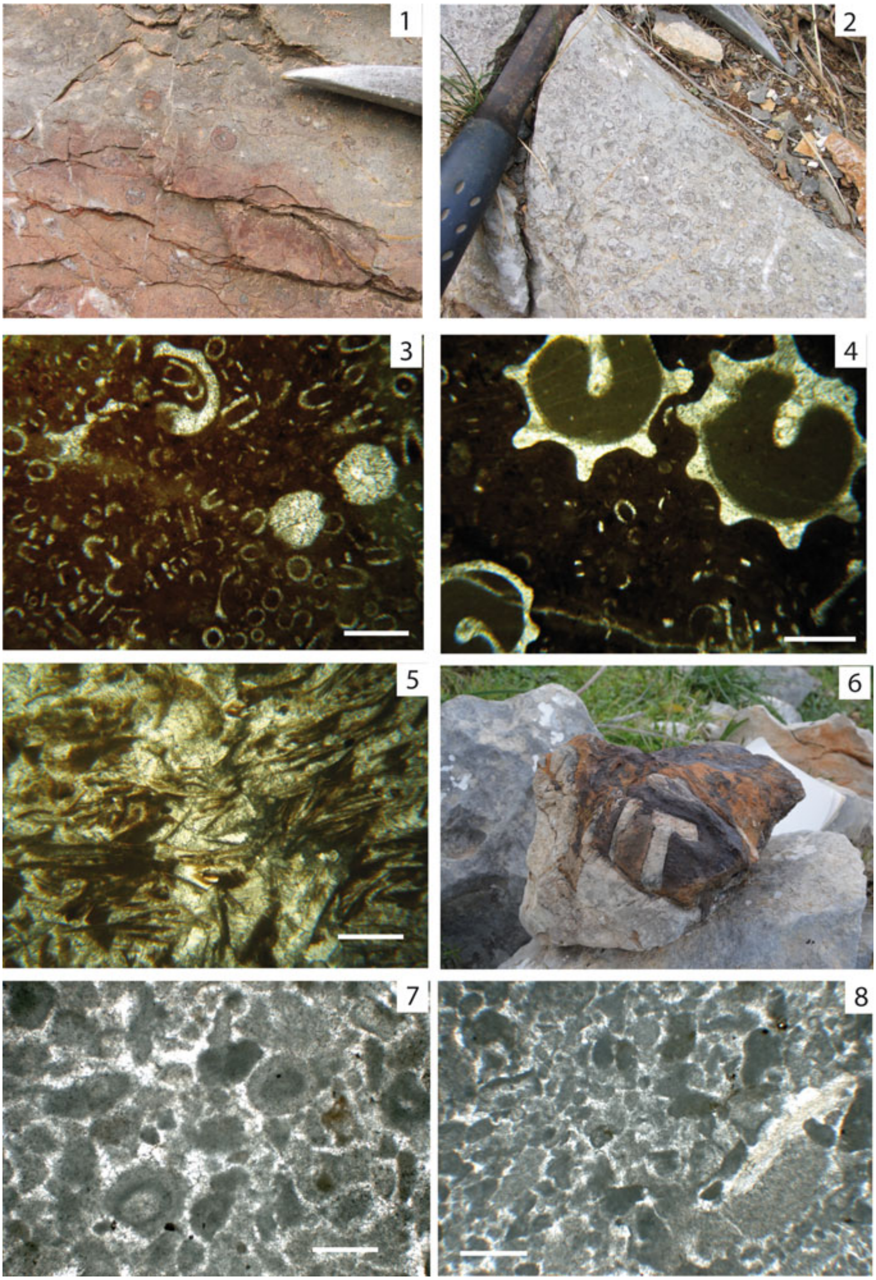
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Plate 6. Typical facies of the Jurassic deep-water carbonate deposits, pertaining to the Buccheri formation. (1) Jurassic Rosso Ammonitico condensed succession, outcropping at Monte Kumeta; the picture puts in evidence the stratigraphic boundary between the Upper Liassic crinoidal limestones (RND) and the lower member of the Buccheri formation (Lower Rosso Ammonitico, BCH_1); the boundary is characterized by darkish crusts, due to Fe and Mn oxides (hard-grounds); (2) basaltic pillow lavas, interlayered in the Bajocian portion of the Buccheri formation (Vicari succession); (3) Fe–Mn nodules and dark crusts characteristic of the *Bositra* limestones lithofacies (Lower Rosso Ammonitico, Rocche Drago, Rocca Busambra); (4) reddish limestones rich in ammonite shells (Lower Rosso Ammonitico, Monte Kumeta); (5) bulbous and laminated Fe–Mn crusts; intraformational microbreccias are dispersed, indicating in situ erosional processes (Piano Pilato, Rocca Busambra); (6) wackestone with ammonites, radiolarians, protoglobigerinids, *Aptychus* and thin-shelled mollusc fragments of the *Bositra* limestones (lower member of the Buccheri formation, Piano Pilato-Rocca Busambra, scale bar 1 mm); (7) the same facies as above with large ammonite shells (scale-bar 1 mm); (8) reddish packstone with mollusc fragments, proto-globigerinids, benthic foraminifers and crinoids of the *Saccocoma* limestone lithofacies (uppermost member of the Buccheri formation, Pizzo Nicolosi succession, Rocca Busambra, scale bar 1 mm); (9) Upper Jurassic reworked carbonates consisting of wackestone-packstone with benthic foraminifers (*Saccocoma* sp.), *Aptychus*, bryozoans, echinoid fragments, thick-shelled bivalve fragments, crinoids, calpionellids and intraclasts. (upper member of the Buccheri formation, Pizzo Marabito succession, Rocca Busambra, scale bar 1 mm).

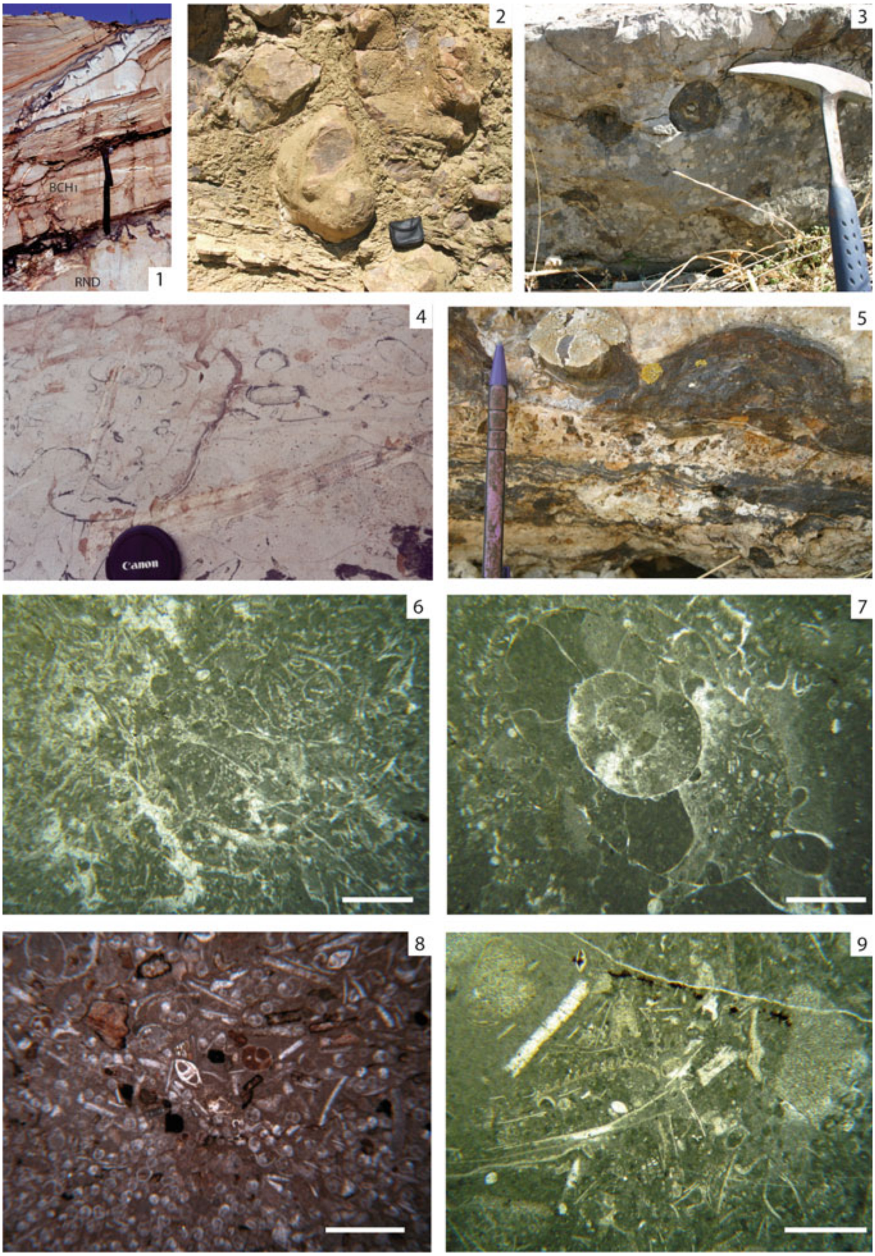
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Plate 7. (1) Upper Eocene calcarenites with large benthic foraminifers of the Valdesi formation (Tana Vipera, Monte Castellaccio, Palermo Mountains); (2) thin section of the sample of the previous picture, consisting of bioclastic wackestone with *Nummulites* spp. (scale bar 1 mm); (3) calcilutite and marl alternations and, upwards, lenticular shape bed of carbonate breccia with bioclasts, crinoid fragments of "calcarenites and marls of Sauci" (Monte Acci, San Vito Lo Capo Mountains); (4) footprints ichnofacies in the calcarenites and marls of Sauci; (5) Tithonian-Neocomian thinly-bedded white limestones and marls with calpionellids and cherty nodules of Lattimusa (Fornazzo section, Inici Mountain, Castellammare del Golfo); (6) thin section of the previous Lattimusa limestone sample, displaying a wackestone with calpionellids, radiolarian and Apthycus (Monte Inici, Castellammare del Golfo, scale bar 1 mm); (7) erosional unconformity relationships between the Lower Miocene Mischio calcarenites (above, in grey) and the Upper Cretaceous rudistid calcarenites of the Pellegrino formation (below, in white) (Pizzo Noce, Monte Sparagio, San Vito Lo Capo Mountains); (8) bioclastic packstone of the lower Miocene Mischio limestone with bivalve fragments, foraminifers, bryozoans, red algae (Monte Sparagio, San Vito Lo Capo Mountains, scale bar 1 mm).

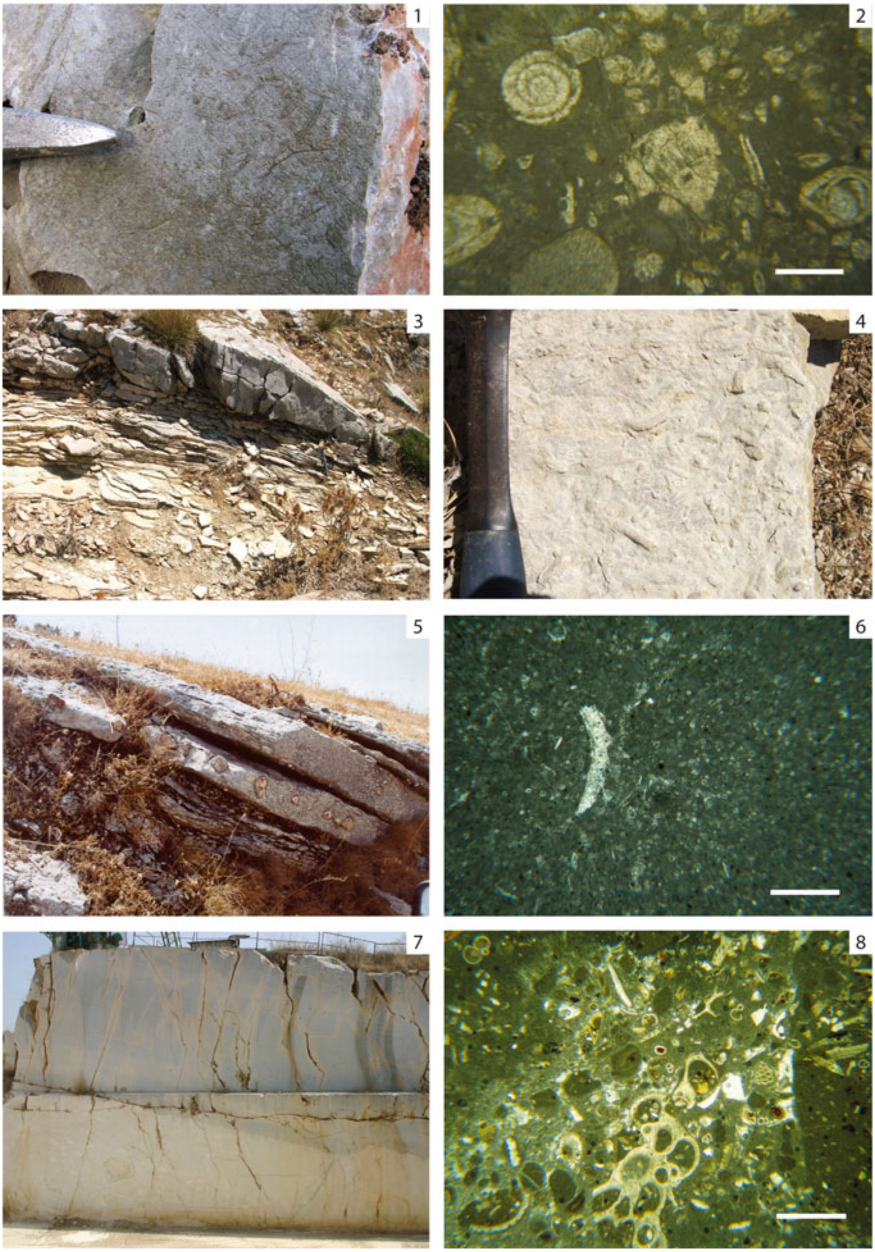
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Plate 8. Typical facies of the Upper Cretaceous-Lower Oligocene pelagic calcareous deposits of the Caltavuturo formation: (1) greenish and red marls alternated with marly limestones outcropping in Contrada Vera Luce type section (Caltavuturo village, Madonie Mountains); (2) thin-bedded red marly calcilutites (Contrada Vera Luce succession, Caltavuturo, Madonie Mountains); (3) wackestone with planktonic foraminifers and packstone with shallow-water reworked fossils, as benthic foraminifers, molluscs and crinoidal plates (Torrente Canalotto succession, Caccamo village, Termini Imerese Mountains, scale bar 1 mm); (4) thin section of the nummulitid breccias lithofacies (CAL_a) interlayered in the pelagic deposits of the Caltavuturo formation. The breccia consists of a packstone with nummulitids, alveolinids, mollusc shells and carbonate platform-derived clasts, merged in red matrix rich in planktonic foraminifers of Eocene age (Torrente Canalotto succession, Caccamo village, Termini Imerese Mountains, scale bar 1 mm); (5) nummulites and alveolines-bearing packstone (nummulitid breccias lithofacies); benthic foraminifers and crinoidal plates, are also present (Caccamo village, Termini Imerese Mountains, scale bar 1 mm); (6) packstone with nummulitids, alveolinids, crinoidal plates, algal fragments and benthic foraminifers (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm); (7) packstone with deformed nummulite and alveoline shells, carbonate platform-derived clasts, surrounded by red micrite with planktonic foraminifers (Caccamo village, Termini Imerese Mountains, scale bar 1 mm). The intense deformation of the large benthic foraminifer shells appears caused by the soft-sediment deformation processes due to gravitational flows acting along the slope during the pelagic deposition; (8) large benthic foraminifer-bearing packstone with *Nummulites* sp., *Alveolina* sp., *Assilina* sp., algae, crinoids and shallow-water reworked clasts (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm).

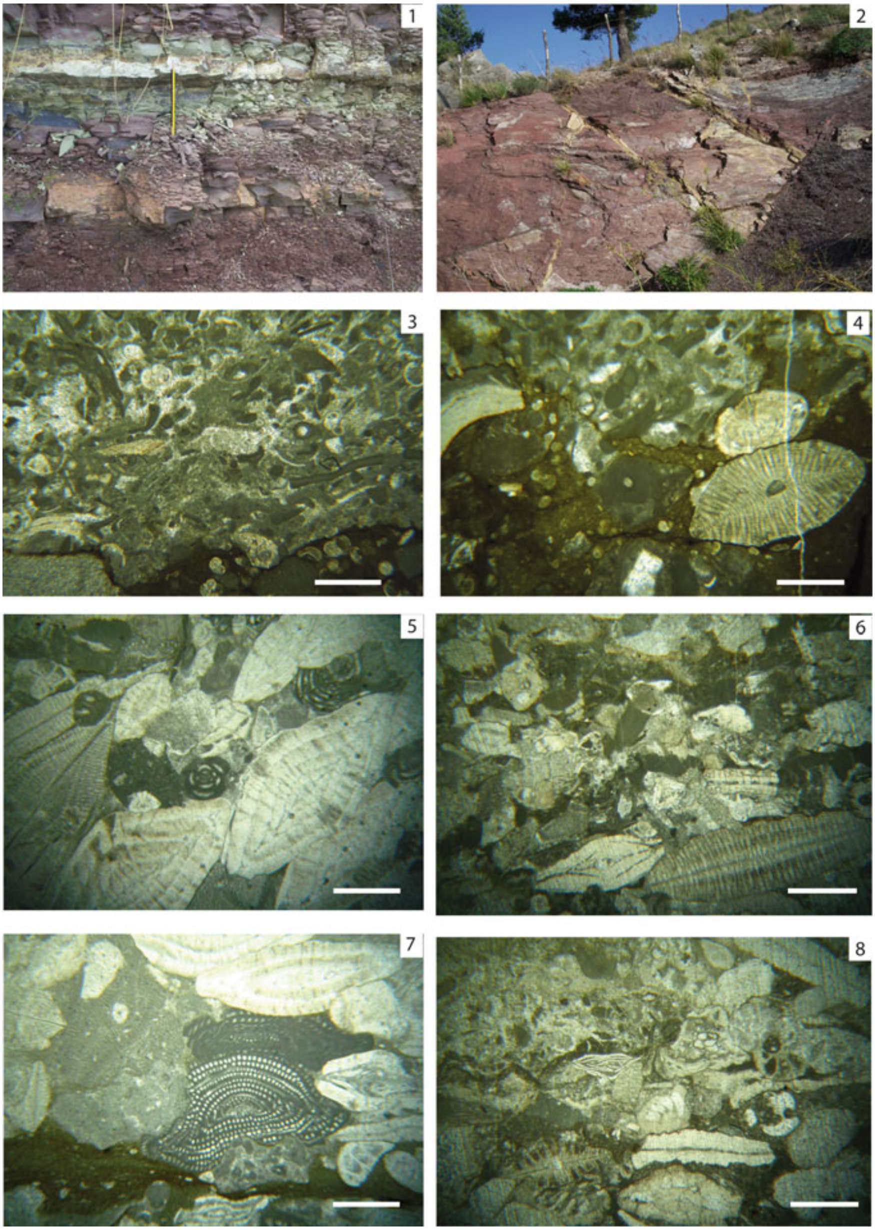
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Plate 9. Typical facies of the Lower Cretaceous carbonate platform deposits of the Capo Gallo limestone: (1) calcilutites with requienids; the mollusc shells display planar orientation, parallel to the bed surfaces, suggesting sea-bottom tractive currents (Pizzo Sella proposed type section, Monte Gallo, Mondello); the subtidal lithofacies pass downward to laminated algal limestone with *fenestrae* structures; (2) planar laminated stromatolitic and loferitic lithofacies, with fenestrae cavities filled with sparry calcite; (3) oolitic limestones (ol) alternated with calcilutites with requienids (rl) (Pizzo Vuturo, Monte Gallo, Mondello); (4) greyish wackestone of the subtidal lithofacies characterized by large gastropod shells (*Nerinea* sp.) and bioclasts (Monte Gallo); (5) bioclastic wackestone with benthic foraminifers (miliolids), ostracods (Monte Gallo, Mondello, scale bar 1 mm), (6) grainstone with algae and benthic foraminifers, requienid fragments and gastropods (Pizzo Vuturo, Monte Gallo, Mondello, scale bar 1 mm); (7) floatstone with black pebbles welded by dark-grey micrite (Pizzo Vuturo, Monte Gallo, scale bar 1 mm); (8) grainstone-packstone with benthic foraminifers (miliolids, textularids), intraclasts, rudistid fragments (Monte Gallo, Mondello, scale bar 1 mm); (9) blackish reworked oolitic grainstone; (Pizzo Vuturo, Monte Gallo, Mondello, scale bar 1 mm).

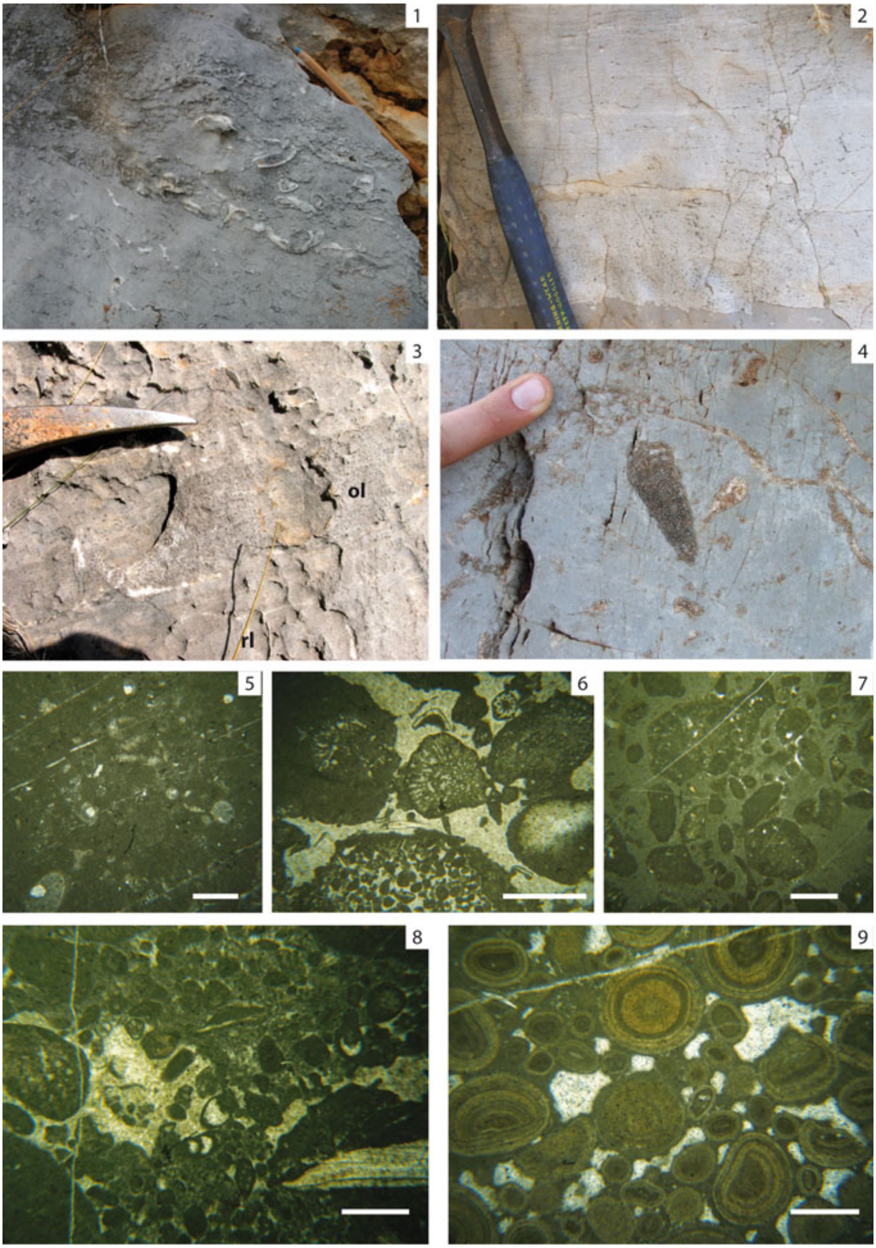
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Plate 10. Typical facies of the Upper Triassic-Lower Liassic carbonate shallow-water deposits pertaining the Capo Rama formation: (1) panoramic view of the Upper Triassic white peritidal limestones along the natural section of Capo Rama (proposed type section), sited near Terrasini village (Palermo). The thick-bedded succession consists of a regular alternation of molluscs (mostly *Megalodon* sp.) and algae wackestone, stromatolitic limestones and loferitic breccias, organized in shallowing-upwards facies sequences (Capo Rama cyclothems). Each cycle is bounded by a subaerial erosional surface, that, in its turn, is superimposed by a submarine ingression surface; (2) limestones and dolomitic limestones with large algal nodules (oncoid grains) and mollusc shells, characterizing the subtidal lithofacies of the formation (Monte Palmeto, North-western Palermo Mountains); (3) brecciated dolomitic limestones with large angular fragments, consisting of darkish micrite (black pebbles) of the black breccias supratidal lithofacies (Monte Sparagio, San Vito Lo Capo Mountains); (4) cavity filled by yellow and reddish paleokarst vadose silt and calcite cements, characterizing the subtidal lithofacies of megalodontid limestones (Monte Sparagio, Monti di San Vito Lo Capo); (5) grainstone-packstone with algae and bioclasts of the subtidal lithofacies (Capo Rama, scale bar 1 mm); (6) dolomitic limestones with corals (patch reef). They consist of framestone made up of colonial corals and sponges with intrareef cavities filled by bioclastic grainstone (Monte Palmeto, Palermo Mountains); (7) loferitic breccias with angular micrite black fragments (Monte Sparagio, San Vito Lo Capo Mountains); (8) white dolomitized limestones with megalodontid shells in life position (subtidal lithofacies), suggesting a low-energy depositional environment (Monte Gallo, Mondello, Palermo); (9) laminated stromatolitic dolostone (infratidal lithofacies), passing upwards to loferitic breccias with tepee structures (supratidal lithofacies); the loferitic breccias are due to in situ subaerial erosion of the unconsolidated original deposits forming breccias with sheet crack structures (Capo Rama, Palermo Mountains).

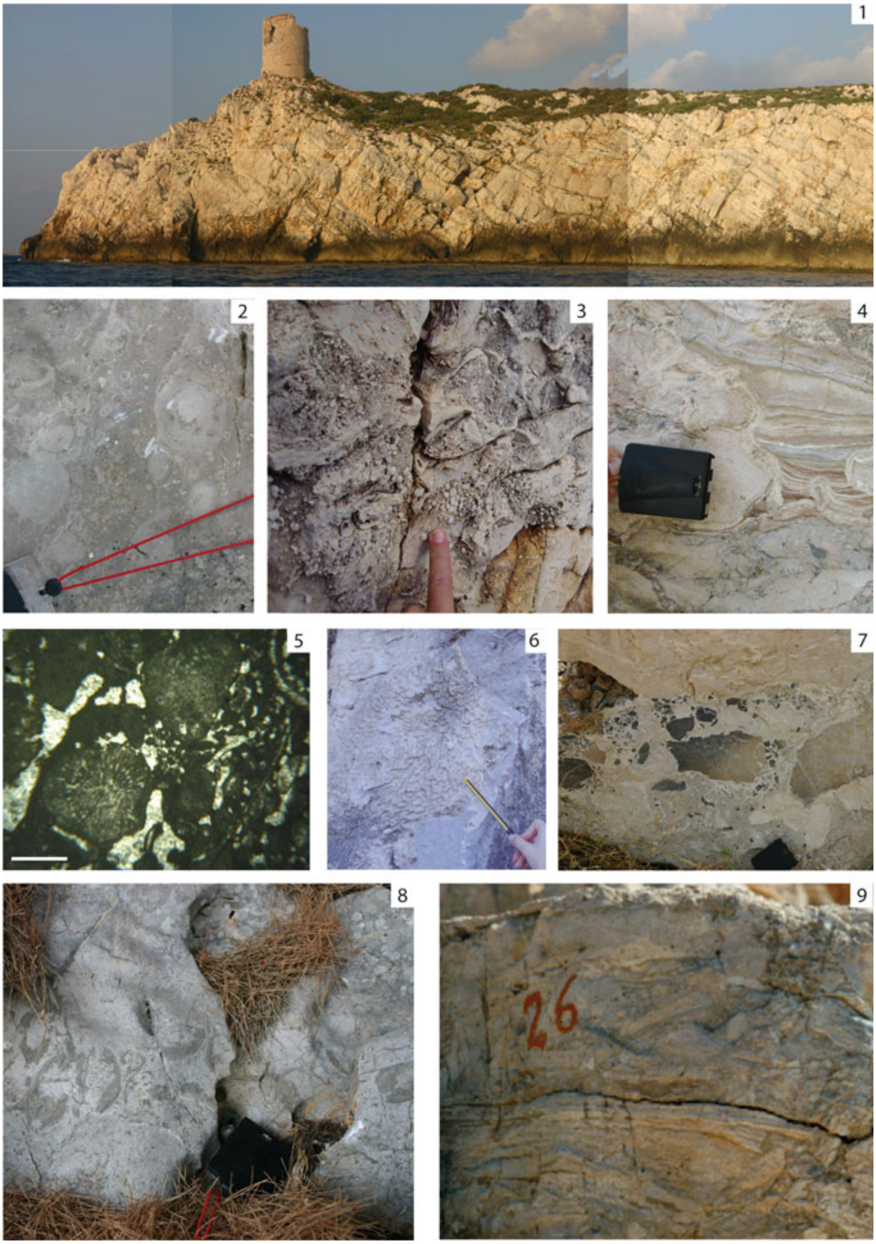
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Plate 11. (1) upper part of the Cardellia marls proposed type section, displaying clays and grey marls succession, with reddish to yellowish quartz and glauconitic sandstone intercalations. The succession is capped by thin-to-thickly-bedded glauconitic limestones of the Corleone calcarenites (Monte Cardellia, Corleone); (2) calcareous clast supported breccias, with carbonate platform-derived elements. These samples are collected from the calcareous breccia beds interlayered in the Oligocene Cardellia marls succession; (3) yellowish calcilutite and marl alternations of the Gratteri formation (Vallone San Biagio, western Madonie Mountains); (4) quartz sandstones interlayered in the brown marly clays of the Gratteri formation (Gratteri village, north-western Madonie Mountains); (5) grey calcilutite and marl alternations of the Hybla Formation (Monte Kumeta); (6) thin section of grey limestones of the Hybla Formation, consisting of planktonic foraminifers and radiolarian-bearing wackestone (Pizzo Marabito, eastern end of the Rocca Busambra ridge, scale bar 1 mm).

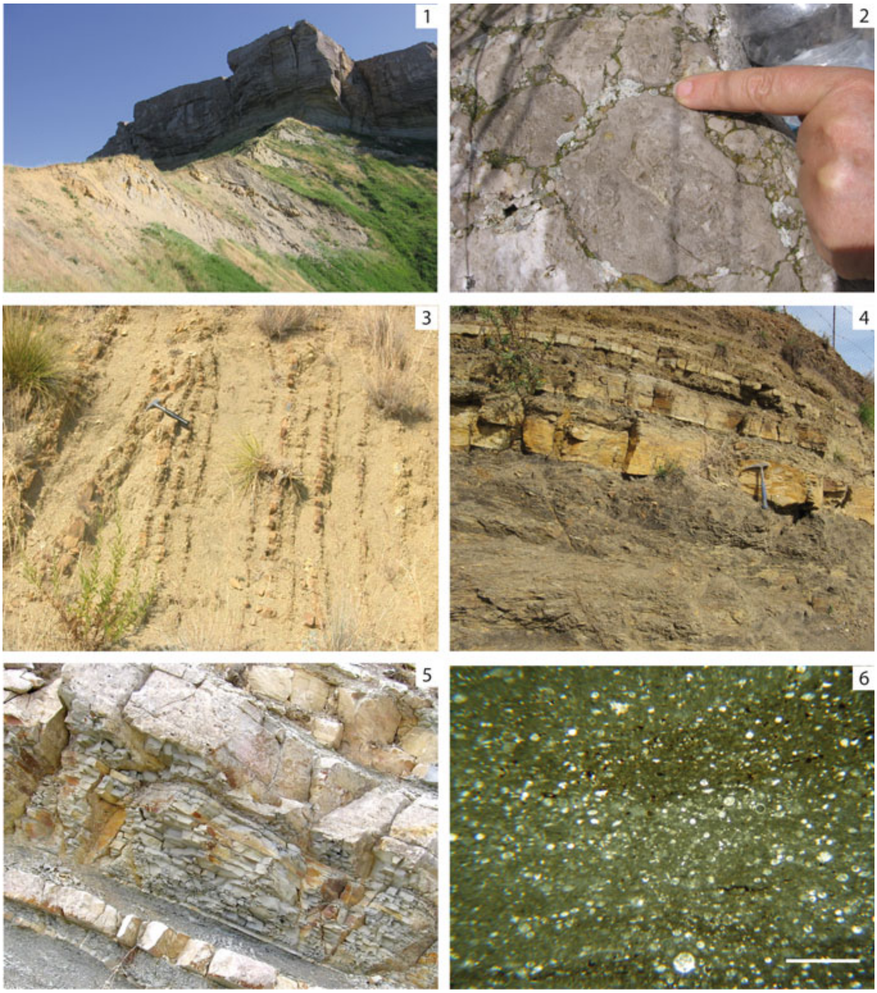
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Plate 12. Typical facies of deposits of the Lower Miocene Corleone glauconitic calcarenites: (1) alternations of thin-bedded calcarenites and green glauconitic marls, with planar and cross stratification (Corleone village); (2) ichnofacies observing at the top of the calcarenite beds, consisting of tracks of benthic organism (Rocca dei Maschi, Corleone); (3) glauconitic calcarenite with oblique to cross stratification (Monte Cardellia, Corleone); (4) paraconformity stratigraphic contact between Lower Miocene glauconitic wackestone (CCR) and in situ breccia lithofacies of the Lower Liassic peritidal limestones (INI); glauconitic deposit sills are present (Rocca Argenteria, westernmost Rocca Busambra); (5) bioclastic packstone with glauconite fragments, nummulitids, algae fragments and intraclasts (Rocca dei Maschi succession, Corleone, scale bar 1 mm); (6) grainstone with large benthic foraminifers, algae, crinoids, echinoids and green glauconite fragments (Rocca dei Maschi succession, Corleone, scale bar 1 mm); (7) grainstone-packstone with algae fragments, large benthic foraminifers, bivalves and glauconite fragments (Rocca dei Maschi succession, Corleone, scale bar 1 mm); (8) grainstone with planktonic foraminifers (globigerinids) and fragments of glauconite (Pizzo Nicolosi, Rocca Busambra, scale bar 1 mm).

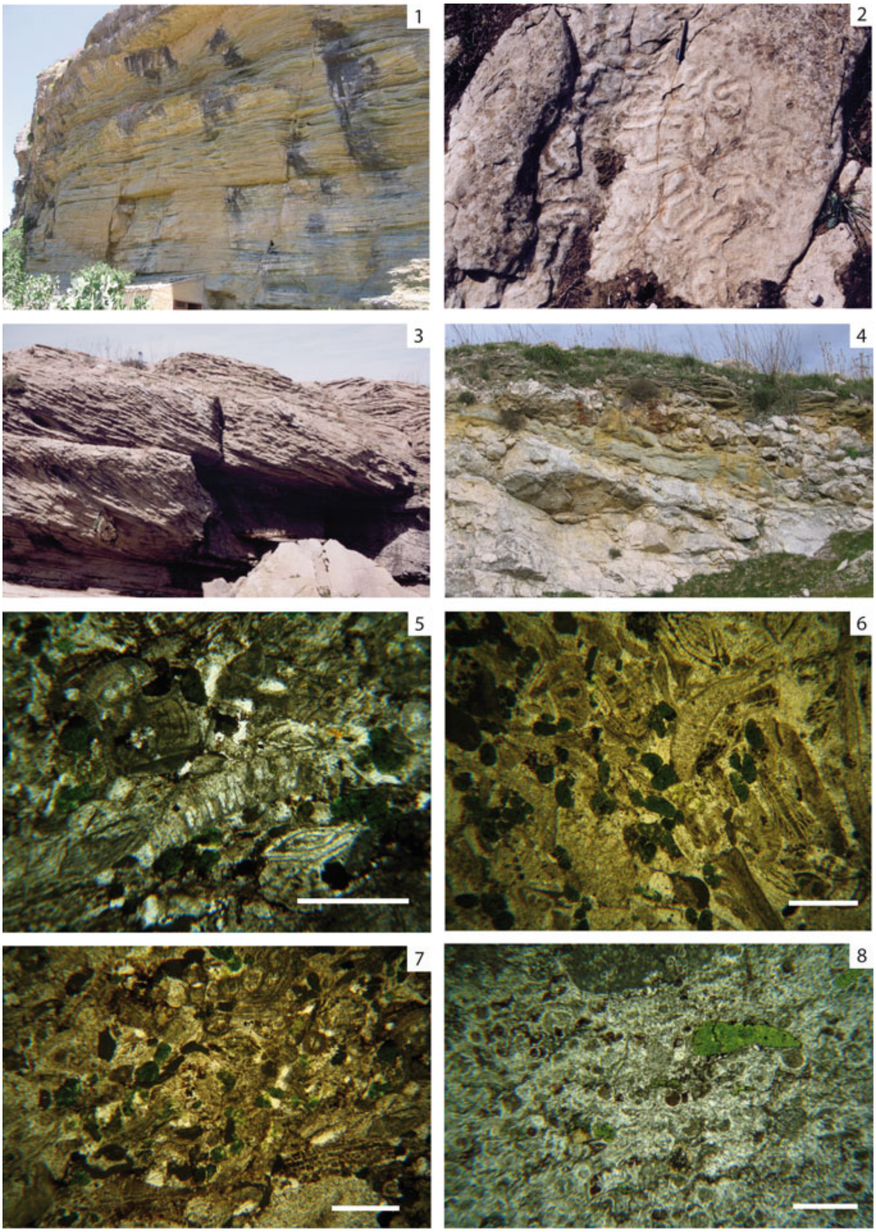
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Plate 13. Typical facies of the Upper Triassic reef limestone of the Cozzo di Lupo formation (CZP) and the equivalent Marabito limestone (ITO): (1) spongid and algae boundstone showing the typical rime cements (Cozzo di Lupo section, Torretta, Palermo Mountains); (2) boundstone with algae and isolated to colonian sponges (s) and with intrareef cavities filled by internal silt and pelagic brown mudstone (m) and bordered by sparry calcite (c) (Cozzo di Lupo section, Torretta, Palermo Mountains); (3) boundstone with spongid specimen and algae, that are the main framebuilder components of the reef limestone; the sample is collected from the upper portion of the Upper Triassic Pizzo Marabito succession (Rocca Busambra ridge); (4) spongid and algae boundstone of the Cozzo di Lupo formation, sampled in the Cozzo di Lupo proposed succession type (Torretta, western Palermo Mountains); (5) and (6) thin-sections showing spongid and algae boundstone (scale bar 1 mm) (Pizzo Marabito, eastern side of Rocca Busambra); (7) and (8) thin sections showing coral and spongid boundstone, with intrareef cavities filled by calcite cements (Cerda 2 well, Termini Imerese Mountains, scale bar 2 mm).

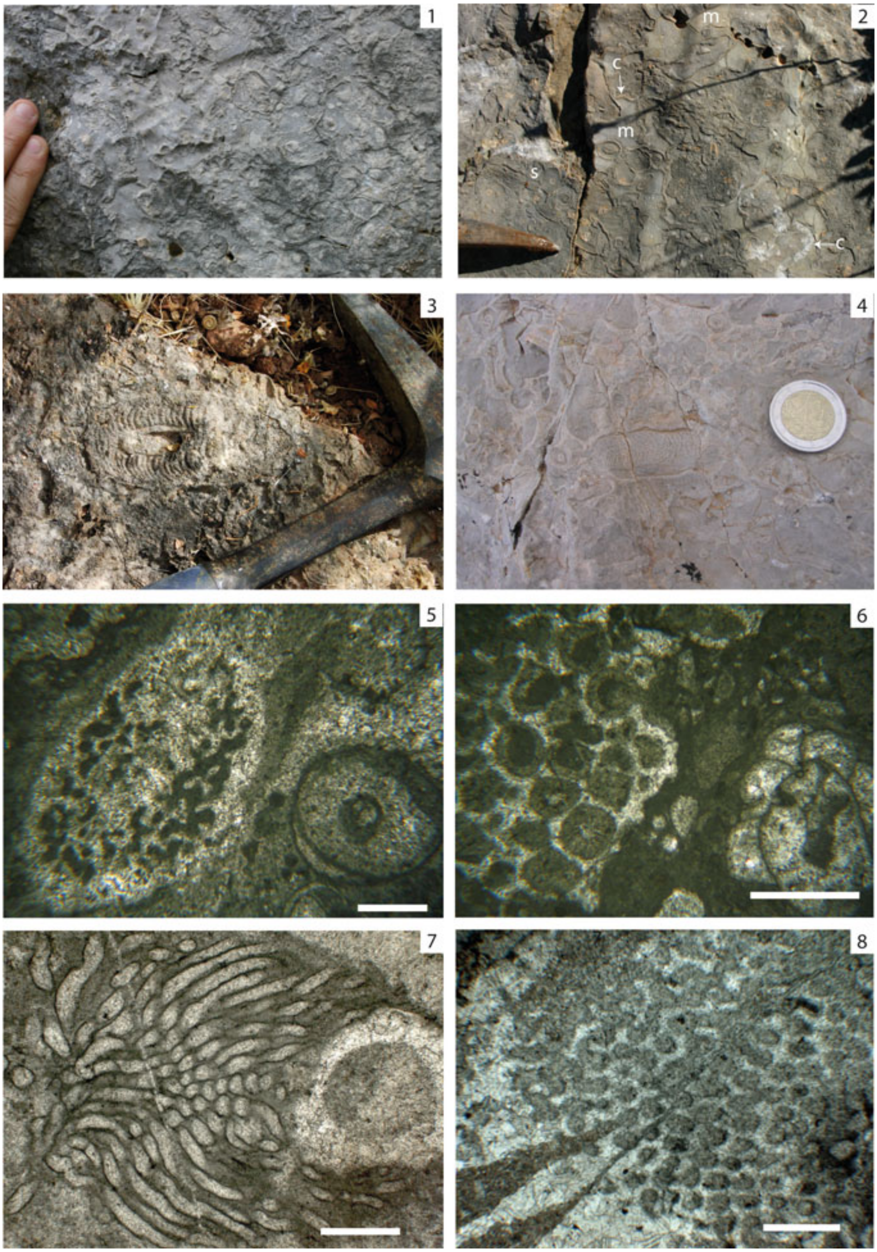
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Plate 14. Typical facies of the Upper Liassic crinoidal limestone (RND), included in the Trapanese succession (see Table 2.4): (1) lower Jurassic condensed section of Monte Kumeta, where the red and light-pink nodular limestones of the lower member of the Buccheri formation (BCH_1), lying unconformably above the crinoidal limestone (RND), that, in turn, are covered by a Fe–Mn oxide crust with a pinnacle morphology (Monte Kumeta); (2) detail of the crinoidal calcarenites of the previous picture, showing oblique and cross laminations (ripples) inside the crinoidal limestone unit; (3) iron-manganese crust (hardground) with pinnacle morphology interposed between the peritidal limestones of the lower Liassic Inici Formation and the upper Liassic crinoidal calcarenites (Rocca Drago, western end of Rocca Busambra); (4) Jurassic condensed succession of Piano Pilato (Rocca Busambra): INI Lower Liassic peritidal limestones, RND Toarcian crinoidal limestones, BCH_1 Bositra limestones, hd Fe–Mn crusts with pinnacles and bulbous morphology; (5) thin section of the grey crinoidal limestone outcropping at Balatelle Mount (Bolognetta), showing a grainstone with surficial oolites, bioclasts, intraclasts and impregnation of iron oxides (scale bar 1 mm); (6) thin section of crinoidal limestone inserted in the Roccapalumba succession (Trapanese domain), consisting of oolitic grainstone with abundant bioclasts, intraclasts and fractures filled by secondary calcite (scale bar 1 mm); (7) bioclastic grainstone with large crinoidal plates (centre of the picture), encrusted mollusc shells (Pizzo Nicolosi, Rocca Busambra, scale bar 1 mm); (8) thin section of the infilling materials of the neptunian dykes that cut the top of the Inici Formation at Rocca Argenteria; the picture shows microbreccias, resulting from the crushing of the Inici Formation peritidal limestone, that are welded in a red arenaceous matrix with bioclasts and crinoidal plates pertaining to the crinoidal limestone (scale bar 1 mm).

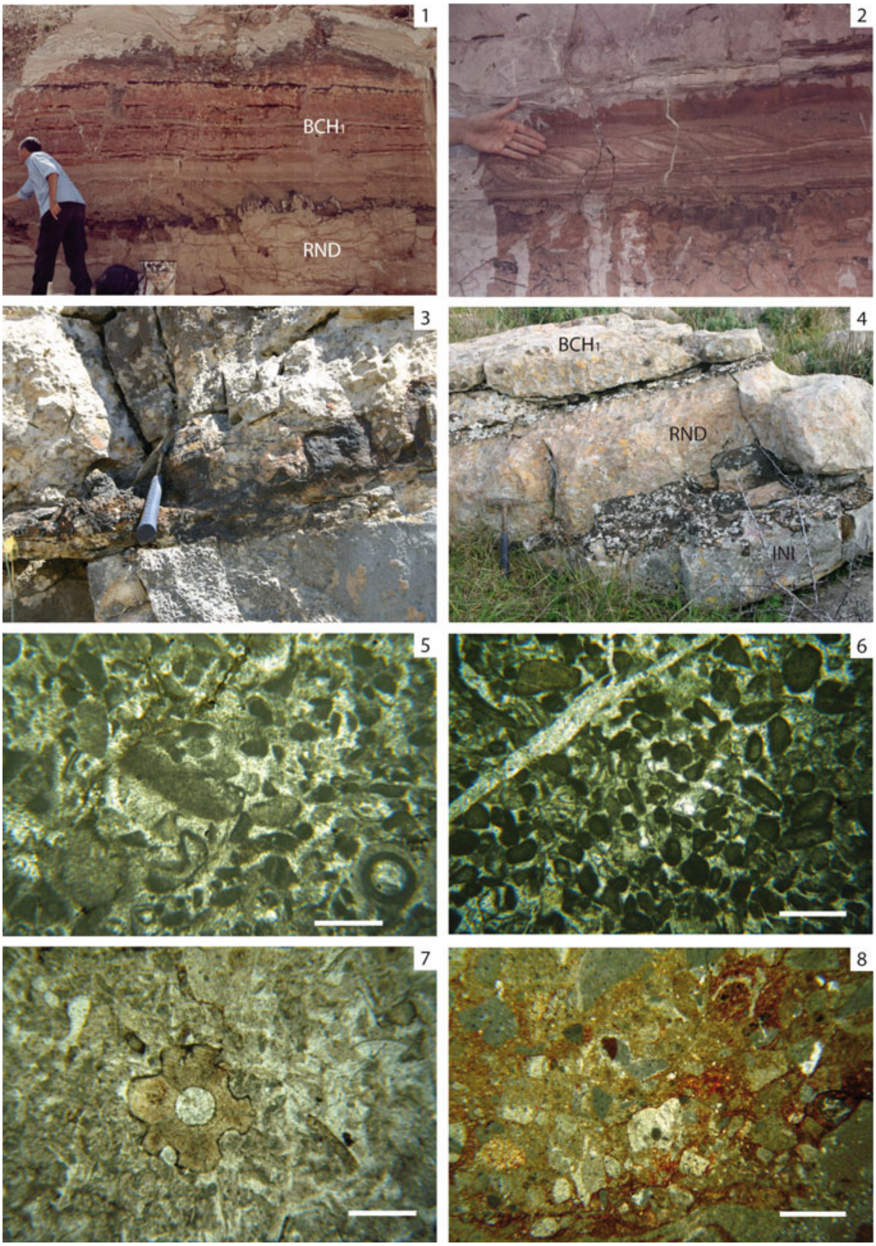
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Plate 15. Typical facies of the Upper Liassic slope deposits of the crinoidal limestone and Altofonte breccias (MCD), included in the Imerese succession (see Table 2.2): (1) yellow crinoid calcarenites, alternated with thin layers of reddish and yellow crinoidal marls (Termini Imerese proposed type succession); (2) clast-supported texture of the Altofonte breccias, whose elements consist of corals and spongid boundstone; (3) grainstone with benthic foraminifers, intraclasts, algal fragments and crinoidal plates (Termini Imerese, scale bar 1 mm); (4) grainstone with intraclasts, fragments of codiacean algae and, upwards, silicified clasts and calcite (Termini Imerese, crossed polarity, scale bar 1 mm); (5) packstone with grey shallow-water derived elements and muddy matrix with crinoidal plates and shells of pelagic bivalves (top of the crinoidal limestone succession at Termini Imerese, scale bar 1 mm); (6) grainstone with crinoidal plates, intraclasts, benthic foraminifers (Abbeveratoio Angelia, Pizzo Cane, Trabia Mountains, scale bar 1 mm); (7) packstone/grainstone with algae, peloids and large oncoids (core 3: 2833–2841 m, Creta 1 well, PPL, scale bar 2 mm); (8) grainstone with codiacean algae, crinoids, benthic foraminifera and intraclasts (core 3: 2833–2841 m, Creta 1 well, PPL, scale bar 2 mm);

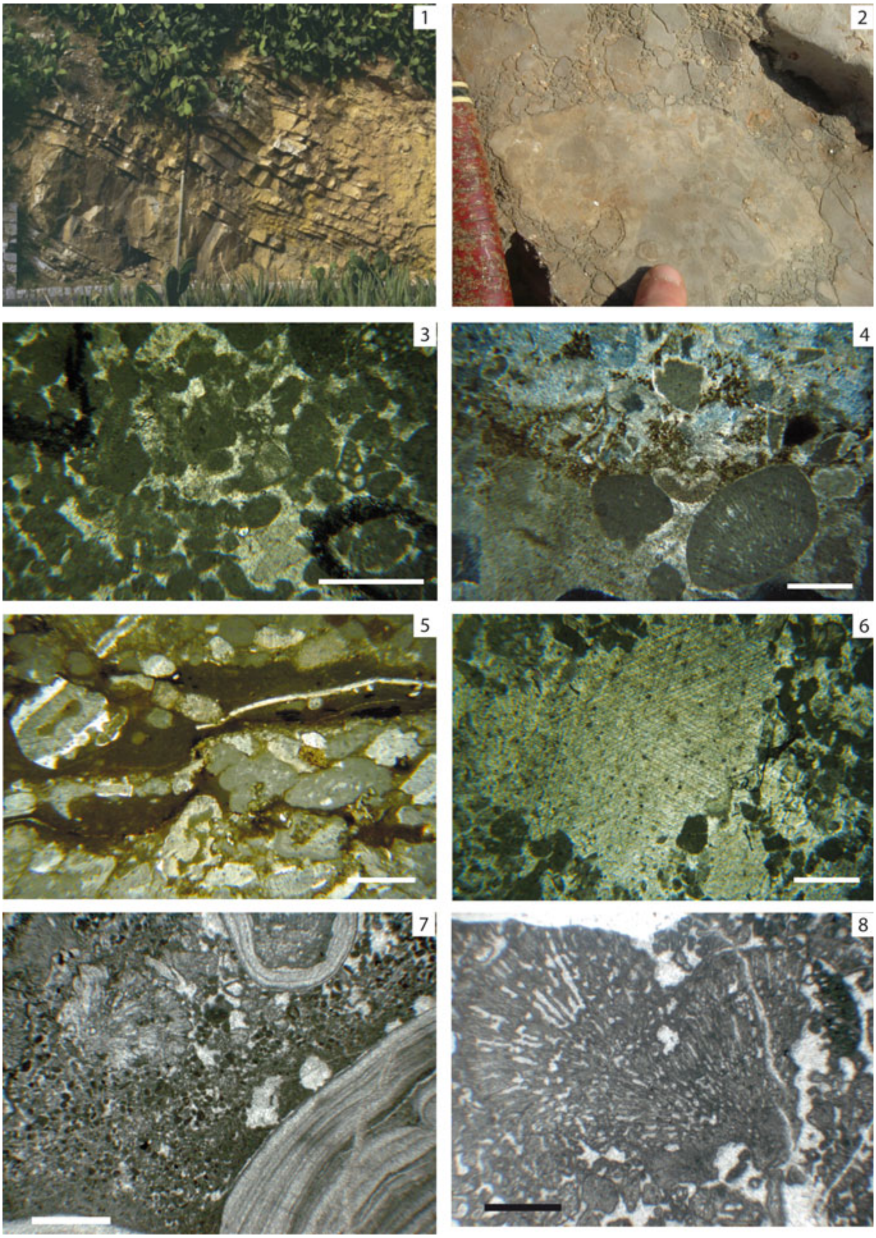
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Plate 16. Typical facies of the Jurassic and Lower Cretaceous deep-water deposits pertain to the black radiolarite (CRI_1) and red spongolithic marly limestone (CRI_2) members of the Crisanti formation, respectively: (1) thin-bedded Jurassic black radiolarites and bedded cherts of the CRI_1 member (Sclafani Bagni succession, Madonie Mountains); (2) Jurassic cherty limestones and white radiolarites of the CRI_1 member, characterized by a large slump (Trabia village); (3) thin section of the black radiolarites of the CRI_1 member of the Sclafani Bagni succession (see picture 1), consisting of radiolarian and sponge spicules bearing mudstone-wackestone with planar and undulate (flaser) laminations (scale bar 1 mm); (4) red Jurassic laminated radiolarian wackestone of the CRI_1 member with manganese oxides (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm); (5) well-bedded, Lower Cretaceous red radiolarites, cherty limestones and bedded cherts with intercalations of dm-thick tabular calcareous beds reworking shallow-water deposits (spongolithic marl member of the Crisanti Formation, Sclafani Bagni succession); (6) close-up of picture 5, showing lenticular geometries, with pinch-out endings of the bioclastic (mainly rudistid fragments and benthic foraminifers) calcarenites, interlayered in the deep-water radiolarites of the CRI_2 member; (7) red radiolarian wackestone of the spongolithic marl member (Valledolmo1 well, 3011 m depth, scale bar 1 mm); (8) thin section of the grey calcarenites interbedded in the red spongolithic marl limestone member of the Crisanti formation, showing a bioclastic dolomitized packstone with crinoidal fragments, benthic foraminifers (*Orbitolina* sp.) and shallow-water calcareous reworked clasts (scale bar 1 mm).

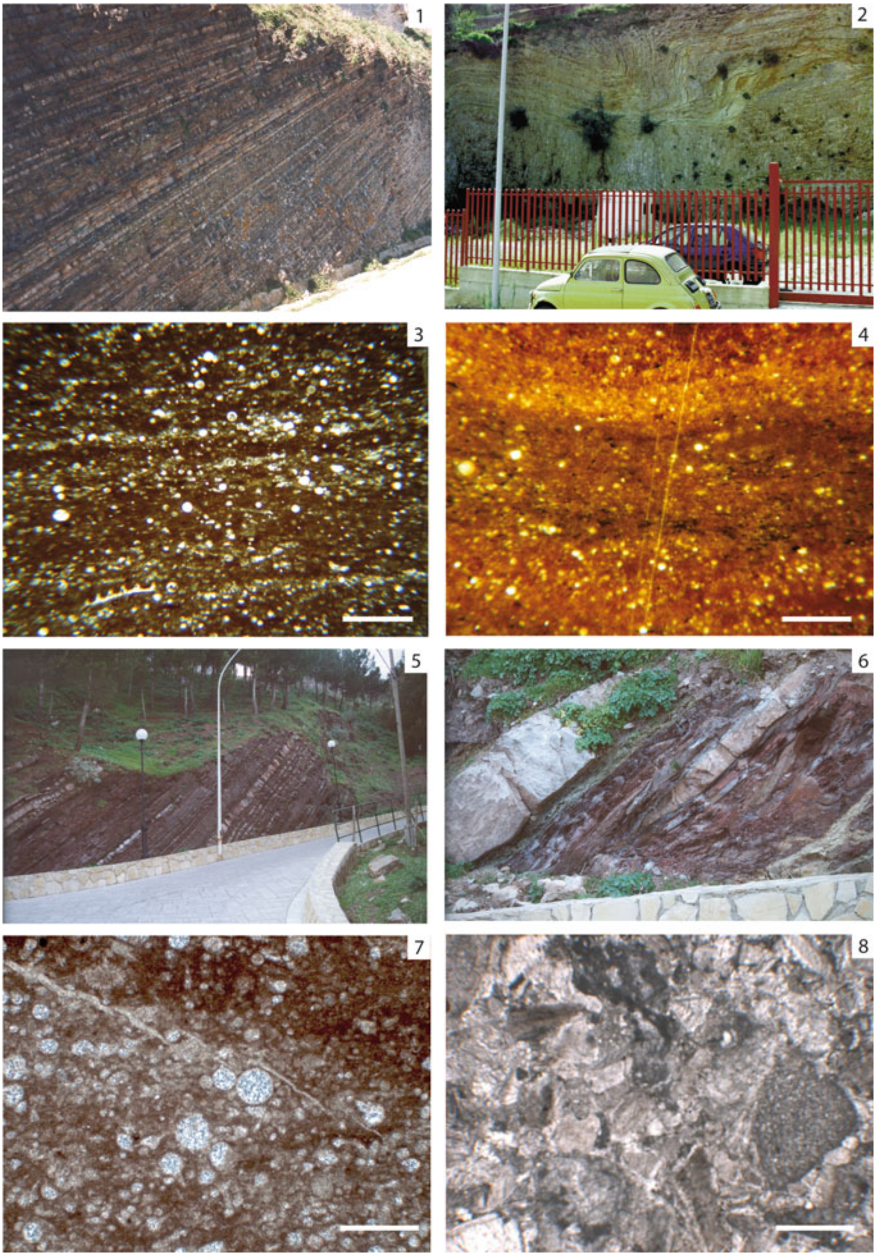
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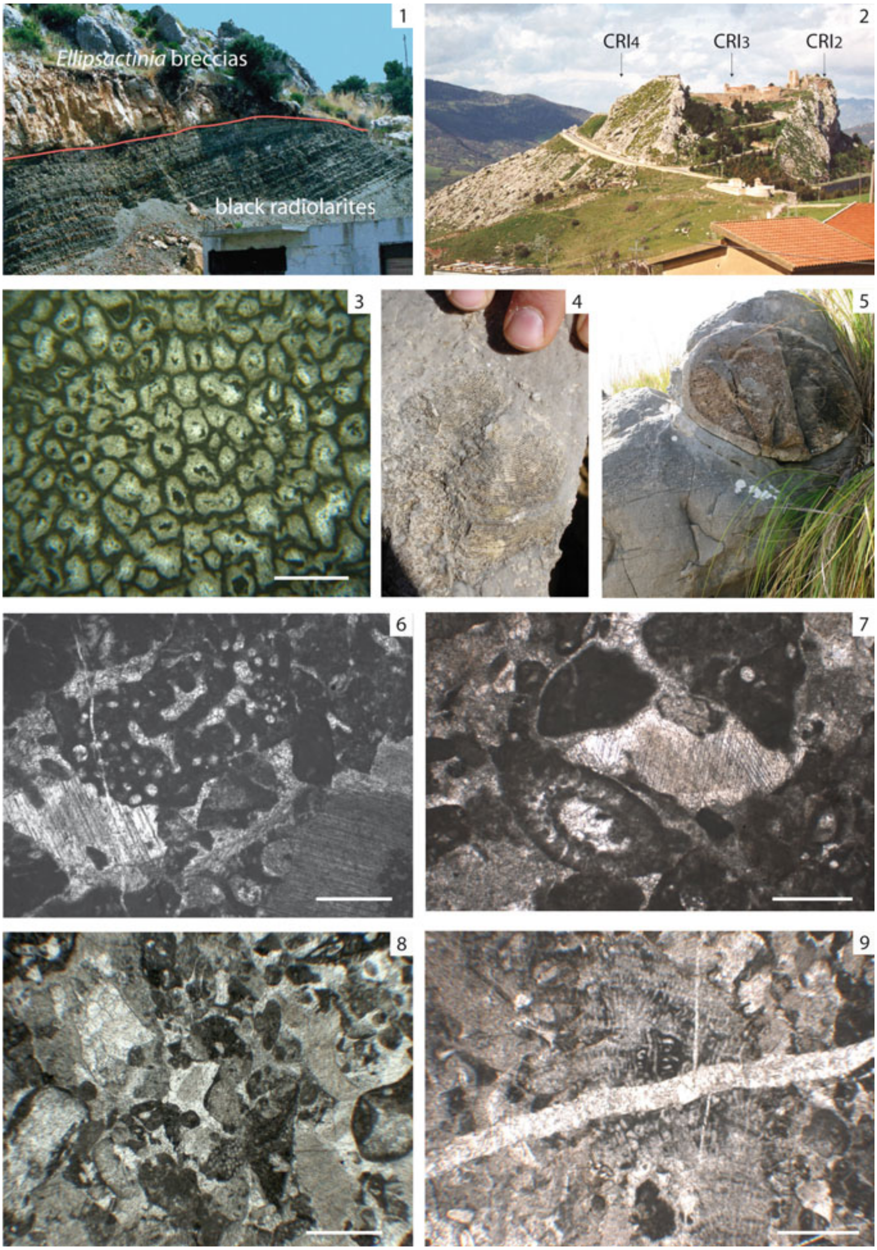
Plate 17. Typical facies of the Upper Jurassic (Tithonian)-Lower Cretaceous (Neocomian) deposits of the *Ellipsactinia* breccias member of the Crisanti formation: (1) erosional contact (in red) between the *Ellipsactinia* breccias and the Upper Jurassic black radiolarites member of the Crisanti formation (Cozzo Petroso, Trabia Mountains); (2) Cretaceous-Eocene succession of Rocca di Sclafani Bagni, where the two carbonate clastic bodies (CRI_2, Ellipsactinia breccias member and CRI_4 rudistid breccias member of the Crisanti formation) are separated from red radiolarites and cherty limestones of the spongolithic marl member (CRI_3). (3) thin section showing the internal structure of a fragment of *Ellipsactinia* sp. (Monte San Calogero succession, Termini Imerese Mountains, scale bar 1 mm); (4) sample of the breccias with a specimen of *Ellipsactinia* sp. (Monte San Calogero succession, Termini Imerese Mountains); (5) graded and laminated breccias and calcarenites with a big cherty nodule (Pizzo Cane succession, Trabia Mountains); (6) rudstone-grainstone with *Ellipsactinia* sp., molluscs, benthic foraminifers, intraclasts, echinoid plates and syntaxial calcite crystals (Colla 1 well, scale bar 2 mm); (7) bioclastic grainstone-packstone with dasycladacean algae, microproblematics (*Bacinella irregularis*), crinoidal plates (Colla 1 well, 1966–1968 m depth, scale bar 2 mm); (8) intra-bioclastic packstone with fragments of bryozoans, molluscs and benthic foraminifers (Colla 1 well, 1966–1968 m depth, scale bar 1 mm); (9) grainstone-packstone with pelagic crinoids (*Saccocoma* sp.), codiacean algae, intraclasts, echinoid plates, (Colla 1 well, 1966–1968 m. depth, scale bar 1 mm).


1
Ellipsactinia breccias
black radiolarites
2
CRI4
CRI3
CRI2
3
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6
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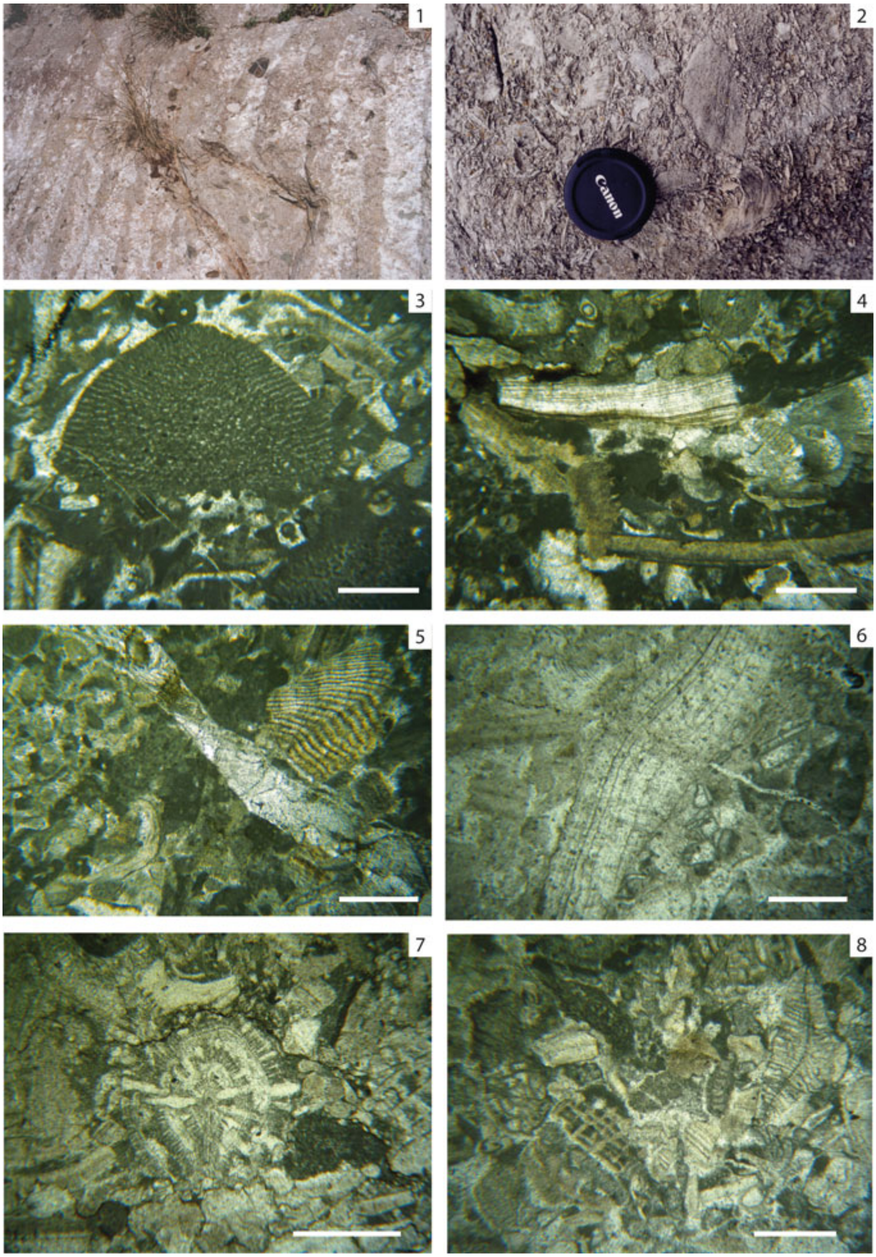
Plate 18. Typical facies of the slope deposits of the Upper Cretaceous rudistid breccias member of the Crisanti Formation: (1) calcareous breccia with shallow-water fragments, deriving from the dismantling of an upper Cretaceous carbonate platform reef margin, and of deep-water fragments, consisting of cherts and siliceous limestone, derived from the erosion of the underlying radiolarites and spongolithic marls member of the Crisanti formation (Rocca di Sclafani Bagni, Madonie Mountains); (2) bioclastic breccias rich in rudistid fragments, molluscs and crinoids (Rocca di Mezzogiorno, Monte San Calogero, Termini Imerese Mountains); (3) bioclastic grainstone-packstone with *Orbitolina* spp., rudistids and crinoids (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm); (4) bioclastic packstone with mollusc fragments (mostly rudistids) with planar orientation parallel to the stratification, due to unidirectional sea-bottom currents (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm); (5) grainstone-packstone with radiolitid fragments, microproblematics, benthic foraminifers, crinoids and calcareous shallow-water derived clasts (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm); (6) grainstone with coarse fragments of rudistid shells (Cozzo Famo succession, Termini Imerese Mountains, scale bar 1 mm); (7) and (8) Campanian-Maastrichtian bioclastic packstone-grainstone with *Orbitoides* sp., *Siderolites calcitrapoides*, rudistid fragments, echinoid spines and carbonate platform-derived clasts (Termini Imerese succession, scale bars 1 mm).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Canon
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Plate 19. Typical facies of the Lower Liassic dolomitic deposits of the Fanusi formation: (1) downlap relationships between the megabeds of the lowermost Jurassic dolomite breccias (Fanusi formation) and upper Triassic cherty limestones (Scillato formation) at Monte San Calogero (Termini Imerese Mountains); (2) panoramic view of the lower Jurassic Imerese succession at Ferrato Marcato (Monte San Calogero, Termini Imerese Mountains). Legend: FUN, dolomite breccias (Fanusi formation), MDC, crinoidal limestones, CRI_1, dark radiolarites member of the Crisanti Formation. The transgressive surfaces with onlap terminations are marked in green; (3) intraformational erosional surface in the dolomitic succession of the Fanusi formation outcropping inside the Termini Imerese village; (4) close-up of the stratal organization of the Fanusi formation (Marcato Ferrato, the sample come from the outcrop highlighted in the rectangle a in Fig. 2), showing that the dolomite succession consists of alternations of megabeds of breccias and thinly-bedded doloarenites with cross and oblique laminations: (5) alternation of doloarenites in thin beds and yellow dolomitic marls, showing lenticular geometries (erosive channels, Termini Imerese succession). (6) thin section of a sample of microcrystalline dolomite, showing the growth of rhombohedral dolomite crystals in inter-crystalline cavities (Monte San Calogero, Termini Imerese Mountains, scale bar 1 mm); (7) thin section of a sample of doloarenites, showing a microcrystalline dolomite with ghosts of planar lamination (Cozzo Stingi succession, Monte San Calogero, Termini Imerese Mountains, scale bar 1 mm).

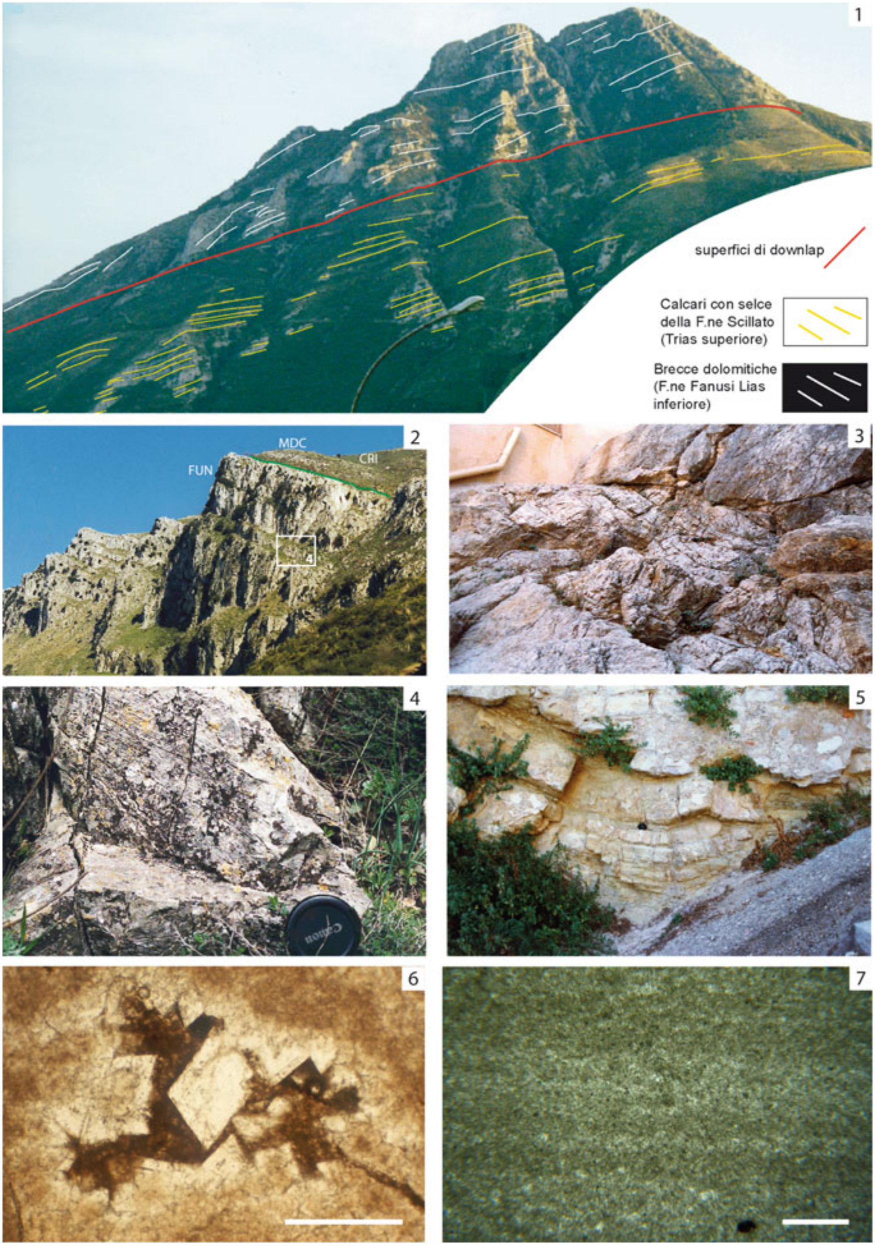
1
superfici di downlap
Calcari con selce
della F.ne Scillato
(Trias superiore)
Brecce dolomitiche
(F.ne Fanusi Lias
inferiore)
2
MDC
FUN
CRI
4
3
4
5
6
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Plate 20. Typical facies of the shallow-water Upper Triassic-Lower Liassic deposits of the Sciacca and Inici Formations: (1) dolomitic limestones with megalodontids (back-reef lagoon lithofacies) of the Sciacca Formation (Monte Inici, Castellammare del Golfo); (2) dolomitic limestone with stromatolites (tidal flat lithofacies) of the Sciacca Formation (eastern slope of Monte Inici, Castellammare del Golfo); (3) oolitic and bioclastic limestones of the Inici Formation (Rocca Busambra); (4) stromatolite lithofacies of the peritidal limestones of the Inici Formation, intersected by sub-vertical neptunian dyke (hammer), filled by the glauconitic sandstones of the Corleone calcarenites (Rocca Busambra ridge); (5) wackestone-packstone with crinoids, algae, intraclasts and peloids (subtidal lithofacies of the Inici Formation) with cavities filled by sparry calcite (Pizzo Nicolosi, Rocca Busambra, scale bar 1 mm); (6) packstone with codiacean algae, bioclasts, intraclasts and peloids of the Inici Formation (Piano Pilato, Rocca Busambra ridge, scale bar 1 mm); (7) tidal flat lithofacies of the Inici Formation, consisting of algal laminated bafflestone, passing upwards to intra-bioclastic fragments (benthic foraminifers and algae) and oolitic packstone-grainstone with loferitic-type cavities filled by sparry calcite; (Monte Magaggiaro, Montevago village, scale bar 1 mm); (8) thin section of oolite lithofacies of the Inici Formation, consisting of oolitic grainstone that displays, also, coated grains, benthic foraminifers, gastropod and bivalve fragments and algae (Rocca Busambra ridge, scale bar 1 mm).

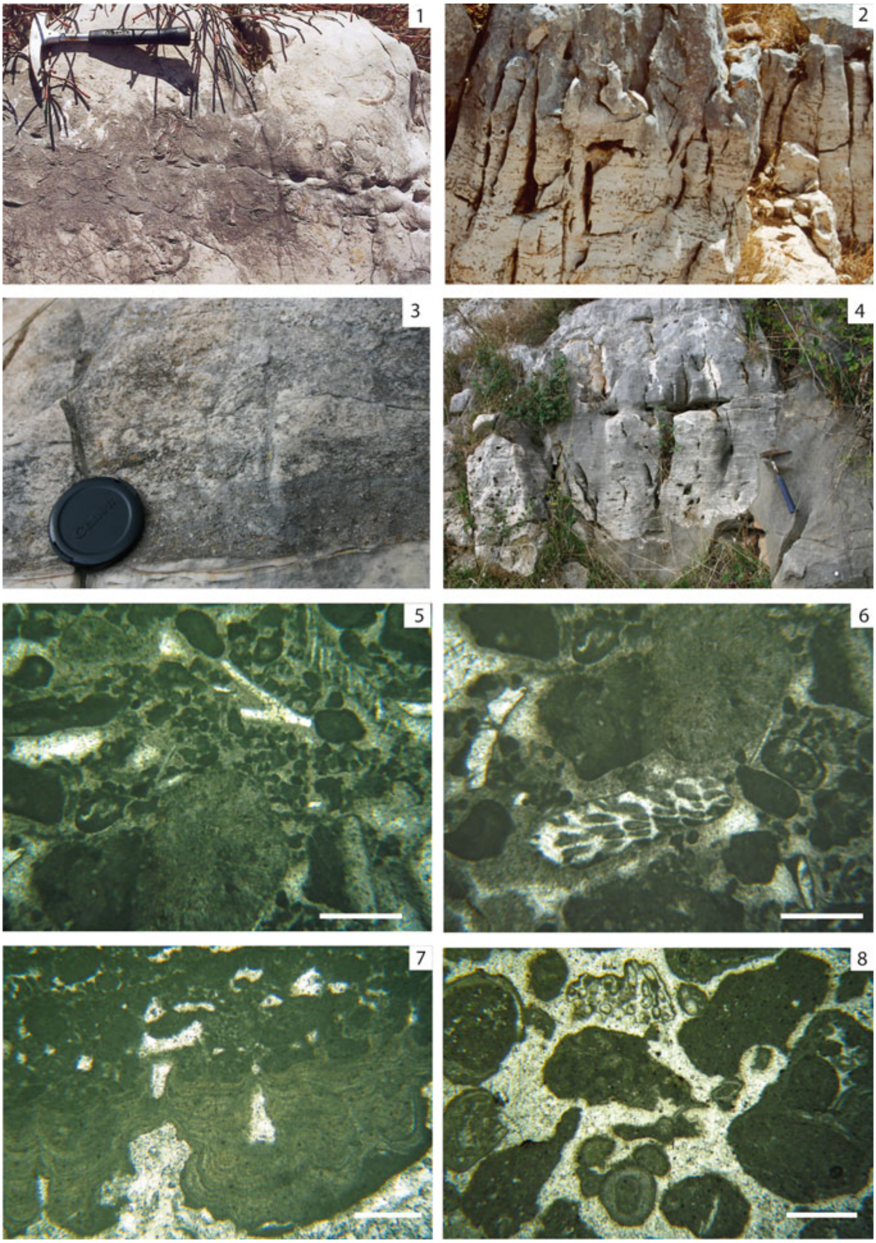
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Plate 21. Mesozoic tectono-stratigraphic features at Rocca Busambra: geometrical relationships between the Lower Liassic peritidal limestone of the Inici Formation and the Jurassic and Upper Cretaceous pelagic deposits of the Buccheri and Amerillo Formations: (1) graben structure at Pizzo Nicolosi. The Upper Cretaceous pelagic limestones of the Amerillo formation (AMM, in green) abut in buttress unconformity, the sub-horizontal Lower Liassic peritidal limestones sub-horizontal beds of the Inici Formation (INI) and the *Bositra* limestones of the lower member of the Buccheri formation (BCH_1) along WNW–ESE paleofaults; the latter thus forming depressions with relative downthrown of more that 50 m (Rocca Ramusa and Pizzo Nicolosi grabens) and draping the horst erosional margins; (2) close-up of the Rocca Ramusa graben filled by the Upper Cretaceous pelagic limestones (AMM, in green) that onlap the peritidal limestones on the floor of the graben and abut, in buttress unconformity, the sub-horizontal beds of INI on the southern flank of the structure; (3) filling of the Pizzo Nicolosi graben (eastern-side); (4) buttress unconformity relationships between the pelagic limestone (AMM) and the INI along a paleofault plane (in red) on the northern flank of the Ramusa graben; (5) angular relationships between AMM and INI along the horst area of Pizzo Nicolosi; (6) view of the angular contact in buttress unconformity between the sub-vertical Upper Cretaceous pelagic beds and the faulted Lower Liassic platform beds; fault plane is in red; (7) View of the Rocca Busambra-peak, where the Upper Cretaceous—Eocene pelagic limestones (AMM) onlap the Lower Liassic platform deposits (INI); close-up of the faulted massive Upper Cretaceous megabreccias (AMM_1 in light green), that onlap and abut, in buttress unconformity, the faulted Lower Liassic peritidal limestones (fault planes in red). (8). View of a quarry front, showing the Mesozoic Trapanese succession at Montagna Grande (Segesta), where several paleofaults dissect the Lower Jurassic peritidal limestones of the Inici Formation; the latter is followed by blackish hardground crusts, in turn, sealed by the pelagic limestones of the Rosso Ammonitico (Buccheri formation); (9) view of the southern slope of Rocca Busambra, where the sub-horizontal beds of the peritidal limestones of the Inici Formation are cut by a dense network of sub-vertical neptunian dykes filled by red crinoidal calcarenites and red Bositra limestones pertaining to the lower member of the Buccheri formation; (10) close-up of Fig. 9, showing the neptunian dykes and their filling materials; (11) sub-vertical neptunian dyke, cutting the peritidal limestones of the Inici Formation, and filled by various generations of sediments comprising the red pelagic deposits of the Buccheri and Amerillo formations and the green Lower Miocene glauconitic Corleone calcarenites (Rocca Argenteria, Rocca Busambra).

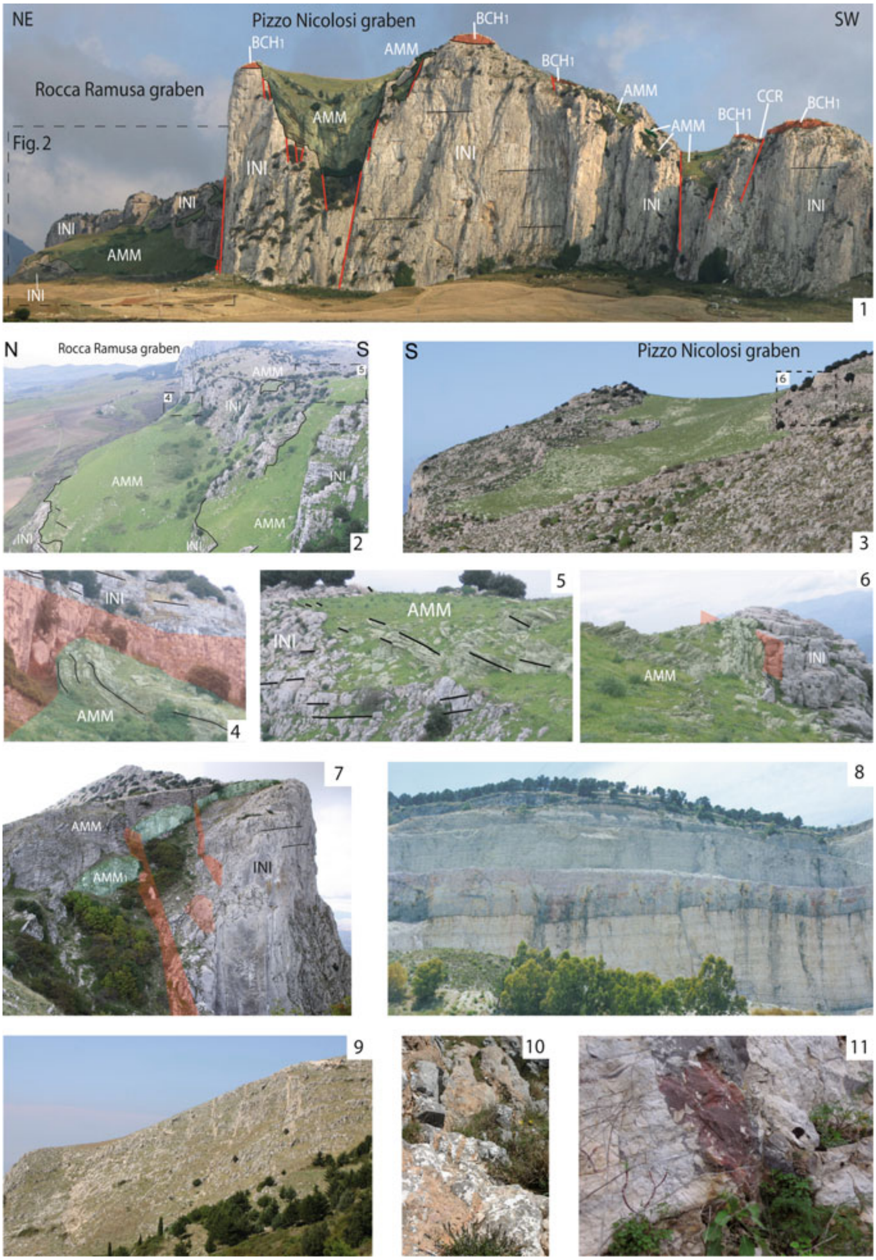
NE
Pizzo Nicolosi graben
BCH1
SW
AMM
Rocca Ramusa graben
Fig. 2
INI
CCR
1
N
Rocca Ramusa graben
S
2
S
Pizzo Nicolosi graben
3
4
5
6
7
AMM1
8
9
10
11

Plate 22. Characteristic facies of the deep-water Upper Triassic deposits of the Mufara (Figs. 1–4) and Scillato (Figs. 5–8) Formations: (1) strongly deformed thinly-bedded calcilutites of the Upper Triassic Mufara Formation (Contrada Casale, southern slopes of Rocca Busambra); (2) wackestone-packstone with halobids and radiolarians of the Mufara Formation; the bivalve shells are aligned at the base of the layers, due to uniform, sea-bottom, currents (Cozzo Tondo, north of Rocca Busambra, scale bar 1 mm); (3) mudstone-wackestone with radiolarians, ammonites and pelagic pelecypods (core 24: 2724.9–2727.3 m, Platani 2 well, PPL, scale bar 2 mm); (4) intra-bioclastic and oolitic fine packstone intercalated in the mudstone-wackestone beds of the sample of Fig. 3 (core 26: 3052–3056 m, Platani 2 well, PPL, scale bar 1 mm); (5) brown wackestone-packstone with radiolarians and pelagic pelecypods (cutting 1740–1743 m, Platani 2 well, PPL, scale bar 0.4 mm); (6) bioclastic and intraclastic (shallow-water derived fragments) grainstone and coral boundstone fragments (core 5, 3067.5–3076 m, Creta 1 well, PPL, scale bar 2 mm); (7) dolomitized calcareous breccias with elements of pelagic mudstone with radiolarians (cores 18–19, 2189–2182 m and 2192–2194 m, Platani 2 well, macroscopic samples, photograph field about 15 cm); (8) grey calcareous breccias with blackish clayey-marls pelagic clasts (core 19, 2192.6–2194.1 m, Platani 2 well, PPL, scale bar 0.4 mm).

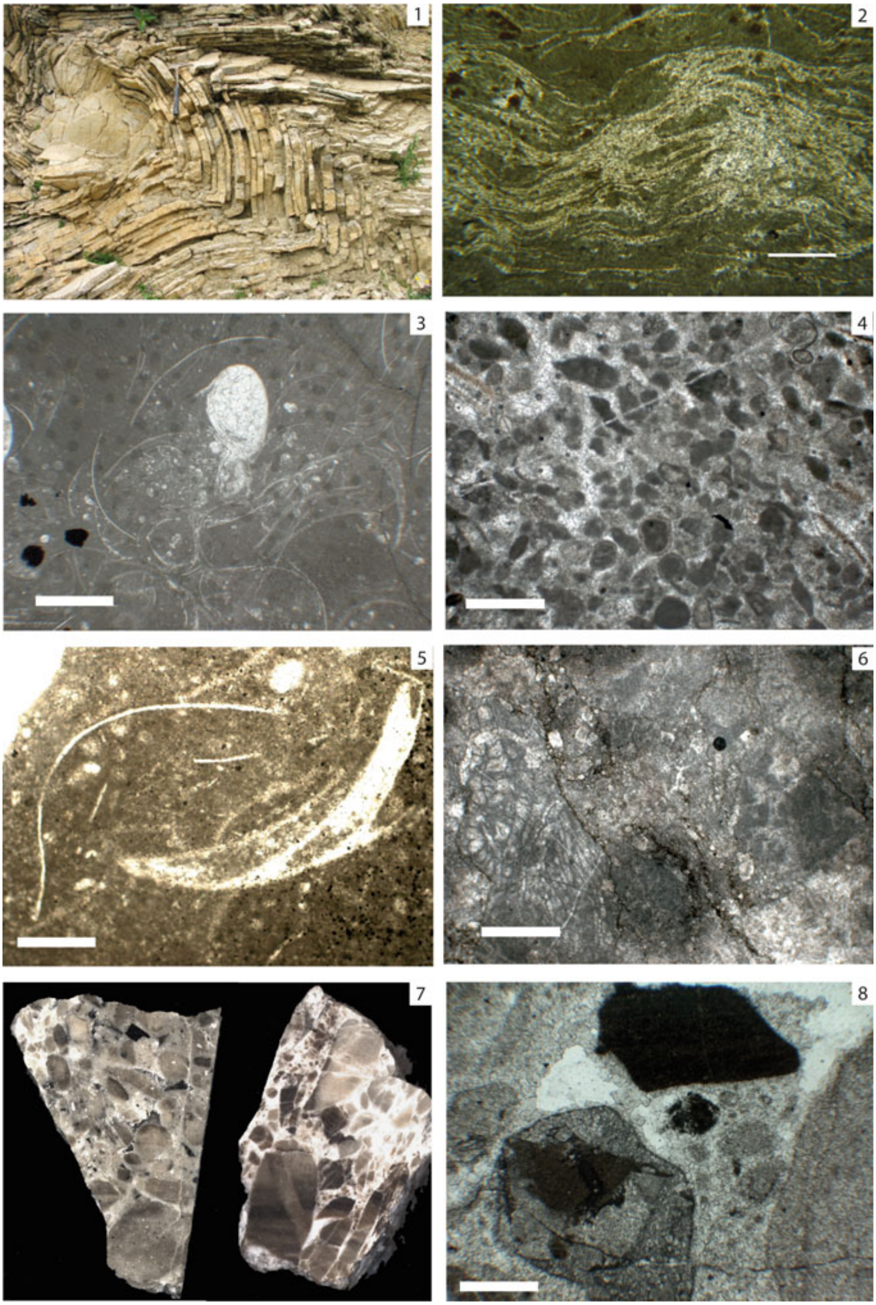
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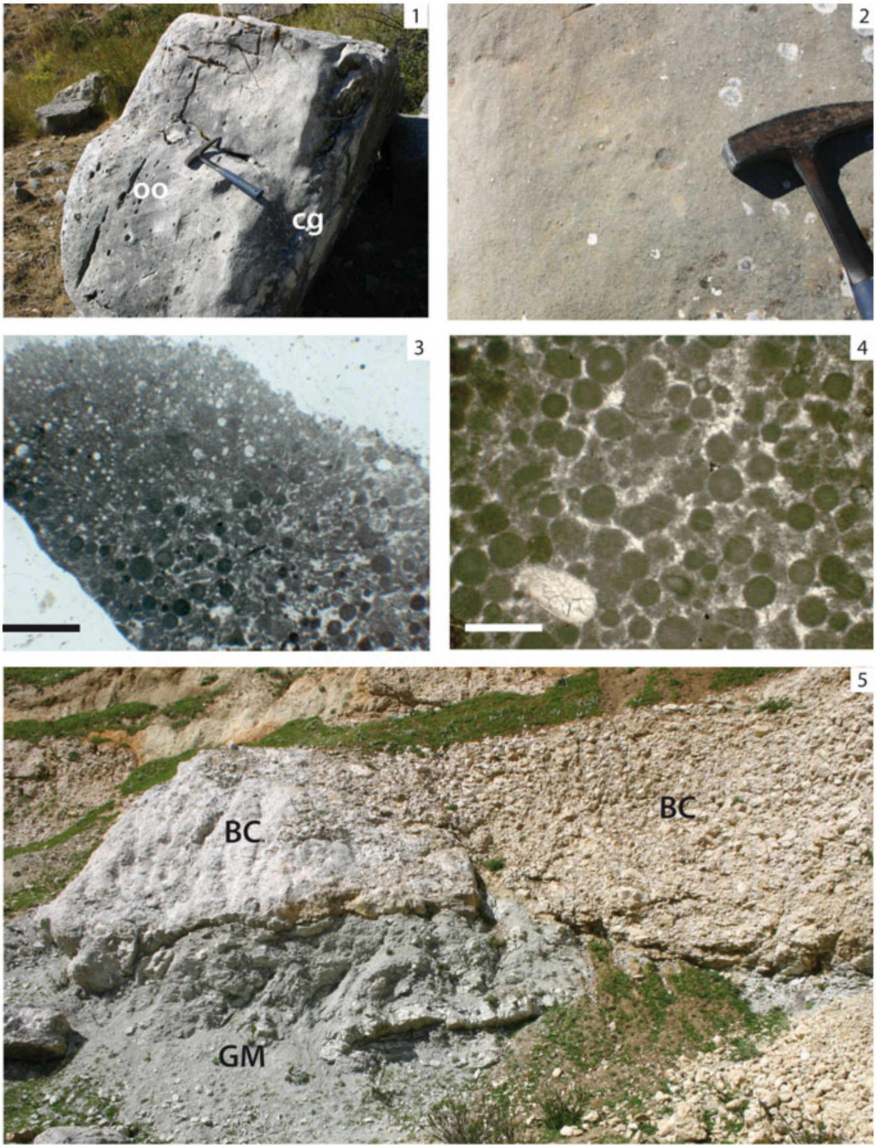
Plate 23. Characteristic facies of the Lower Jurassic oolitic limestones and belemnitic conglomerates. (1) thick bed of calcareous conglomerates (cg) changing to oolitic calcarenites (oo) (Monte Cammarata, Sicanian Mountains); (2) calcarenites with large oolitic grains and bioclasts; (3) oolitic packstone/grainstone (cutting, 1666–1664 m, Platani 2 well, PPL, scale bar 1 mm); (4) oolitic grainstone (cutting, 1691–1694 m, Platani 2 well, PPL, scale bar 0.5 mm); (5) outcrop photo showing the belemnitic conglomerates (BC) and the underlying eroded green marls (GM) (Pizzo Lupo, E Sicanian Mountains).


1
oo
cg
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4
5
BC
BC
GM

Plate 24. Typical facies characteristics of the Upper Cretaceous, shallow-water limestones of the Pellegrino formation: (1) massive beds of grey-blackish calcilutites and fine calcarenites rich in rudistid shells and fragments (Rocca di Cefalù); (2) rudistid reef limestone (Monte Sparagio, San Vito Lo Capo Mountains); (3) thick bed of grey wackestone with algae and molluscs with intercalations of floatstone with large shells and fragments of rudistids; the mollusc shells are oriented along the bed surface, suggesting the action of sea-bottom paleocurrents (Monte Gallo, Mondello); (4) radiolitid boundstone. The intrareef cavities are filled by whitish micrite (Raffo Rosso, Monte Castellaccio, eastern Palermo Mountains); (5) thin section of the reef lithofacies of the Pellegrino formation; these rocks are rich in rudistid shells, showing the typical laminated structures. Calcite cements fill intrareef cavities and post-diagenetic fractures (Monte Sparagio, San Vito Lo Capo Mount, scale bar 1 mm); (6) grainstone with benthic foraminifera (*Orbitolina* sp.), rudistids, algae and crinoid fragments (Pizzo Mollica, Monte Castellaccio, eastern Palermo Mountains, scale bar 1 mm). (7) grainstone with *Orbitolina* sp., large rudistid fragments, crinoids (Monte Gallo, Mondello, scale bar 1 mm); (8) oolitic and bioclastic grainstone; the oolite grains are coated by thin laminae (surficial oolite) and, frequently, they are broken and reworked. Intraclasts, benthic foraminifers and algae are present (Raffo Rosso, Monte Castellaccio, eastern Palermo Mountains, scale bar 1 mm).

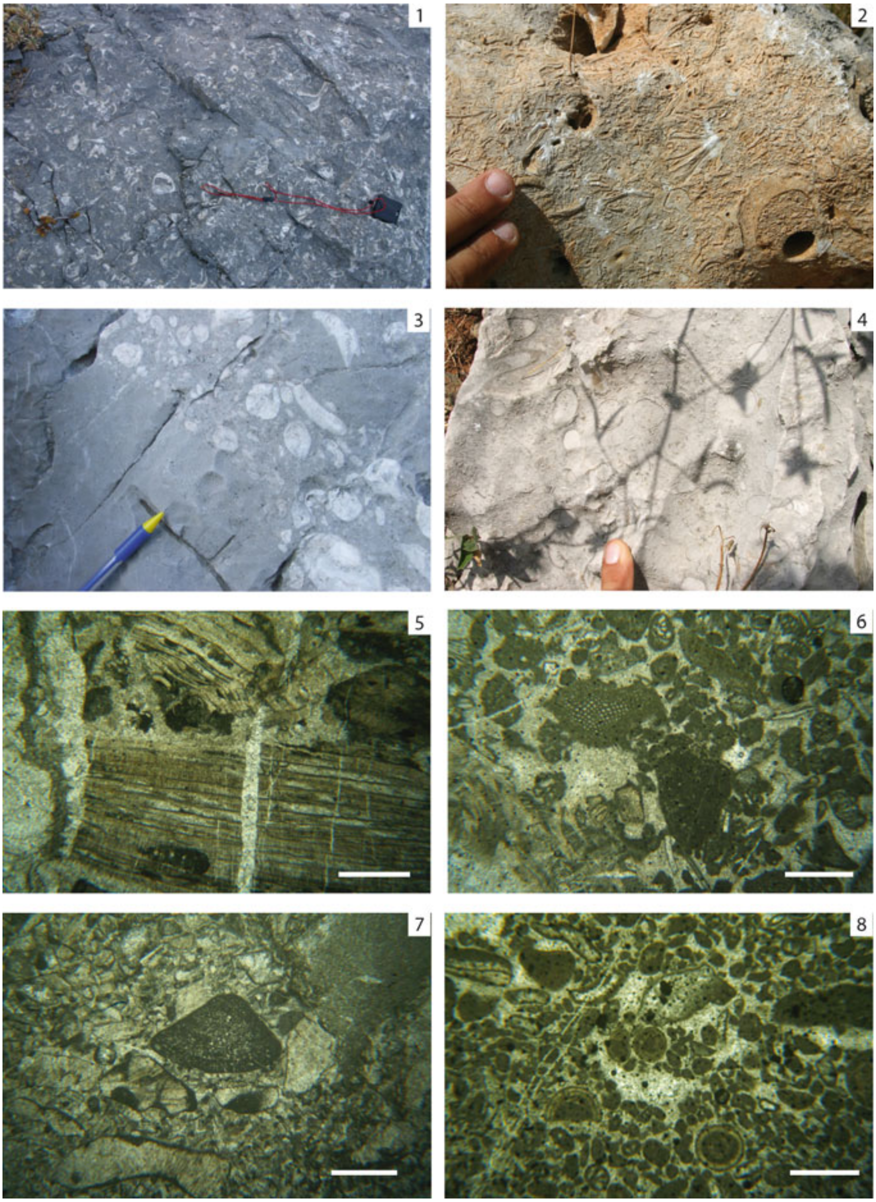
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Plate 25. Field images of the outcropping lithofacies of the Piano Battaglia reef limestone and the Pizzo Manolfo limestone: (A) wackestone–packstone with *Nerinea* sp. (n), large oncoids (o), bioclasts (FA1a, Castellaccio section); (B) small coral framestone (patch reef) interlayered in the subtidal limestone of FA1a (Castellaccio section); (C) mm-sized loferitic laminae (FA1b) with fractures filled by white vadose silt (desiccation cracks) and in situ breccias (flat pebble breccias, FA1c, Castellaccio section); (D) densely packed gastropods (*Nerinea* sp.) bearing wackestone (FA2b, Giglio section). The mollusc shells, showing geopetal structures, are filled by white vadose silt and capped by calcite cement; (E) carbonate breccias (FA3d, Acapulco section), whose elements deriving from the erosion of the underlying oolitic grainstone lithofacies (o, FA3c) and bioclastic mudstone lithofacies (m, FA3a); (F) wackestone with large diceratids (white arrows, FA4a, Torretta outcropping site); (G) oolitic grainstone (FA4c, Colombrina section); (H) facies sequence of the FA5 (Carini section), where the reef-derived breccias (FA5a), cutting with erosion a packstone–grainstone with oolite and bioclasts, are followed upwards by coarse-grained bioclastic grainstone (FA5b) and by oolitic grainstone (FA5c); (I) large colonial corals in life position (FA6a, Longa section); (J) boundstone with corals (c) enveloped by microbialites (m) and intrareef cavities filled by sparry calcite (cc, FA6b, Pecoraro section); (K) densely packed mound-shaped *Ellipsactinia* sp. boundstone (FA6b, Pecoraro section); (L) intra-reef cavities filled by white vadose silt (v) and bordered by rim-cements (c) characterizing the reef limestone with *Ellipsactinia* sp. (e, FA6b, Pecoraro section).

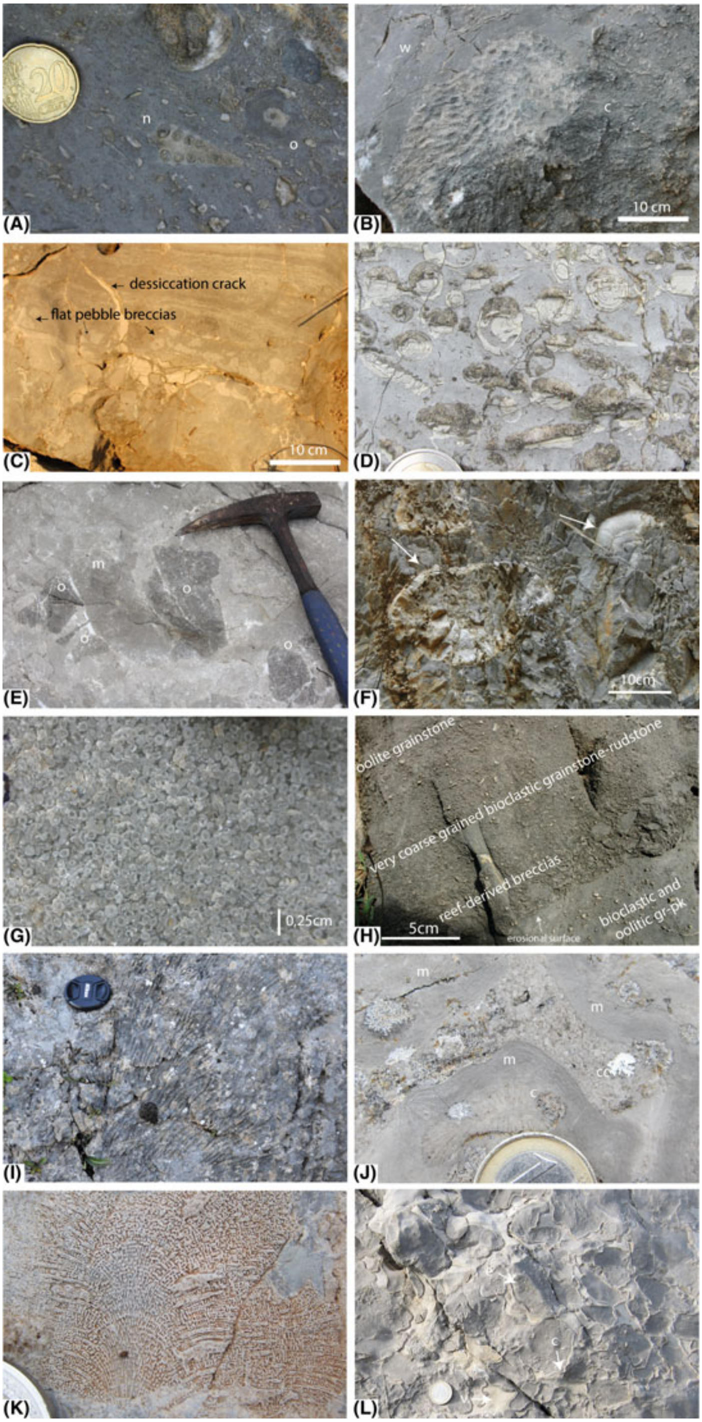
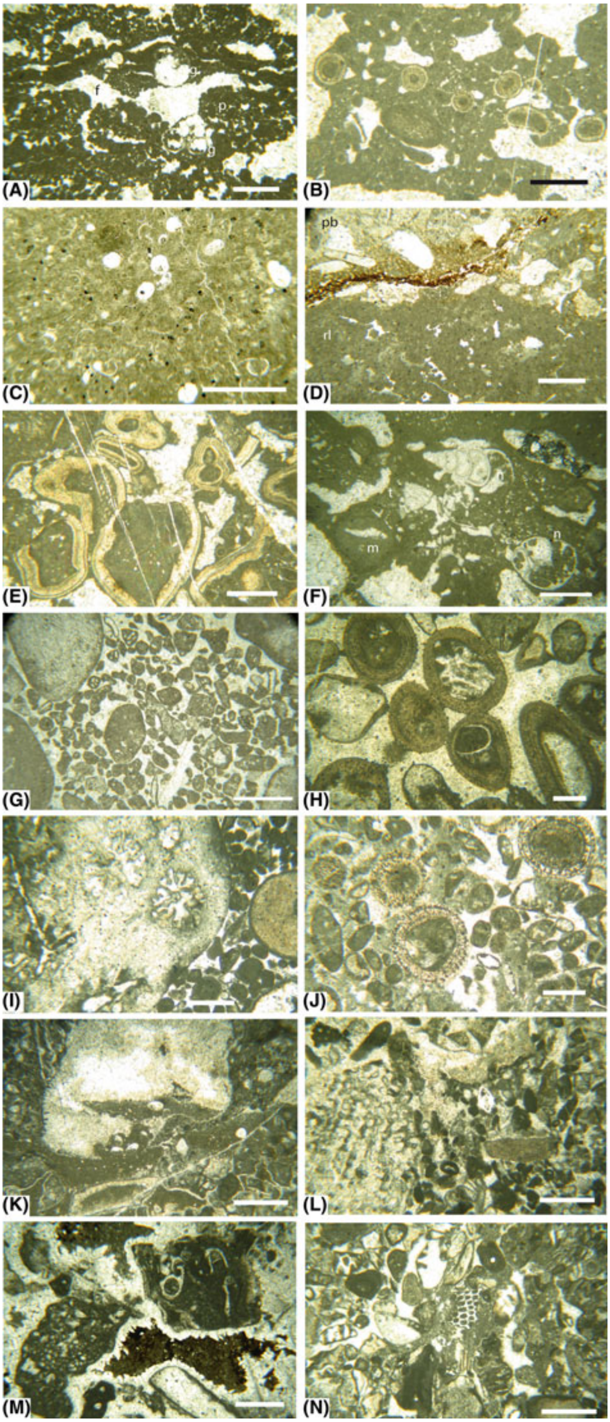

(A)
n
o
(B)
w
c
10 cm
(C)
dessiccation crack
flat pebble breccias
10 cm
(D)
(E)
m
o
(F)
10cm
(G)
0,25cm
(H)
oolite grainstone
very coarse grained bioclastic grainstone-rudstone
reef-derived breccias
bioclastic and oolitic gr-pk
erosional surface
5cm
(I)
(J)
m
c
(K)
(L)
c

Plate 26. Microfacies from the Upper Tithonian–Valanginian shallow-water carbonates outcropping in the Palermo Mountains (scale bars are 1 mm): (A) fenestral (f) packstone with peloids (p) and small gastropods (g, FA1b, Castellaccio section); (B) peloidal and bioclastic packstone with radial-fibrous ooids (FA3a, Castellaccio section); (C) mudstone with partly disarticulated ostracod shells (FA2a, Giglio section); (D) erosional ravinement surface, marked by reddish ferromanganese crust, separating the low-energy restricted lagoon deposits (rl) by the pebbles breccias (pb) of the upper cycle (FA2, Giglio section); (E) oolitic grainstone–packstone with large ooids, frequently broken and eroded. Compaction deformation is also visible (FA3c, Acapulco section); (F) wackestone with small nerineids (n), algae, benthic foraminifers (*Trocholina* sp. (t), miliolids, textularids), micro-encrustants (m), mollusc fragments (FA4a, Colombrina section); (G) bioclastic packstone with large philloyd-type algae and mollusc fragments, benthic foraminifers, crinoids, and intraclasts (FA4b, Colombrina section); (H) grainstone with tangential ooids slightly micritized (FA4d, Colombrina section); (I) intraclastic and bioclastic breccias and coarse grainstone with *Scleractinia*, gastropods, benthic foraminifers, crinoids (FA5a, Carini section); (J) bioclastic and oolitic grainstone with broken and strongly micritized ooids showing tangential structure. The nuclei of the ooids are reef-derived bioclasts and *Bacinella* sp. fragments (FA5c, Carini section); (K) coral framestone. The intra-reef cavities, bordered by fibrous calcite, are filled by reddish pelagites with thin-shelled molluscs, which are in their turn filled by vadose geopetal silt and later sparry calcite (FA6a, Longa section); (L) *Ellipsactinia* sp. boundstone. The intra-reef debris consists of grainstone–packstone with *Protopeneroplis* sp., algae (*Cayeuxia* sp., *Rivularia* sp., *Salpingoporella* sp.), intraclasts and mollusc fragments (FA6b, Pecoraro section); (M) reef-derived breccias with intra-reef cavities bordered by scalenohedral dogthoot cements and filled by reddish pelagic limestone with planktonic foraminifers (FA7a, Pecoraro section); (N) well-sorted and rounded fine-grained grainstone with abundant Ellipsactinia sp. and Cayeuxia sp. fragments, benthic foraminifers, thin-shelled molluscs, bryozoans, echinoids, crinoids, frequently enveloped by thin calcite film (FA7b, Tondo section).


(A)
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(K)
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(M)
(N)

Plate 27. Typical facies of the Upper Triassic deep sea deposits of the Scillato formation: (1) Monte dei Cervi ramp anticline (western Madonie Mountains), showing about 500 m of thickness of thin bedded cherty limestone succession (Scillato formation). The structure is heavily deformed with folds and listric normal faults, NE–SW oriented, that downthrow the structure towards the northern sectors; (2) grey limestones with thick cherty beds and planar-to-undulate laminations, suggesting the action of sea-bottom currents during the deposition; (3) thin-bedded grey limestones with cherty nodules (Monte Barracù, western Sicanian Mountains); (4) cherty limestones with pseudo-nodular texture (Monte Cammarata, eastern Sicanian Mountains); (5) prograding parasequence cycles in the upper portion of the upper Triassic Scillato formation limestones (a), consisting of several simple cycles represented by regular alternations of mudstone-wackestone and vari-coloured clays (b); at the base of the succession a reworked bed, consisting of intraclastic rudstone-grainstone, is present (Monte San Calogero, Termini Imerese Mountains); (6) clast-supported pebbly conglomerates, with yellowish sandstone matrix (Monte San Calogero succession, Termini Imerese Mountains); (7) wackestone with radiolarians and bivalve shells (*Halobia* sp.), scale bar 2 mm; sample collected in the lower portion of the Monte San Calogero succession (Termini Imerese Mountains); (8) intraclastic and bioclastic grainstone-packstone, whose elements consist both of shallow-water derived black clasts, made up of micrite with crinoidal fragments and peloids, and deep-water derived grey limestone clasts with radiolarian (thin section of a sample collected from Creta1 well, AGIP, sited in the eastern Sicanian Mountains).

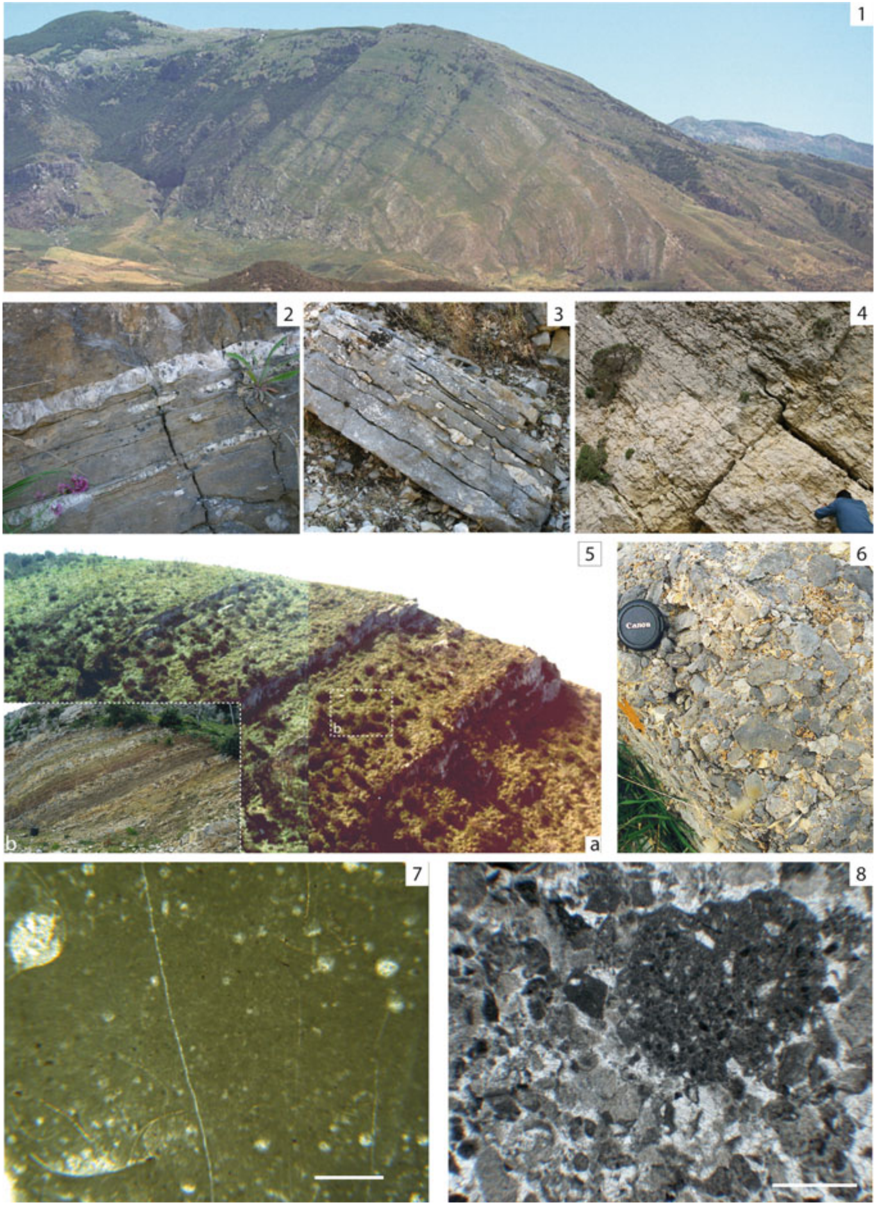
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Plate 28. Typical facies of the Oligo-Miocene shales and arenaceous strata of the Numidian flysch and Tavernola formations: (1) the two pictures display the whole Bouma sequence of a turbiditic bed of the Geraci Siculo member (Numidian flysch formation), consisting of graded conglomerates with quartz pebbles and laminated arenaceous layers; in the arenaceous bed, planar, oblique, ripple and convolute laminations, occur (Alia region); (2) clays with ferruginous oxides of the Portella Colla member of the Numidian flysch formation (Pizzo Candreo, Campofelice di Fitalia); (3) detail of an arenaceous layer interlayered in the quartzitic clays of the previous picture, showing an incomplete turbiditic facies sequence (Tc-e of Bouma); (4) quartz-conglomerates lithofacies interbedded in the quartzitic sands and arenites of the Geraci Siculo member of the Numidian flysch formation (Cozzo Tondo, north-east of Pizzo Marabito, Rocca Busambra); (5) erosional relationships between quartz pebbles conglomerate facies (of the previous picture) and the quartzitic siltstone interlayered; (6) detail of picture 4, showing the coarse quartz conglomerate grains and their clast-supported texture; (7) limestone with large bivalve shells, pertaining to “Lucina limestones level” of the Tavernola formation (Erbe Bianche, Roccapalumba, PA); (8) quartzitic and glauconitic sandstones with bioturbations of the Arcivocalotto sandstones lithofacies of the Tavernola formation (Arcivocalotto Mount, Roccamena).

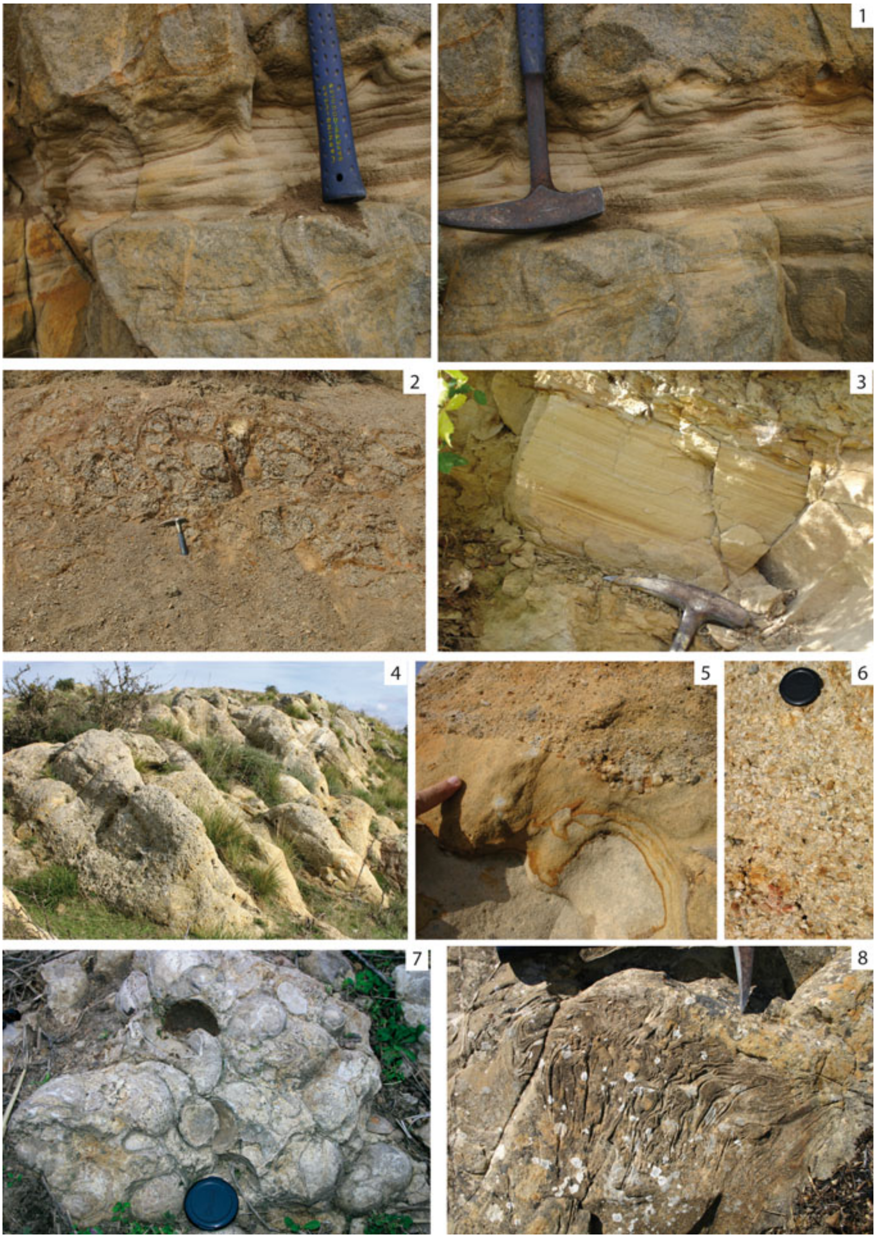
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Plate 29. Typical facies of the Middle, Upper Miocene-Pliocene terrigenous, clastic, carbonate and evaporitic deposits: (1) typical conglomeratic rock texture of the lower member of the Terravecchia formation (TRV_1); the elements of the conglomerate consist, mainly, of glauconitic limestones derived from the dismantling of the lower Miocene Corleone calcarenites, welded by quartz-calcareous sands (Cozzo Riddocco, Campofiorito town, Sicani Mountains); (2) well-cemented sandstones of the sand member of the Terravecchia formation (TRV_2), with ripple structures (Scillato basin, Madonie Mountains); (3) white-yellowish diatomite marly limestones and marls of the Tripoli (Aragona); (4) yellowish marly limestones of the Tripoli, characterized by planar and undulate laminations (Palma di Montechiaro); (5) massive selenite gypsum of the selenitic member of the Cattolica Formation (Monte Giammaria, Roccamena,); (6) whitish laminated gypsum pelites of the gessoarenites member of the Pasquasia Formation (Contrada Quattro Finaite, Grotte); (7) grey-yellowish clayey marls with bivalve rests of the Enna marls (Monte Capodarso); (8) clinoforms and toplap geometries in the parasequences of the calcareniti di Capodarso (Monte Capodarso).

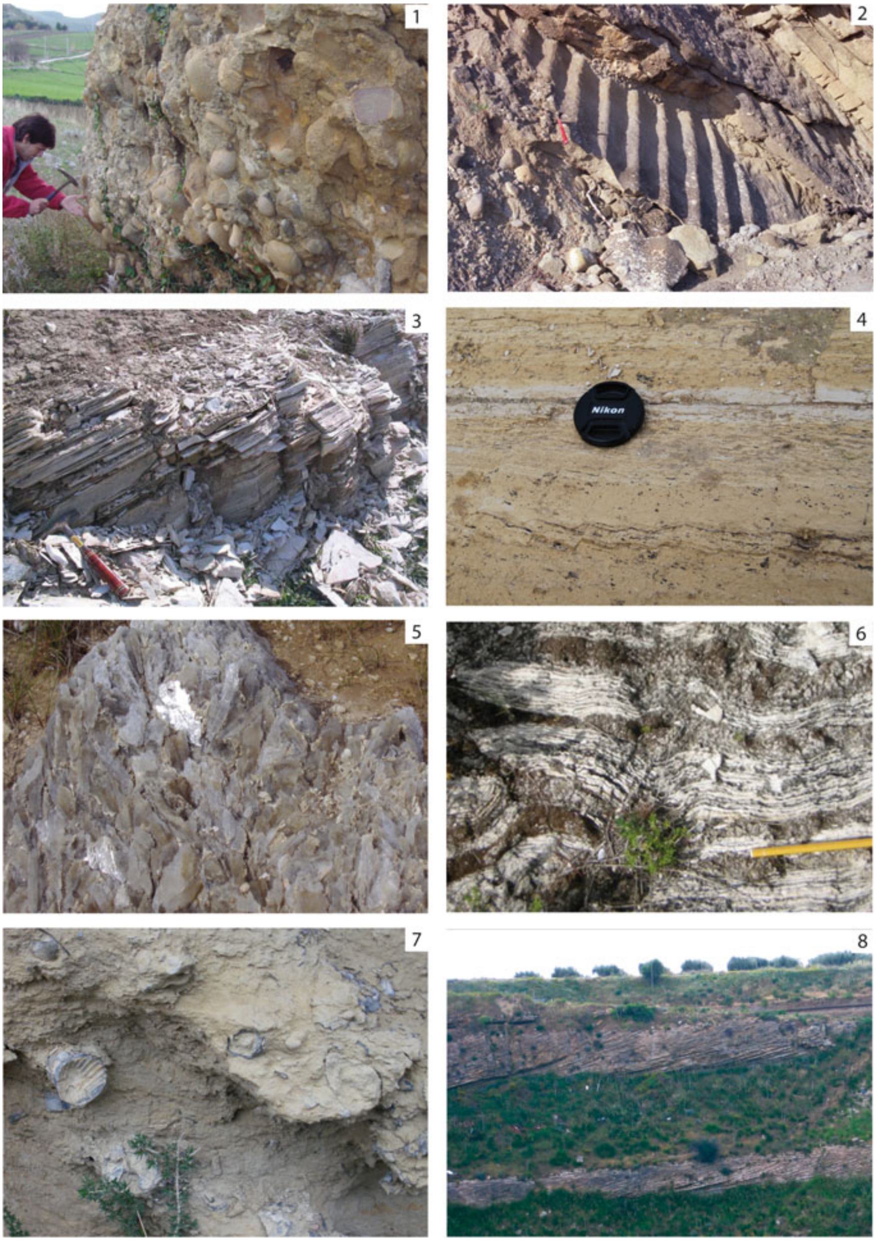
1
2
3
4
Nikon
5
6
7
8

Plate 30. Stratigraphy and facies of the Barcarello synthem (SIT). (1) Columnar type section of SIT measured and sampled at Barcarello (see index map of Fig. 2.98 for location). Legend: 1. Middle Pleistocene aeolian sands of the Polisano synthem (BLT); 2. very coarse sands and calcarenites with *Strombus bubonius*; 3. bioclastic coarse-to-fine calcarenites with intercalations of continental scree; 4. very coarse sands and calcarenites with corals, bivalves, gastropods; 5. marine sandy clays; 6. well-cemented stratified slope deposits of the Raffo Rosso synthem (RFR). (2) Cross-laminated bioclastic calcarenites (Sferracavallo, see Fig. 2.98). (3) Well-cemented conglomerates and reddish calcarenites with an exemplar of *Strombus bubonius* (Macari coastal plain). (4) Line drawing of the Sferracavallo natural section (see the index map of Fig. 2.98) illustrating different lithofacies and stratigraphic relationships. (5) Reddish calcarenites and breccias (SIT) unconformably covering the Mesozoic carbonates (Mz) at Barcarello outcropping site. (6) Reddish burrowed sands, followed with erosion by well-cemented and laminated foreshore coarse calcarenites (Sferracavallo outcropping site).

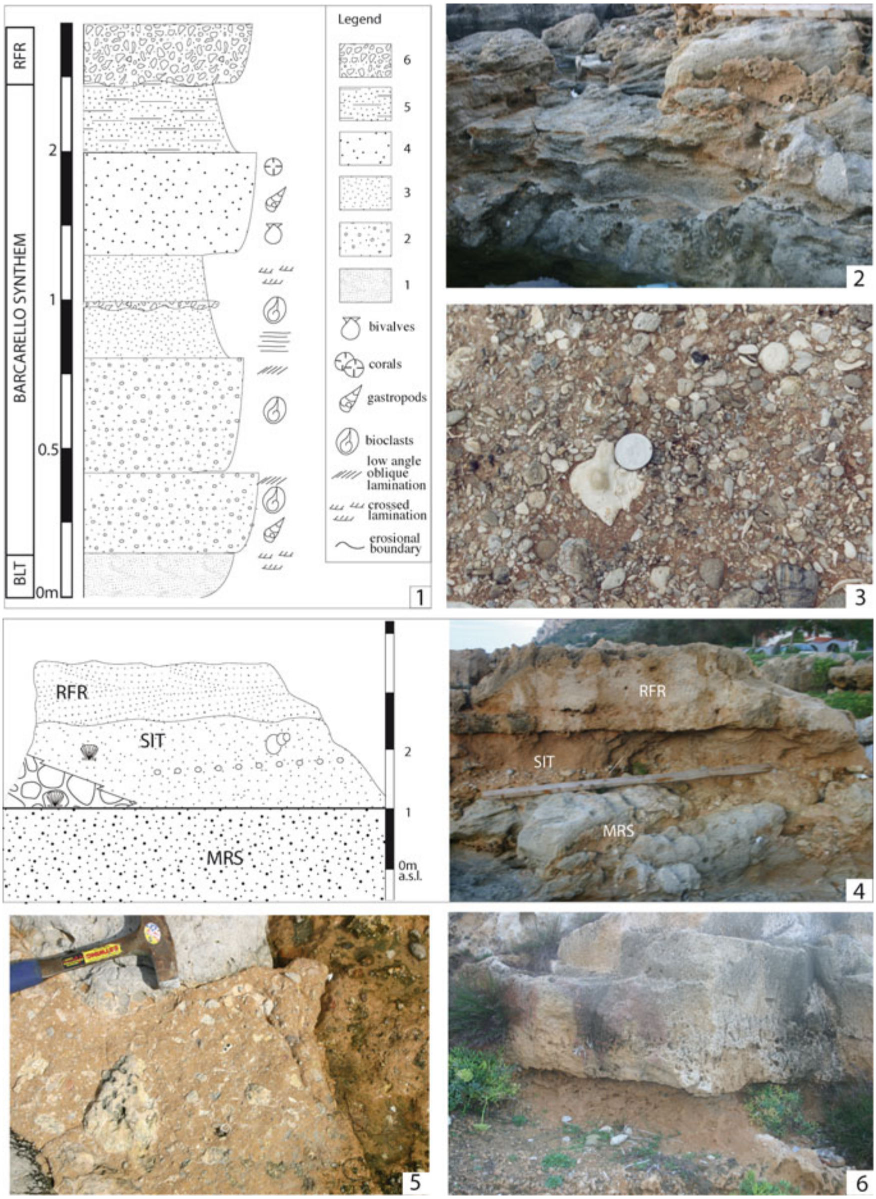
RFR
BARCARELLO SYNTHEM
BLT
0m
0.5
1
2
Legend
6
5
4
3
2
1
bivalves
corals
gastropods
bioclasts
low angle oblique lamination
crossed lamination
erosional boundary
1
2
3
RFR
SIT
MRS
0m a.s.l.
1
2
RFR
SIT
MRS
4
5
6

Plate 31. Stratigraphy and facies of the coastal-to-marine deposits of the Marsala synthem (MRS). (1) Type section of the MRS measured and sampled along the valley of the Jato River (Balestrate, see index map of Fig. 2.98 for location). Legend: 1. Upper Pliocene clays, marls and arenaceous turbidites (BLC); 2. calcareous conglomerates; 3. coarse to fine bioclastic sands and clayey sands; 4. well-cemented bioclastic calcarenites; 5. clay siltstone with planktonic foraminifers; 6. marine terrace deposits of the SNP. (2) Intensively bioturbated clayey sands (lower shoreface facies) (Balestrate). (3) Planar-bedded well-cemented calcarenites alternated with massive bioturbated sands (Balestrate). (4) Well-cemented calcarenites rich in pectinids (foreshore facies) (Punta Raisi, see index map of Fig. 2.98 for location). (5) Angular unconformity between the MRS and the deformed Mesozoic carbonates (Mz) and Cenozoic clays (Cz) at the Punta Raisi section (see index map of Fig. 2.98 for location).

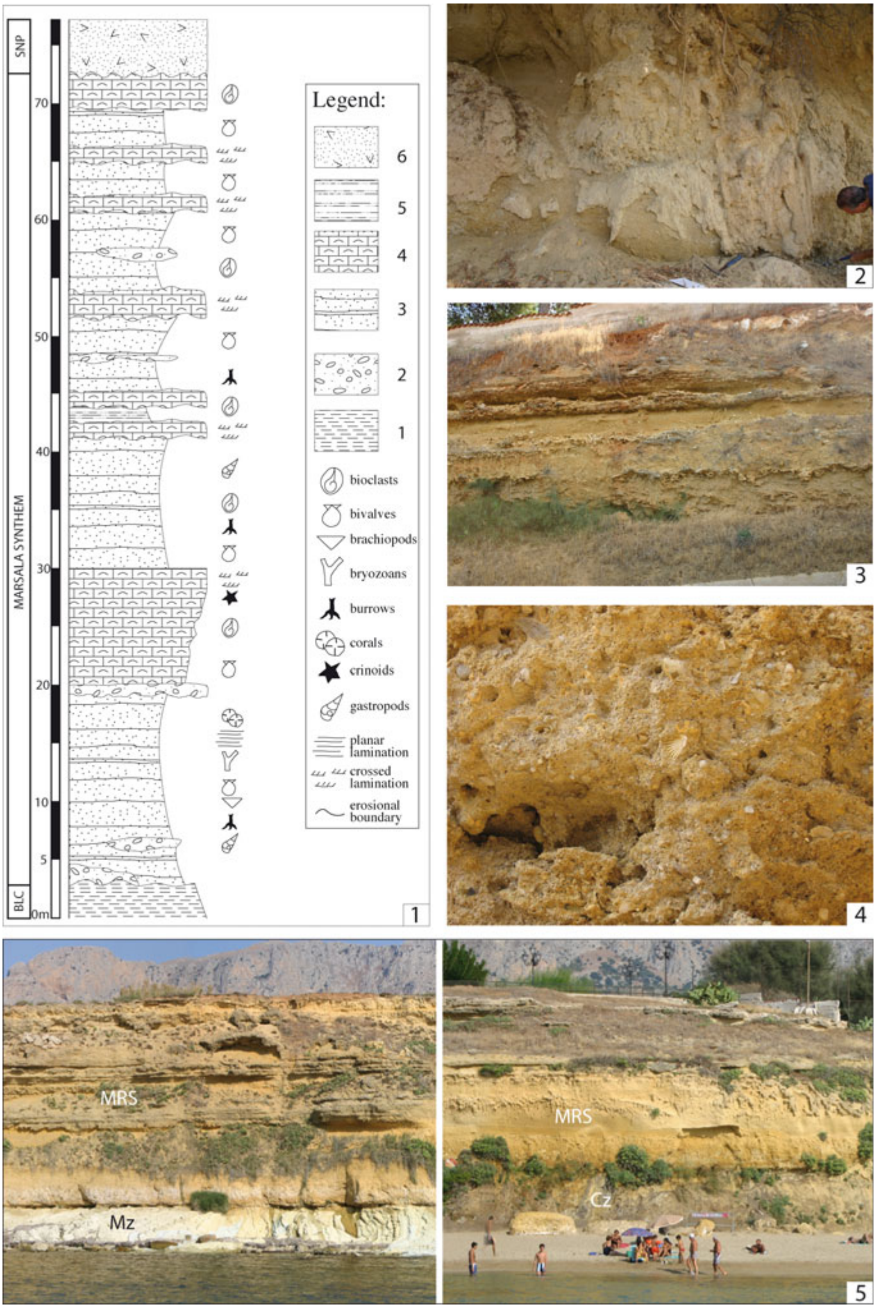
SNP
MARSALA SYNTHEM
BLC
70
60
50
40
30
20
10
5
0m
Legend:
6
5
4
3
2
1
bioclasts
bivalves
brachiopods
bryozoans
burrows
corals
crinoids
gastropods
planar lamination
crossed lamination
erosional boundary
1
2
3
4
MRS
Mz
MRS
Cz
5

Plate 32. Stratigraphy and facies of the aeolian sandstones of the Polisano synthem (BLT). (1) panoramic view of the natural type section of BLT at Macari coastal plain (see index map of Fig. 2.98 for location) and lower unconformity (white line) with the marine deposits of the Marsala synthem (MRS). (2) columnar type section of the Polisano synthem. Legend: 1. Lower Pleistocene calcarenites with pectinids of the Marsala synthem; 2. marine calcarenites and 3. cemented conglomerates of the Buonfornello synthem (SNP); 4. planar- and 5. cross-bedded aeolian sandstones with continental gastropods (BLT); 6. Holocene soils and eluvial deposits of the AFL synthem. (3) Aeolian obstacle dune of BLT, located at the foot of carbonate massif, where planar- and cross-stratification dip seawards (Palmeto Mount, Terrasini, see Fig. 1). (4) Burrowed reddish aeolian calcareous sandstones forming the basal bed of the BLT stratal succession at Macari coastal plain. (5) Landward dipping cross-laminated aeolian calcarenites (Macari coastal plain). (6) Ripples and cross-lamination characterising the BLT deposits (Mondello outcropping site, see index map of Fig. 2.98).

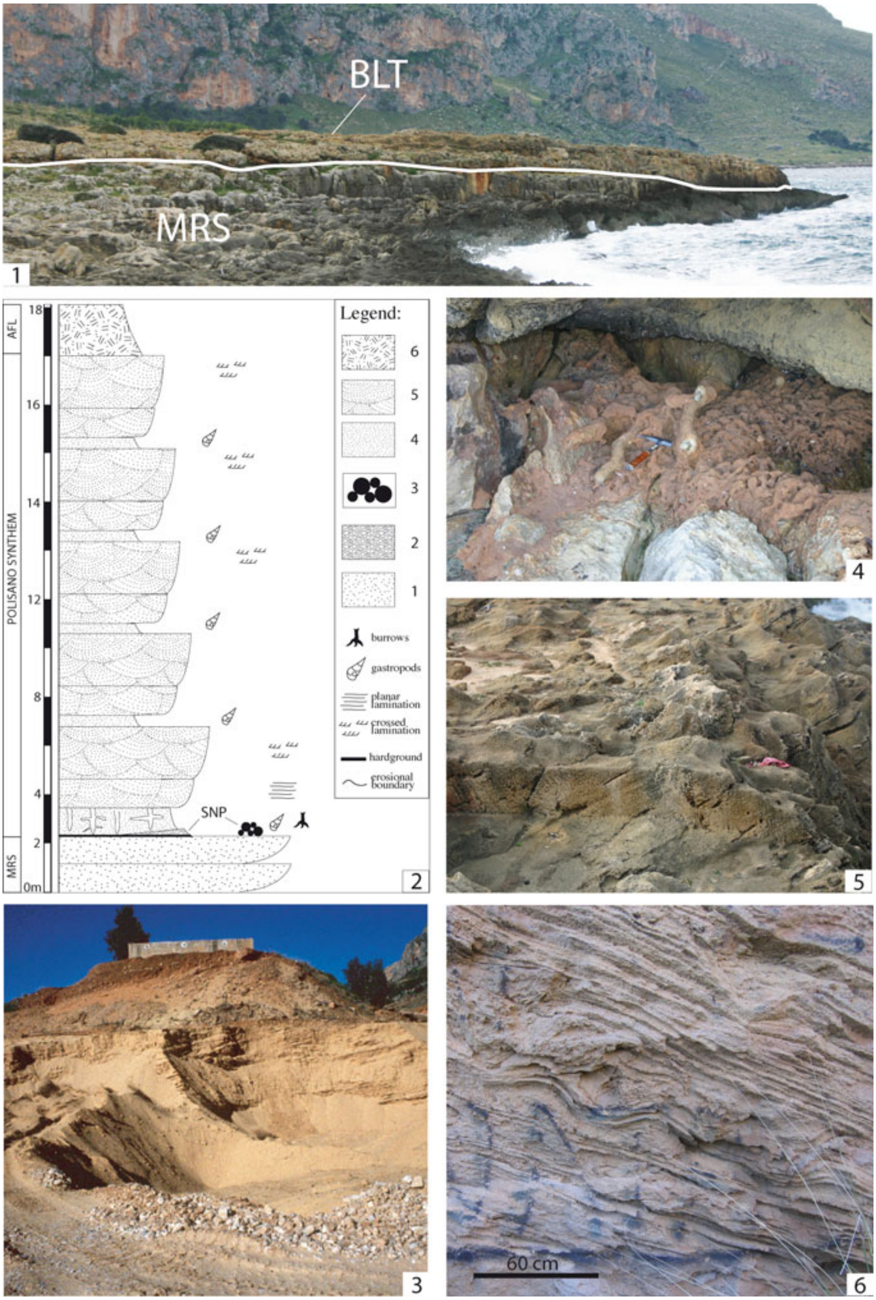
BLT
MRS
1
AFL
POLISANO SYNTHEM
MRS
18
16
14
12
8
4
2
0m
SNP
Legend:
6
5
4
3
2
1
burrows
gastropods
planar lamination
crossed lamination
hardground
erosional boundary
2
4
5
3
60 cm
6

Plate 33. Stratigraphy and facies of the Raffo Rosso synthem (RFR). (1) Panoramic view of the natural type section of the Raffo Rosso synthem (Capo Gallo, see index map of Fig. 2.98 for location). (2) Columnar type section of RFR. Legend: 1. Upper Pleistocene (Tyrrhenian) bioclastic conglomerates and calcarenites of the Barcarello synthem (SIT); 2. mud-supported fine breccias; 3. well-cemented coarse breccias; 4. paleosoils; 5. soil and debrites of the Capo Plaia synthem (AFL); 6. normal (a) and reverse (b) gradational structures. (3) Well-cemented stratified debrites cyclically alternated with mud supported fine breccias. (4) Paleo-soil (pa) interlayered into the well-cemented and stratified breccias (csb). (5) Lower boundary of the Raffo Rosso synthem (RFR), marked by red paleo-soil (pa), with the continental lithofacies of the Barcarello synthem (SIT). All the photos come from the Capo Gallo outcropping site (see index map of Fig. 2.98).


1
2
AFL
RAFFO ROSSO SYNTHEM
SIT
12
10
8
6
4
2
0m
a
b
6
5
4
3
2
1
3
csb
pa
csb
4
RFR
pa
SIT
5