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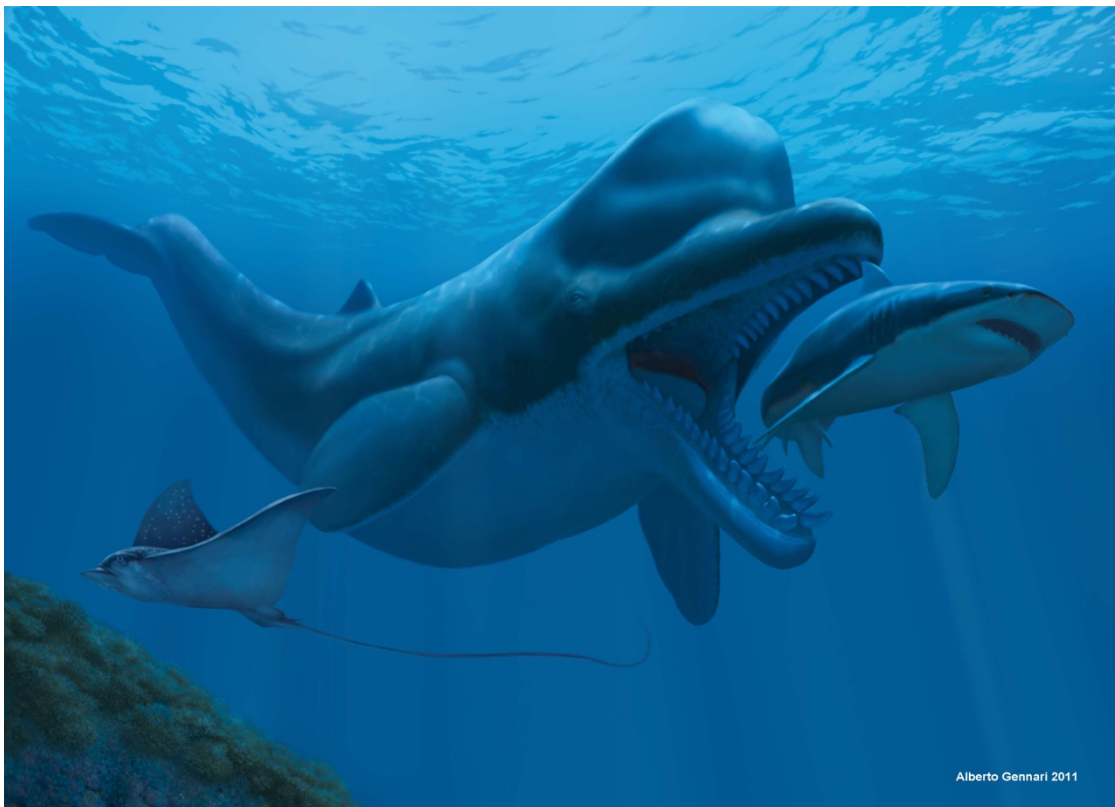
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INTRODUCTION

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The Salento Peninsula is the southernmost part of the Apulia region; it stretches for about 120 km in NW–SE direction between the Ionian and the Adriatic Seas. At present, the Salento Peninsula comprises the administrations of three main cities, Taranto, Brindisi and Lecce, with a population of about 1,800,000 people. The Peninsula is an outcropping portion of the Apulia Carbonate Platform, which represents one of the carbonate platforms developed along the southern margin of the Tethys Ocean since the Triassic. This NW-SE oriented platform is about 650 km long and 180 km wide and consist of a 5 to 7 km thick Meso-Cenozoic undeformed carbonate succession that develops in emerging and submerged areas. The Apulian Platform occupies the southern end of the Adria microplate which is generally considered to be the northern promontory of the African plate. The Salento Peninsula together with its submerged portion offshore of the Ionian Sea (Apulian swell) constitutes the foreland of the SW-verging Dinarides-Albanides-Hellenides and the NE-verging Southern Apennines verging SW. From a structural point of view, the Salento Peninsula represents the culmination of a lithospheric anticline, about 100 km wide, affected by E-W strike-slip faults in the northern sector and a NW-SE oriented extensional faults giving rise to a horst and graben systems. Most authors consider the migration of the two chains responsible for the extensional tectonic regime developed during the Pliocene and Pleistocene as well as for the significant block rotations as recognized in the Salento area. The Middle Pleistocene SW-NE extension was followed by the Late Pleistocene radial extension indicating a recent bulge of the foreland area.

Main tectonic phases occurred during the Eocene-Oligocene, the Middle Pliocene, and the Middle Pleistocene periods. The final uplift of the Apulia foreland started during the Middle Pleistocene, after general subsidence that took place in the Early Pleistocene period. The Salento Peninsula was marked by uplift rate strongly decreased at Marine Isotope Substage (MIS) 9.3, about 330 ka; since then, the highest uplift rates have been recorded in the Taranto area (about 0.25 mm/year), whereas they lower to zero in the southernmost part of the region. Finally, subsidence has affected the Peninsula's coast during the last four millennia, most likely due to present dome-like deformation of the region.

From the geomorphological point of view, Salento is a low elevated region attaining the maximum altitude of 195 m a.s.l. on the top of Serra di San Eleuterio morphostructural ridge. The Peninsula comprises five areas marked by a peculiar assemblage of landforms. The northeastern area, stretching between Brindisi and Lecce just to the south of the Soglia Messapica, is characterized by a low-elevated Middle Pleistocene sedimentary plain gently sloping from west to east. It is drained by a relict hydrographic network flowing toward the Adriatic coast (sector 1 in Fig. 1).

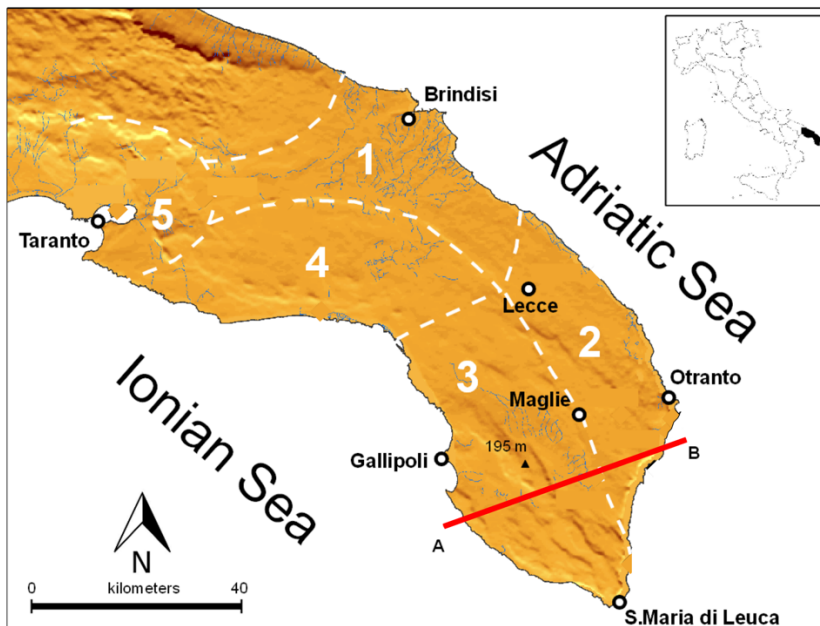


Fig. 1 Geographical position of Salento Peninsula. Dashed white lines separate the five main morphological districts that be detected in the Salento Peninsula landscape (modified from Mastronuzzi & Sansò, 2017).

The southeastern area, placed to the east of Lecce–Santa Maria di Leuca alignment (sector 2 in Fig. 1), emerged most likely at the beginning of the Pleistocene and is mostly shaped on pre-Quaternary carbonate rocks. Peculiar landforms can be observed: the Paleogene tropical karst surface on the top of morphostructural ridges (Capo d’Otranto, Serra di Montevergine, Serra di Poggiardo and Serra di Martignano) and tectonic depressions stretching from Roca to south. The widest of these depressions host the Alimini Lakes.

The mid-western area, roughly stretching to the west of Lecce–Santa Maria di Leuca alignment, (sector 3 in Fig. 1) emerged definitively during the Middle Pleistocene. It is marked by wide sedimentary plains interposed among NW–SE trending morphostructural carbonate ridges, the Serre (Fig. 2). The particular stratigraphic architecture allowed the development of a contact karst, where a hydrographic network brings surficial waters into a number of sinkholes.

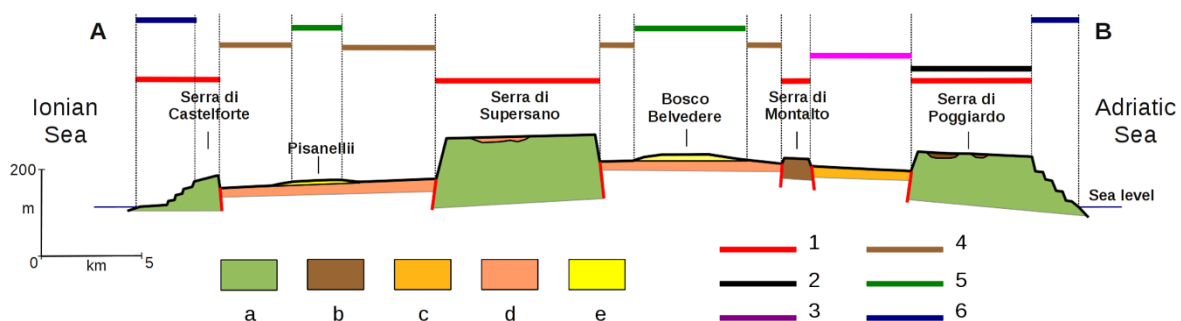


Fig. 2 Schematic geomorphological section of Salento Peninsula from the western to the eastern coast. The position of the section A-B is reported in Fig. 1. Legend: a) pre-Neogene units, b) Miocene units, c) Pliocene units, d) Early Pleistocene units, e) Middle-Late Pleistocene units, 1) morphostructural ridge, 2) Paleogene tropical karstic surface, 3) denudation surface shaped on Pliocene units, 4) Early Pleistocene karstic surface, 5) Middle-Late Pleistocene sediplain, 6) Marine terraces (modified from Sansò et al., 2015).

The Murge Tarantine (sector 4 in Fig. 1) is a singular landscape marked by a low-elevated, W–E oriented morphostructural ridge. Its northern limit is constituted by a low scarp of regional importance that in the surroundings of Oria village is marked by a long, elevated relict dune belt. Finally, the Taranto area (sector 5 in Fig. 1) is marked by a well-known sequence of Middle-Late Pleistocene sedimentary plains and marine terraces.

All around the Salento Peninsula, a low-elevated landscape made of several Pleistocene marine terraces bordered by differential erosion scarps and relict cliffs can be recognized. Its development has been strictly connected to repeated marine regression-transgression cycles produced by glacio-eustatic sea-level changes which have occurred since the Middle Pleistocene and were superimposed on the tectonic uplift of the region. Some of these terraces display a thin sedimentary cover composed of calcareous sandstones very rich in fossil remains (*panchina*), associated in some places with dune deposits, whereas others are only wave-cut platforms. Particularly interesting is the sequence of marine terraces recognizable along the coast from Taranto to Gallipoli formed during the Middle-Late Pleistocene. In fact, the lowest marine terrace is marked by the occurrence of a rich Senegalensis fauna marked out by specimens of *Persististrombus latus* (= *Strombus bubonius*).

From the geological point of view, the Salento Peninsula comprises a Variscan basement covered by a 3–5-km thick Mesozoic carbonate sequence (Calcari delle Murge unit) overlain by thin deposits of Cenozoic age (Fig. 3). A brief description of the lithostratigraphic units cropping out in the Salento Peninsula is reported below (Fig. 4).

1. Altamura limestone

This unit, about 1000 m thick, is the oldest outcropping formation of the Salento Peninsula (Campanian-Maastrichtian) and constitutes the substrate disconformably covered by Paleogene, Neogene, and Quaternary deposits. This formation is exclusively made up of shallow-water facies, referable to the internal part and to the high-energy margin of a platform. The marginal and slope carbonate successions, corresponding to the formations of the Santa Cesarea Limestone and the Ciolo Limestone (Bosellini & Parente, 1994) in the Salento area and the Ostuni Limestone and the Caranna Limestone (Luperto Sinni & Borgomanno, 1969) in the Murge south-eastern regions, in the Geological Map of Italy on a scale of 1:50,000 (Leuca Sheet), are referred to the Member of the Ciolo Limestone. The transition between Altamura limestone and Ciolo Limestone is gradual. The top of this unit is locally characterized by karst structures and by the presence of thick residual soils with bauxite and pisoids, suggesting a long periods of emersion at the end of the Cretaceous.

2. Bauxitic deposits

Bauxitic deposits formed after the definitive emersion of the Apulian carbonate platform between the end of the Cretaceous and the beginning of the Paleogene due to the collisional phase between the European and African plates, can be found between Mesozoic limestones and Paleogene units.

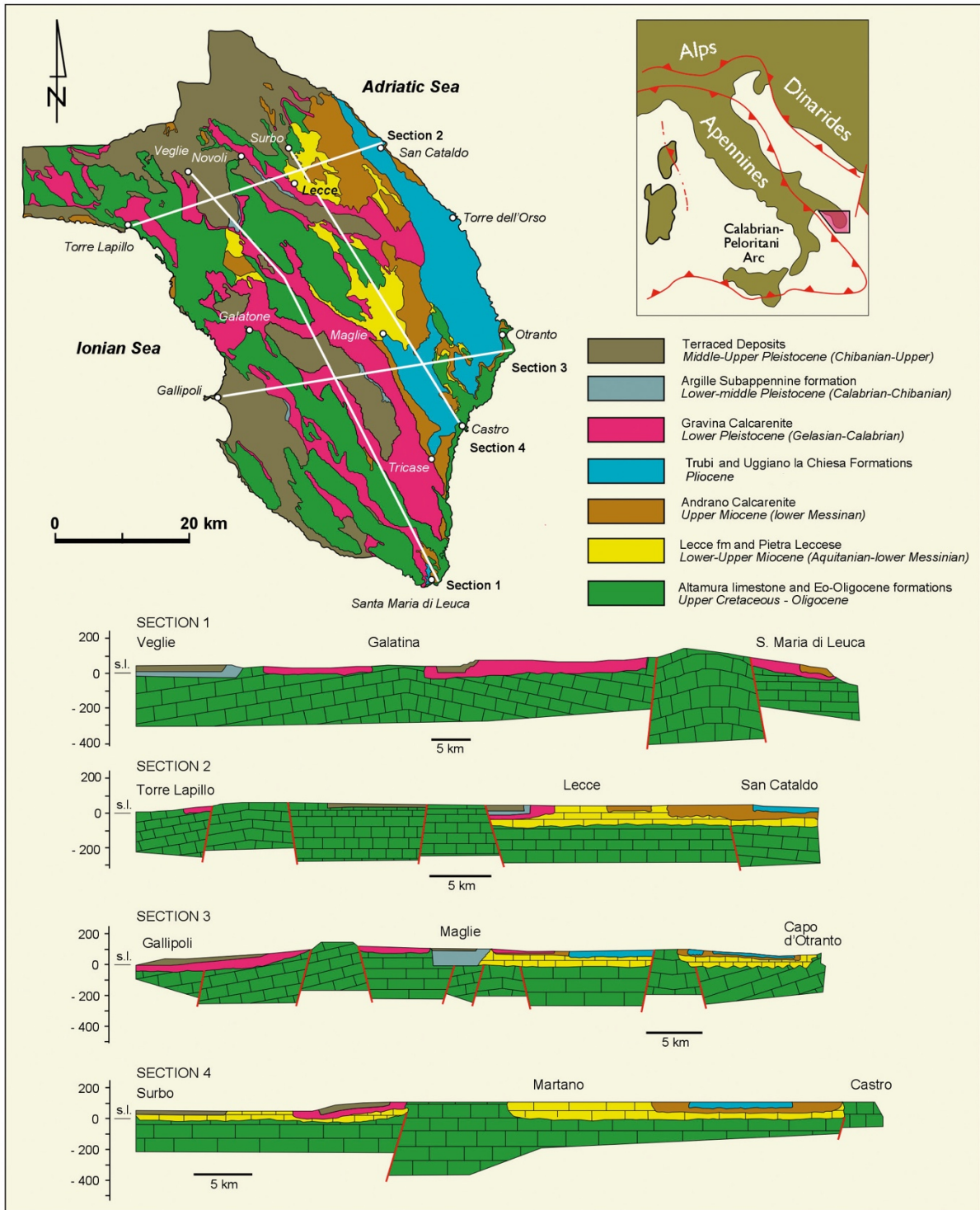


Fig. 3 Geological map and cross profiles of Salento Peninsula (modified from Tancredi et al., 2022).

3. Torre Tiggiano limestone

This limestone constitutes the first Eocene (early Lutetian-late Bartonian age) unit deposited along the margin of the Apulian Platform when its internal sector was subaerially exposed. The deposits of this formation consist of parallel- and cross-laminated grainstone/packstone forming units 1-2 m thick with lenticular geometry. The biogenic component is represented by abundant smaller and larger benthic foraminifers (milioids, alveolinids, and nummulitids) which are associated with encrusting

foraminifers, coralline red algae, subordinate echinoids, and green algae. Other less frequent bioclasts include bivalves and bryozoans.

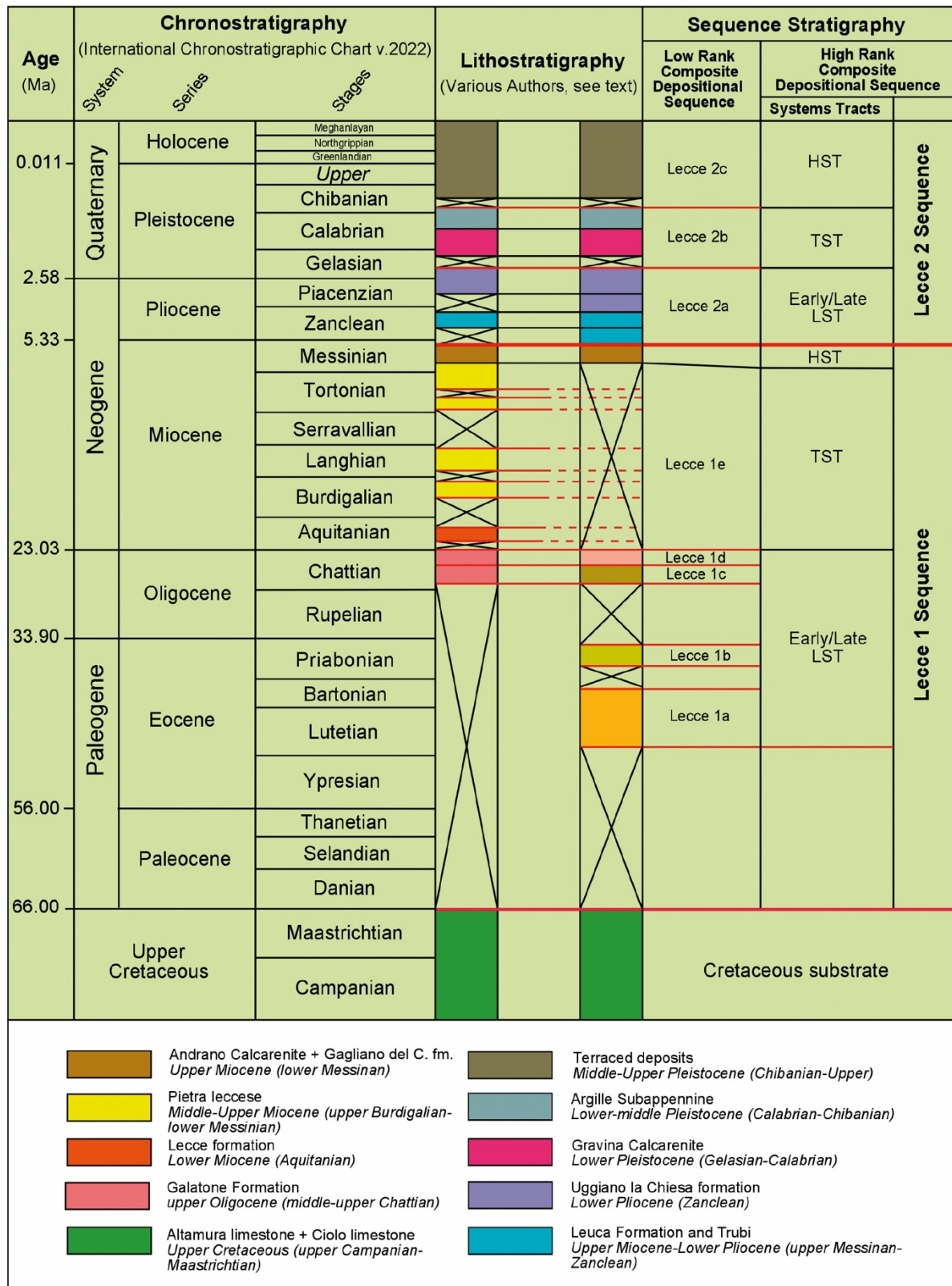


Fig 4. Chronostratigraphic and sequence-stratigraphic scheme of the Cenozoic deposits of the Salento Peninsula. HST, Highstand Systems Tract; TST, Transgressive Systems Tract; LST, Lowstand Systems Tract (modified from Tancredi et al., 2022).

4. Torre Specchia la Guardia limestone

This unit is the second formation of Eocene age that crops out at some places along the Salento eastern coast. It is a reef slope deposit constituted by breccias and bioclastic sediments onlapping onto the Cretaceous substrate and/or on the middle Eocene deposits through an angular unconformity. Benthic foraminifer assemblage characterized by the presence of *Asterocyclina priabonensis* and *Heterostegina gracilis*, suggest a late Priabonian age.

5. Castro limestone

This upper Oligocene formation crops out along the eastern coast of the Salento Peninsula from Capo d'Otranto to S. Maria di Leuca and overlies unconformably the underlying Upper Cretaceous and Eocene formations. Such unit, whose thickness ranges from 5 to 80-100 m, has been interpreted as a fringing reef complex having recognized the sub-environments of back reef, reef flat, reef crest, reef front and reef slope. This unit has been referred the middle-late Chattian.

6. Porto Badisco calcarenite

This informal unit crops out along the eastern coast of the Salento Peninsula and is constituted by a poorly cemented bioclastic calcarenite that reaches 50-60 m of thickness at Porto Badisco locality, where it seems to fill a paleodepression. This formation overlies disconformably the Upper Cretaceous, Eocene, and upper Oligocene formations, having always an erosional base locally marked by a rhodolith horizon 1-2 m thick. The Castro limestone and the Porto Badisco calcarenite belong to the same stage (Chattian) although stratigraphically the latter is superimposed on the former.

7. Galatone Formation

The Galatone Formation consists of whitish-greyish micritic limestones that are interbedded with cm-scale layers of whitish limestone and laminated yellowish calcareous marls, silt, and clays. Paleosols and lignite layers, from a few cm to several dm thick, occur at different levels in this unit thus suggesting a sedimentary cyclicity and frequent subaerial exposure. Bivalves, gastropods, and ostracods of different environments (freshwater, brackish and marine) are the most common fossils occurring in this formation, and together with the assemblages of benthic foraminifers living in a seagrass environment (planktonic foraminifers are absent), indicate a lacustrine to marshy/swampy restricted lagoonal environment, locally open to the sea. The Galatone Formation, whose maximum thickness is about 100 m, is heteropic of the Calcari di Castro and the Porto Badisco formations so that it covers the time interval of the middle-late Chattian, as testified by its bio-chronostratigraphic framework based on the ostracofauna. The Galatone Formation thus represents the product of deposition in the internal parts of the Salento Peninsula where a lacustrine-lagoonal environment occurred, passing seaward to the carbonate facies of the Castro limestone and the Porto Badisco calcarenite.

8. Lecce formation

The Lecce formation crops out to the south-west of the town of Lecce, Copertino, Nardò and lies unconformably on the Galatone Formation, through the interposition of a paleosol from a few tens of cm to about 2 m thick. This unit, about 60 m thick, consists of whitish massive calcarenites with gray marly and micritic limestone intercalations which show extensive bioturbation. The faunal assemblage is characterized by rare bivalves (especially *Cardium*), echinoids (*Scutella*), gastropods, and larger foraminifers (*Operculina*). The microfauna is represented by microforaminifers and calcareous nannofossils. The unit can be referred to the Aquitanian.

9. Pietra Leccese formation

The Pietra Leccese formation reaches a maximum thickness of about 90 m in the Lecce area, whereas towards the Ionian and Adriatic coasts the Pietra Leccese is extremely thin or entirely absent. It consists of a pale-yellow soft and friable biomicrite rich in planktonic foraminifers and nannofossils and with macrofossil assemblages rich in pectinids, echinoids, bivalves, and brachiopods. Overall, the sediment is very bioturbated and the stratification, poorly distinguished, appears in banks with thickness ranging from 50 to 100 cm. One of the features characterizing this unit is the presence of a high percentage of phosphatic and glauconitic grains whose frequency and abundance allow to detect different intervals separated by hiatuses with a duration variable from 1.2 to 3.7 Ma. The (macro)palaeontological importance of the Pietra Leccese mostly relies on its exceptional content of fossil marine vertebrates, including cetaceans, sirenians, turtles, crocodiles, and bony and cartilaginous fishes.

Numerous sub-vertical karst cavities, locally named *ventarole*, are easily recognizable along quarry cliffs of Pietra Leccese formation. Ventarole are karst (crypto-solution processes) landforms developed along the main joints affecting the carbonate bedrock and formed during the Late Pleistocene, as clearly indicated by a very interesting continental fossil fauna, preserved when cryptosolution processes were promoted by humid-warm climatic conditions.

The deposition of Pietra Leccese spanned an interval of about 11 Ma, from the late Burdigalian to the early Messinian. The Pietra Leccese lies unconformably on different Paleogene and Cretaceous strata. On the southeastern margin of platform, the Pietra Leccese is extremely thin or missing; here it is represented in many places by a characteristic layer (“Livello ad *Aturia*”), a 10-30 cm thick reddish-brown or greenish-brown hardground, containing some phosphatized pebbles from the underlying units and rich in fossils such as planktonic foraminifers, fish teeth, cephalopods, and solitary corals. In the Geological Map of Italy on a scale of 1:50,000 (Leuca Sheet) this facies belongs to a distinct lithostratigraphic unit named “Calcarenite coralligena di Serra del Mito” that represents an important stratigraphic marker accumulated in the southern part of Salento on submarine reliefs (seamounts) with respect to the coeval succession of Pietra Leccese sedimented in the deeper northern part.

10. Andrano Calcarenite

This unit crops out with reduced thickness along the internal and the eastern sectors of the Salento Peninsula, whereas it reaches a thickness of about 90 m in the subsurface. In the internal sector of Salento, Andrano Calcarenite constitutes the regressive phase of the Miocene cycle including Pietra Leccese formation. It shows a gradational boundary with the underlying Pietra Leccese and is constituted at the base by thin-bedded whitish fine-grained marly calcarenite with rare greenish granules of glauconite grading upward to wavy, subparallel bedded (30-40 cm) whitish/yellowish medium-grained marly calcarenites. Fossils are very abundant and dispersed in the deposits or forming concentrated layers; the most frequent fossils are represented by annelids, serpulids, balanids, bryozoans, gastropods (mainly *Turritella* sp.), bivalves (*Chlamys* sp., *Cardium* sp., *Ostrea* sp., *Modiola* sp.), brachiopods and calcareous algae. Based on micropaleontological data the age of the Andrano Calcarenite is attributed to the early Messinian and most likely to the pre-evaporitic stage. In the Leuca area, Pietra Leccese and Andrano Calcarenite constitute two different sedimentary cycles. Andrano Calcarenite was deposited on a shallow shelf, behind a reef margin.

11. Gagliano del Capo formation

This unit crops out discontinuously along the eastern coast of the Salento Peninsula from Porto di Tricase to Cape S. Maria di Leuca. The Gagliano del Capo formation corresponds to “Novaglie formation” and shows a well-developed reef complex with coral reefs, and clinostratified breccias forming prograding slope and base-of-slope deposits. Based on benthic foraminifers and ostracod assemblages, the Gagliano del Capo formation was dated to the early Messinian and considered by authors as heteropic of the Andrano Calcarenite.

12. Leuca Breccia

This unit, maximum 30 m thick, is constituted by breccias and conglomerates. Breccias and conglomerates are formed by carbonate heterometric pebbles included in a mainly sandy or marly sandy matrix. In the Geological Map of Italy on a scale of 1:50,000 this unit is part of Andrano Calcarenite formation formed for post-diagenetic slumping. According to other Authors, considering its stratigraphic position, its sedimentological character and relationships with underlying and overlying units, the Leuca Breccia (type locality at Punta Ristola, Leuca town) represents a terminal Messinian lowstand deposit associated with the Mediterranean salinity crisis, derived from the subaerial dismantling of the exposed Salento ridge. Others considered Leuca breccia as the transgressive basal terms of the first Pliocene sedimentary cycle.

13. Trubi Formation

Trubi Formation is a marly unit passing upward to a glauconitic mudstone rich in planktonic foraminifers with subordinate benthonic forms. The glauconitic biomicrites are the sedimentary expression of an abrupt deepening (up to the deepest outer neritic zone) and of an intense

erosive/dispersive action of the currents. Trubi Formation is referred to the lower Pliocene (Zanclean) based on the faunal assemblage.

14. Uggiano La Chiesa Formation

This unit of Plio-Pleistocene age crops out along the eastern coast of the Peninsula and overlies mostly the Leuca Formation and locally older units; its thickness is variable reaching a maximum value of about 50 m in the Poggiardo area and 90 m in the Cesine area. This formation is constituted in the lower portion by a discontinuous basal conglomerate 30-70 cm thick with phosphatic pebbles passing upward to fine-grained marly calcarenite in turn replaced by a yellow and well-stratified medium-grained calcarenite rich in foraminifers, ostracods, echinoderms, mollusks, bryozoans, and red algae. The planktonic foraminiferal assemblage suggests an upper Piacenzian-Gelasian age for this unit; while, in its type area, Uggiano la Chiesa Formation has shown a wider stratigraphic range, in the Lecce area, the deposition of the formation can be referred to the Zanclean and starts in a similar context, characterized by erosive/dispersive processes alternated to active processes of phosphatization. In fact, the local occurrence of a basal conglomerate with phosphatic pebbles, as well as the benthonic assemblages, indicating the outer neritic zone, are in contrast with the evidence of a transgression.

15. Gravina Calcarenite

This formation shows thicknesses variable from 10 to 40-50 m in outcrop and reaches 70-80 m in the subsurface. This formation has an age variable from the Gelasian to the Calabrian (Early Pleistocene) in the Murge area, while its corresponding deposits in the Salento area, originally known as “Salento Calcarenite”, have been attributed to the Calabrian (probably Sicilian substage) on the basis of the rich fossil assemblages (macrofossils are represented by bivalves as *Arctica islandica*, *Mya truncata*, and *Panopea norvegica*, and micro- and nannofossil are referred to the *Globorotalia truncatulinoides excelsa* and “small” *Gephyrocapsa* zones). From the lithological point of view, this unit is characterized by massive poorly diagenized calcarenite with medium-large grains, whitish in color. Above the calcarenites, a sandy detrital sequence (“Sabbie a brachiopodi”), about 4 m thick, can be seen. The lower bearing surface of this range is wavy and marked in several points by a particular concentration of fossils (bivalves, among which prevalent *A. islandica* and *Acanthocardia* sp. with disarticulated valves, gastropods, corals and, above all, serpulids), which appear chaotic. The sandy (sometimes more or less clayey) sediment is massive, of brownish-greenish color, very rich in fossils (Arcticidae, Cardiidae, Pectinidae, Glossidae, Veneridae, Lucinidae, Solecurtidae, Nuculidae, Fasciolaridae, Muricidae, Nassaridae, Naticidae, Trochidae, Xenophoridae, Turritellidae, Dentaliidae, *Caryophyllia* sp., and *Ditrupa cornea*), with the brachiopods that are particularly abundant, consisting essentially of specimens of *Terebratula scillae* with not-disarticulated valves. Remains of cetaceans (Odontoceti and Mysticeti) are recovered in the inner part of the Salento Peninsula (Cutrofiano town), in this part of the succession. The deposits discontinuously crop out along the present-day eastern Salento sea cliff, forming isolated fan-shaped bodies, up to 1 km wide and up to 40 to 50 m thick.

16. Argille Subappennine

In the Salento area this formation crops out with a reduced thickness (a few meters) in very small areas; whereas in the subsurface the thickness increases to about 230 m towards the western sector, in the direction of the Bradanic Trough, within the depressions placed between the structural highs of the Cretaceous substrate. In the Salento area, it is represented by blue-gray marly-silty clay with a macrofossil assemblage consisting of bivalves, brachiopods, corals, algal nodules, and arborescent bryozoans and with a microfossils-rich fauna represented by benthic and planktonic foraminifers. The age of this unit, based on the microfaunal assemblage, has been referred to as a generic Calabrian, although considering the age of the underlying Gravina Calcarenites attributed to the Sicilian substage, it should be referred to the end of the Calabrian and to the beginning of the Middle Pleistocene.

17. Marine Terraced Deposits

The most recent units are the Marine Terraced Deposits from the Middle-Upper Pleistocene period that were deposited all around the Salento Peninsula up to an elevation of 160 m during repeated marine transgressions and frequently associated with well-cemented aeolian deposits, arranged in continuous dune belts. Marine Terraced Deposits comprise, bioclastic sandy-calcarenite sediments, up to 15-20 m thick, crop out all around the Salento Peninsula. The best known among the Marine Terraced Deposits are those along the coast stretching from Taranto to Gallipoli, referred to the latest Middle Pleistocene and/or to the Last Interglacial Period, as well as those belonging to the Middle-Upper Pleistocene succession recognized between Gallipoli and Leuca. On the contrary, several outcrops in other parts of Salento are still poorly studied. Along the Ionian side, the two lowermost units are represented by algal biocalcarenites rich in tropical fauna (i.e., *Persististrombus latus*, *Cardita calyculata senegalensis*, *Patella ferruginea*, *Hyotissa hyotis*) and reef build-ups bio-constructed by *Cladocora caespitosa*. This fossil content, and the impressive set of relative (amino acid racemization) or absolute (U/Th ratio) age determinations associated, indicates a tropical environment of Late Pleistocene age, that corresponds to the MIS 5.5. Deposits referred to sub-stages more recent than MIS 5 are also locally exposed. Along the Adriatic side of the Murge Plateau and of the Brindisi Plain, well-cemented sterile calcarenites with rare bioturbations are exposed, ascribed to a beach/dune environment. The absence of fossil remains did not allow any biostratigraphic correlation or absolute age determination. A rough chronological constraint is provided by a man-splinted flint found in the colluvium underlying the beach-dune deposits and ascribed to the Middle Paleolithic-Mousterian Age. This suggests a Late Pleistocene age, corresponding to a generic MIS 5, for the overlying marine deposits.

To know more

The Cretaceous fishes of the Salento Peninsula

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Upper Cretaceous fish beds are broadly exposed in the Salento Peninsula in the territory surrounding the city of Lecce. A laminated limestone extensively used for construction activities and locally known as *chiancaredda* at times includes articulated skeletal remains of bony fishes as well as of other vertebrates. The first report of Cretaceous articulated fish remains from Salento was published by Geremia D'Erasmus (1911), who described material collected from the vicinities of Nardò and Presicce-Acquarica. Several productive sites have been discovered during the XX century in the territory surrounding the town of Nardò (Castello di Agnano, Contrada Donna Donata, Palude del Capitano, Parco di Porto Selvaggio), and numerous nicely preserved fossil fishes have been collected in a quarry close to the town of Alessano (Località Rotiglione).

The fish-bearing deposits consist of laminated light brown micritic limestone beds, up to 150 cm thick, which have been traditionally referred to the Coniacian-Campanian “Melissano Limestone” (Altamura limestone above) (e.g., Sorbini, 1978), the lowermost unit of the Cretaceous successions exposed in the Salento Peninsula (e.g., Bosellini et al., 1999). However, a detailed stratigraphic setting of the known fish-bearing localities remains elusive, so that an attribution to the Campanian “Santa Cesarea Limestone” or to the Campanian-Maastrichtian “Ciolo Limestone” (e.g., Bosellini et al., 1999; Schlüter et al., 2008) cannot be ruled out.

Fossil fishes are usually rare in the majority of the productive layers, although they can be extremely abundant at certain sites. The preservation is usually excellent, and a large part of the specimens consist of partially or fully articulated skeletons. The size spectrum of the fish specimens ranges from a couple of centimeters up to more than 1 meter. The fish assemblages include shark and batoids and representatives of the actinopterygian lineages Pycnodontiformes, Ichthyodectiformes (Figs 5-6), Aspidorhynchiformes, Crossognathiformes, Elopiformes, Anguilliformes, Clupeiformes, Ostariophysi, Aulopiformes, Myctophiformes, plus a diverse contingent of acanthomorphs (lampridiforms, zeiforms, beryciforms, and percomorphs).

The fossil assemblages also contain algae, jellyfishes, crustaceans, cephalopods, reptiles and rudist remains. The fossiliferous deposits possibly originated in intraplatform paleobiotopes with anoxic bottom and separated from the open sea by organogenic reefs, primarily formed by rudists. The fish-bearing micritic limestone beds show no evidence of bioturbation and benthic fauna, and the abundance of well-preserved fossils is considered to be related to transportation following death in cyclic events of mass mortality (see Sorbini, 1981; Tyler & Sorbini, 1996).

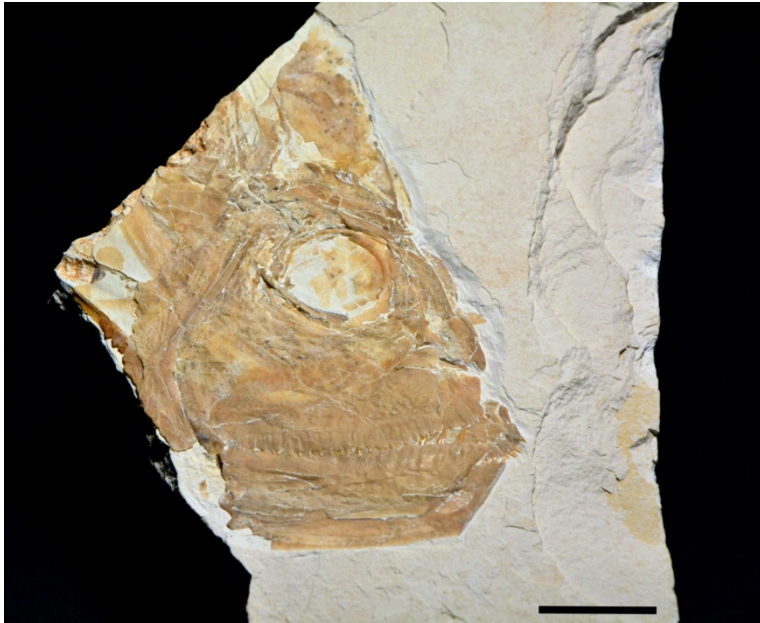


Fig. 5 The Cretaceous fishes of Nardò. The ichthyodectiform fish *Capassoichthys alfonsoi*; holotype; right lateral view. Scale bar: 30 mm.

The Upper Cretaceous fish assemblages from the Salento Peninsula (especially that of Nardò) unquestionably represent some of the most important and diverse ichthyofaunas of the Tethyan realm, providing the most complete documentation of the structure and composition of the shallow marine fish faunas preceding the end-Cretaceous extinction (e.g., Friedman, 2009). In addition, these assemblages include some of the earliest representatives of the modern acanthomorph clades that dominate the marine environments today (see Carnevale & Johnson, 2015), including the syngnathiform *Gasterorhamphosus zuppichinii*, the “perciforms” *Johnsonperca annavaccarii*, *Nardoichthys francisci* and *Zorzinperca weverberghi*, and the putative tetraodontiform *Cretatriacanthus guidottii* (Sorbini, 1981; Tyler & Sorbini, 1996).



Fig. 6 The Cretaceous fishes of Nardò. The ichthyodectiform fish *Altamuraichthys meleleoii*; holotype; right lateral view. Scale bar: 30 mm.

To know more

History and collections of the Museum of the Environment of the University of Salento (MAUS)

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The history of MAUS

The MAUS (Lionello et al., 2021) stems from an initial proposal of Scientific Museum that was put forward by Livio Ruggiero in 1979 (Ruggiero, 1981, 2011) and was supported by the activity of the “Gruppo Naturalisti Salentini”, which was active in Lecce in the 1980s and 1990s and provided the initial bulk of the collection of fossils together with other scientific material. In this period, Angelo Varola discovered many of the most relevant fossils of the collection, which brought to the identification of a set of holotypes (Ruggiero, 2016, 2017). The group organized a series of important events of scientific dissemination, with a remarkable affluence of public which in one case reached ten thousand visitors, and important scientific meetings, such as the annual congress of the Società Paleontologica Italiana (SPI) and of the Associazione Nazionale Musei Scientifici (ANMS) in 1993 (Ruggiero 1991, 1995). After an initial period, during which it was not possible to find a permanent location for the collections, the present building was constructed in 2001, thanks to a project of the Universities of Lecce and Catania funded by the European Union and the Italian Ministry for University and Research. The MAUS’ headquarter is a large two-store modern building that was built engulfing a former ancient farm (*masseria*). Unfortunately, structural problems, with a very substantial leakage of rainwater from the roof and consequent damages in the interior of the museum, prevented after 2007 the permanent opening of the museum to the public, but did not prevent to continue an intense scientific and outreach activity. In a first stage of restoration a new roof complemented with photovoltaic panels was built. Subsequently, the damaged parts were repaired. Finally, the museum was officially opened to the public in February 2020. Presently the MAUS collection is displayed on the ground floor of the building, covering a surface of about 500 m², while the first floor is used by the University Community Library.

The collections

The collections mainly contain fossils found in Salento, most of them of Cretaceous and Miocene ages, but also numerous from the Oligocene, Pliocene, and Pleistocene periods.

Cretaceous

The MAUS houses about 800 Cretaceous specimens, mainly coming from quarries in the Nardò and Alessano areas (see previous section). In fact, the Salento area is particularly rich in Cretaceous

fishes, which in 2014 have been the theme of a dedicated exhibition resulting from a collaboration between MAUS, the Municipality of Nardò, and the Civic Museum of Natural History of Verona (Belmonte, 2014). The holotypes of three Cretaceous species are presently displayed: *Tethybatis selachoides*, a complete specimen of a ray in two complementary blocks of limestone (De Carvalho, 2004); *Capassoichthys alfonsoi*, of which only the front part of the body is available; and the complete skeleton of *Altamuraichthys meleleoi* (Fig. 6) It is expected that new holotypes will be identified by studying other Cretaceous fossils of the collection.

Particularly interesting are the remains of fossil plants found in a quarry near Surbo (Belmonte, 2016), which are attributable to primitive conifers, such as *Brachyphyllum*, *Pagiophyllum*, *Frenelopsis*, *Geinitzia*, and *Cupressinocladus* (Fig. 7). They document the presence of these plants in the emerged lands comprised between the Tethys carbonate platforms in the early Upper Cretaceous and are suggestive of a humid and warm climate, with a marked seasonality.



Fig. 7 Some of the more than 100 limestone slabs bearing the remains of fossil land plants from the Cretaceous of Surbo (Lecce).

Miocene

Most of Salento Miocene fossils have been extracted from a local limestone, the so-called Pietra Leccese, mainly from quarries in the areas of Lecce-Cavallino and Cursi-Melpignano. The museum hosts at least 29 species of cetaceans, of which at least three represented by holotypes (Bianucci & Varola, 2014; Belmonte, 2015). The most impressive fossil is the nearly complete skeleton of the sperm whale *Zygophyseter varolai* (see next chapter), named after its discoverer A. Varola (Bianucci & Landini, 2006). The skeleton, belonging to an animal over 6 m long, has been reconstructed by extracting 255 bone pieces (corresponding to 52 bones and 8 loose teeth) from dozens of blocks already sectioned for building use. Two other currently exhibited holotypes are those of the delphinid *Messapicetus longirostris* (Bianucci et al., 1992) and of the balaenid *Archaeoschrichtius ruggieroi*, named after L. Ruggiero (Bisconti & Varola, 2006), who played a fundamental role in the establishment of the MAUS.

Beside cetaceans, many other marine fossils represent the vast Miocene biodiversity. Among these, the enormous, almost complete carapace of *Psephophorus polygonus* (an extinct relative of the extant leatherback turtle; Chesi et al., 2007) and another specimen of the same species, bearing the mark of a shark bite; several sirenian bones (Borgia et al., 1981, Varola et al., 2003); the nearly complete skull of a tomistomine crocodile (Delfino et al., 2003); numerous bony fishes including a well-preserved skull of a billfish (Carnevale et al., 2002); and thousands of teeth of rays and sharks, including the gigantic *Carcharocles megalodon* (see next chapter for more details). More Miocene fossils are waiting to be extracted from blocks of Pietra Leccese that are stored in the deposits of MAUS.

Other fossils and the museum exhibition

The Museum exhibition also includes some remains of Oligocene corals recovered in various areas of the Salento Peninsula, an exceptionally preserved partial skeleton of a bird (perhaps an ardeid) found in a Pliocene coastal deposit, and numerous Pleistocene marine invertebrates (mainly mollusks) from the Argille Subappennine (Cutrofiano quarries) and Calcarcareniti di Gravina formations (see first chapter). Some remains of continental mammals from karst cavities (*ventarole*) of the Cursi-Melpignano quarry district are also on display and represent the most recent materials (Late Pleistocene) that can be found in the MAUS (see third chapter).

Alongside fossil remains, it is also possible to appreciate full-scale models that reproduce the real appearance of the extinct animals, and scaled tridimensional models to visually compare their dimensions. Finally, three spectacular paintings by paleoartist Alberto Gennari are also displayed, representing, respectively, the history of life on Earth (Fig. 8), a natural-sized *Tyrannosaurus rex*, and the intersection between the many branches of Natural Sciences.



Fig. 8 Acrylic painting by paleoartist Alberto Gennari exhibited at MAUS showing the history of life on Earth. The panel is about 4.5 m long.

The open pit quarries of the Cursi-Melpignano area and the fossils of the “Pietra Leccese”: a window onto the Miocene Mediterranean marine vertebrate paleodiversity

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Historical rationale

The monuments and historical buildings of the “Barocco Leccese” (16th to 18th centuries) are mostly made of the Miocene “Pietra Leccese” limestone (Calia et al., 2014; Margiotta, 2015). The latter is an informal calcareous formation cropping out across the Salento Peninsula, mostly in the area between the Lecce hinterland and Santa Maria di Leuca (Mazzei et al., 2009; Margiotta, 2015). Its intensive use as an appreciated construction stone caused the Pietra Leccese to be quarried and subsequently cut into slabs and blocks at several localities of Salento. Such a quarrying activity, which typically develops in the form of open pits (Margiotta & Sansò, 2017), has led to the discovering and collecting numerous marine vertebrate specimens that comprise a significant portion of the palaeontological content of the Pietra Leccese formation (Bianucci & Varola, 2014). Such specimens include bony and cartilaginous fishes, crocodiles, turtles, sirenians and, especially, cetaceans (both toothed and baleen whales). This impressive fossil vertebrate assemblage has attracted the attention of Italian paleontologists since the 19th century. One of the earliest scientists to study the Pietra Leccese vertebrates was Oronzo Gabriele Costa, who gathered and partly investigated the collection that is currently kept in the Gabinetto di Scienze Naturali dell’Istituto Tecnico Economico “O.G. Costa” in Lecce (Costa, 1850, 1856, 1865). Later on, celebrated paleontologists like Giovanni Capellini devoted their energies to characterizing the fossil assemblage of the Pietra Leccese (Capellini, 1878). After these pioneering publications, other important descriptions were provided by Bassani & Misuri (1912), Moncharmont Zei (1950, 1956), and Menesini & Tavani (1968). However seminal these early studies were, many of the historical vertebrate finds from the Pietra Leccese suffered a lack of precise geographic and stratigraphic whereabouts. In the 1980s, the late paleontologist Angelo Varola, in collaboration with the Dipartimento di Scienze della Terra dell’Università degli Studi di Pisa, started monitoring some active quarries and sawmills in the classical type areas of the Pietra Leccese at Lecce and Cursi-Melpignano with the aim of retrieving new specimens in a stratigraphically controlled way (Bianucci et al., 2016). This monitoring activity led to the discovery and collection of a large number of fossil marine vertebrates, many of which have been described in the subsequent decades. Most of these finds were initially collected by the “Gruppo Naturalisti Salentini” and then became the first nucleus of the fossil vertebrate collection of the Museo dell’Ambiente dell’Università del Salento (MAUS) (Bianucci et al., 2016). Other remarkable vertebrate specimens are kept in the Museo di Storia Naturale dell’Università

di Pisa (MSNUP), Museo Civico di Paleontologia e Paleontologia di Maglie, Museo Paleontologico dell'Università di Napoli and Museo Geologico Giovanni Capellini dell'Università di Bologna.

Geological setting

The Pietra Leccese is mainly comprised of yellowish, poorly stratified biomicrites and biosparites that contain abundant planktonic foraminifera and calcareous nannofossils (Bossio et al., 2005; Margiotta, 2015). Benthic foraminiferal and ostracod associations suggest that the depositional environment of the Pietra Leccese formation was located in the deepest part of the neritic zone (Bossio et al., 2005, 2006; Mazzei et al., 2009; Margiotta, 2015).

The Pietra Leccese transgressively overlies the Upper Cretaceous Calcarei di Melissano Formation (Altamura limestone above) and the lowermost Miocene (Aquitanian) Lecce Formation; upwards, it gradually passes into the Messinian Calcareni di Andrano Formation that closes the Miocene sedimentary cycle of the Salento Peninsula (Bossio et al., 2006; Mazzei et al., 2009). According to micropaleontological analyses, the Pietra Leccese deposited between the late Burdigalian and the early Messinian (Foresi et al., 2002; Bossio et al., 2005; Mazzei et al., 2009). Despite its long depositional history, accounting for a time span of about 11 Ma, the Pietra Leccese formation displays a reduced thickness, not exceeding 80 m in its thickest portions (Bossio et al., 2006; Margiotta, 2006; Mazzei et al., 2009). This is explained by the erosive and/or dispersive action of marine currents that repeatedly interrupted the sediment accommodation (Bossio et al., 2005, 2006; Mazzei et al., 2009). Such processes resulted in several depositional hiatuses that are usually marked by horizons rich in glauconite, an authigenic mineral that typically forms in shelfal depositional settings with slow depositional rates (Foresi et al., 2002; Bossio et al., 2005; Mazzei et al., 2009; Margiotta, 2015). The occurrence of glauconite also characterizes some stratal packages within the Pietra Leccese itself (Mazzei et al., 2009).

Nowadays, rock quarrying still flourishes in the Cursi-Melpignano area (Fig. 9), whereas most quarries in the vicinities of Lecce are abandoned or have been converted to other finalities (Margiotta, 2015). In the Cursi-Melpignano area, a plethora of open pit quarries (Sansò et al., 2015) have yielded abundant vertebrate remains of mostly Early and Middle Miocene forms. Conversely, the Pietra Leccese deposits quarried at the Cisterna quarry (near Lecce) are home to an impressive Late Miocene marine vertebrate assemblage. Besides many celebrated marine vertebrate specimens, the macrofossil content of the Pietra Leccese includes remains of invertebrates such as bivalves (mostly pectinids) and echinoids (Margiotta, 2015).



Fig. 9 The landscape of the open-pit quarries of Pietra Leccese in the Cursi-Melpignano district. Courtesy of Ecomuseo della Pietra Leccese e delle Cave, Cursi.

Vertebrate paleontology

Fishes

Elasmobranch (shark and ray) teeth are commonly discovered in the Pietra Leccese. The first analyses of the selachian fossils of the Pietra Leccese date back to the late 19th and early 20th centuries (Bassani, 1895, 1903, 1905, 1915). A major reappraisal of these fossils was provided by Menesini (1969), who recognized as many as nineteen species of sharks and rays in fourteen genera from several localities and horizons. These taxa belong to ground sharks (Carcharhiniformes), mackerel sharks (Lamniformes), angel sharks (Squatiformes) and stingrays (Myliobatoidei). In addition, sawfishes (Pristidae) are also known by means of a phosphatized rostrum on which Vigliarolo (1890) based the description of *Pristis lyceensis* (it had been previously misidentified as a toothed whale). The most spectacular elasmobranch finds from the Pietra Leccese are large, finely serrated, triangular teeth that are currently assigned to the extinct “mega-toothed” shark genus *Carcharocles* (both the Early Miocene *C. chubutensis* and the Middle Miocene to Pliocene *C. megalodon*), which played the role of apex predators in the Miocene marine settings worldwide (Fig. 10a).

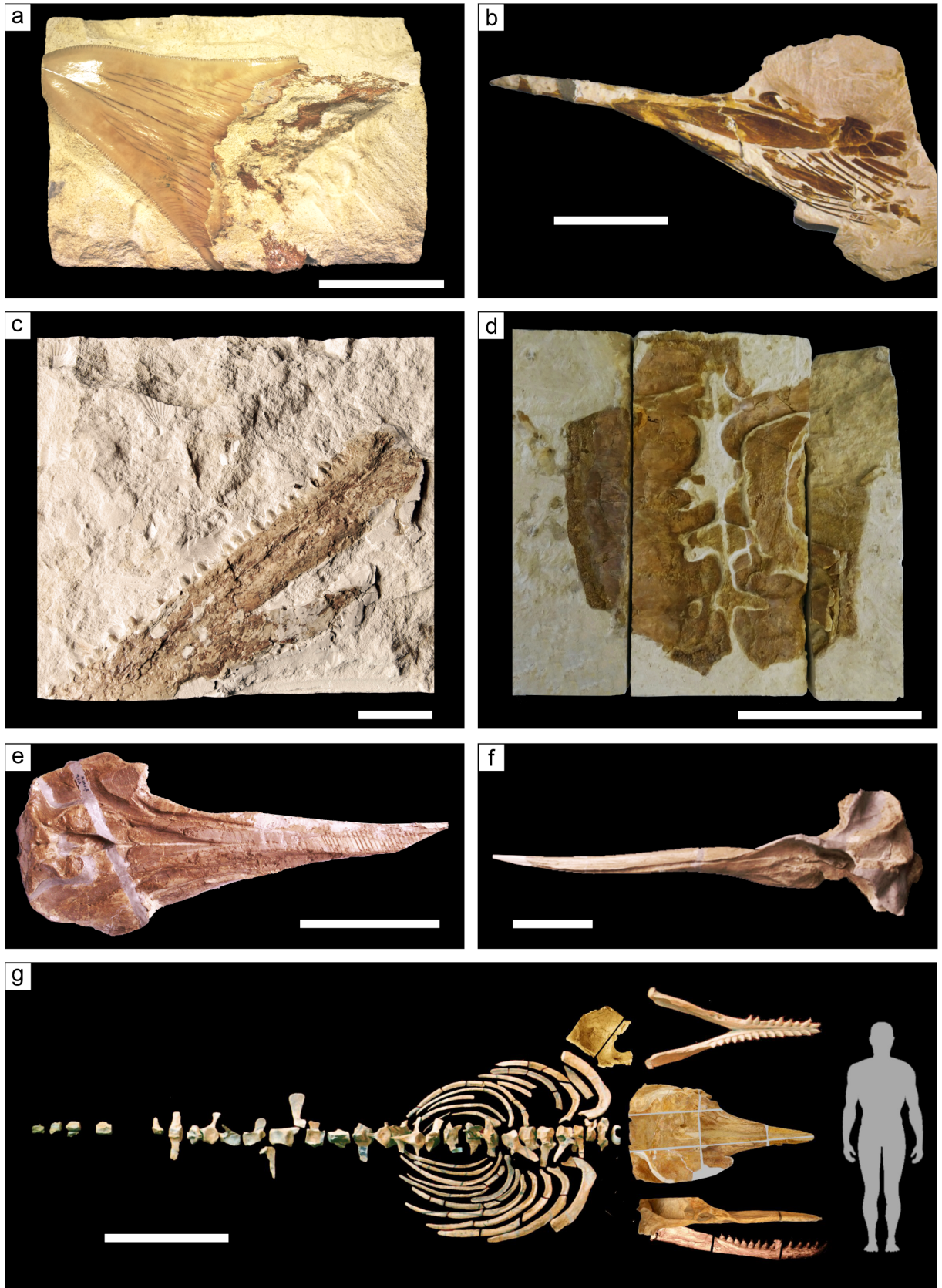


Fig. 10 Marine vertebrates from the Miocene Pietra Leccese limestone. a) Tooth of the otodontid *Carcharocles megalodon* (MSNUP I-16958). b) Skull of the istiophorid *Makaira* cf. *nigricans* (MAUS 917/1). c) Dentary of the scombrid *Acanthocybium* cf. *solandri* (MAUS 917/1). d) Carapace of Cheloniidae indet. (MAUS 991/1a-c). e) Skull of the eurhinodelphinid *Xiphiacetus* aff. *bossi* (MAUS 7). f) Cranium of the ziphiid *Messapicetus longirostris* (MAUS 240, holotype). g) Skeleton of the physeteroid *Zygophyseter varolai* (MAUS 229, holotype). Scale bars equal 5 cm for panels a and c; 20 cm for panels b, d, e, and f; 100 cm for panel g.

Among the most remarkable finds of bony fishes from the Pietra Leccese are numerous specimens of billfishes (Istiophoridae). The earliest record of this group of large-sized teleosts in the Pietra Leccese was provided by Capellini (1878) who described some fragmentary rostra. Although Capellini's material has gone lost, several new, more complete specimens assigned to *Makaira* cf. *nigricans* were described by Carnevale et al. (2002) from the Tortonian strata of the Cisterna quarry, near Cavallino (Fig. 10b). Other bony fishes from the same quarry include large-sized members of Scombridae (the wahoo *Acanthocybium* cf. *solandri* and the Spanish mackerel *Scomberomorus*), indeterminate Holocentridae (squirrelfishes), Fistulariidae (the flutemouth *Fistularia* cf. *commersoni*) and Epinephelinae (groupers) (Carnevale et al., 2002) (Fig. 10c). Other bony fish remains from the Pietra Leccese include dental elements of Sparidae (sea breams) and Diodontidae (porcupinefishes), as well as an isolated paraxial ossicle of Molidae (ocean sunfishes) whose stratigraphic whereabouts are hitherto uncertain (Menesini, 1969; Collareta et al., 2021).

Reptiles

The presence of chelonian remains in the Pietra Leccese is known since the 19th century, when Costa (1851) reported on an “almost complete chelonian shield” under the then new name *Testudo varicosa*. The latter is currently regarded as a junior synonym of *Trachyaspis lardyi*, a cosmopolitan Mio-Pliocene species of hard-shelled sea turtles (family Cheloniidae) characterized by a thoroughly sculptured external surface of the carapace (Chesi et al. 2007). Some sixty year later, Misuri (1910) described an unsculptured, hard-shelled sea turtle skeleton as the type of *Euclastes melii*. Though this specimen may be lost to date, new finds of chelonians from localities such as Cursi, Melpignano and Cavallino revealed additional specimens of *T. lardyi* and smooth cheloniids, as well as abundant carapacial fragments belonging to the leatherback turtle family Dermochelyidae (Chesi et al., 2007) (Fig. 10d). These specimens compare favorably with the widespread Miocene species *Psephophorus polygonus*, and include the largest carapace portion of this species reported to date in the literature (Chesi et al., 2007).

Crocodylian fossils are also known from the Pietra Leccese. The earliest such find consists of a mid-snout segment that had initially been assigned either to *Streptospondylus* or *Steneosaurus*, before Aldinio (1896) transferred it to *Tomistoma* (as *T. lyceense*). This referral to *Tomistoma* was harshly criticized by Capellini (1897). Today, the type of *T. lyceense* cannot be located, but a cast of it was recently revised by Nicholl et al. (2020), who argued that the remains once assigned to *T. lyceense* does not show any feature allowing to confirm its specific status, and as such, they should be regarded as indeterminate representatives of tomistomines (false gharials). A much more complete tomistomine specimen, consisting of a partial skull with associated vertebral fragments, has been collected more recently (Delfino et al., 2003).

Mammals

Marine mammals from the Pietra Leccese belong in two main groups: cetaceans and sirenians. Cetaceans, in particular, are represented by abundant remains, including many holotypes and

remarkably preserved specimens that, on the whole, contribute significantly to illustrate the Miocene diversity of toothed whales (Odontoceti) and baleen whales (Mysticeti).

The following odontocete lineages are currently known from the Pietra Leccese: Inticetidae and Squalodontidae (archaic heterodont toothed whales), Eurhinodelphinidae and kin (extinct long-snouted homodont toothed whales), ?Inioidea (relatives of the Amazon river dolphin), Kentriodontidae (basal delphinidans), Ziphiidae (beaked whales) and Physeteroidea (sperm whales). Inticetids are represented by an isolated cheek tooth, referred to cf. *Inticetus* sp., from the Melpignano area (Peri et al., 2019). This specimen is characterized by a transversely compressed, roughly semi-circular crown featuring several large, broad-based accessory denticles that are arranged radially. To date, this find represents the sole evidence of the elusive presence of inticetids in the Mediterranean region during the Miocene – one that suggests that faunal exchanges occurred through the Central American Seaway between the Mediterranean Sea and the Pacific Ocean in Early Miocene times (Peri et al., 2019). Squalodontids, also known as “shark-toothed dolphins” in light of their shark-like postcanine teeth, are represented by two fragmentary specimens (including rostral, mandibular and dental elements) that conform to the widespread Early Miocene genus *Squalodon* (Bianucci et al., 1994b), which has sometimes been interpreted as a nektic or nektobenthic cetacean that thrived in fluvial and/or neritic environments, feeding near the bottom. Both these specimens were collected in 1987 in the Cursi-Melpignano area (Bianucci et al., 1994b). The genus *Squalodon* had already been recorded from the Pietra Leccese by Capellini (1878) on the basis of isolated teeth that he referred to *S. antwerpiensis*. Due to their fragmentary status, the taxonomic assignment of these historical remains has nonetheless been questioned (Bianucci et al., 1994b). Eurhinodelphinid remains are more abundant, consisting of several skulls referred to the genera *Eurhinodelphis*, *Schizodelphis* and *Xiphiacetus*, most of which originate from the Cursi-Melpignano area (Bianucci et al., 1994b; Lambert et al., 2005) (Fig. 10e). This material also includes the holotype skull of *Eurhinodelphis salentinus*, which was collected in 1923 from a quarry near Melpignano (Montcharmont Zei, 1950); however, this specimen is too badly damaged to identify significant diagnostic characters (Bianucci et al., 1994b). Eurhinodelphinids were bizarre dolphins that used their extremely elongated rostra to stun shoaling fish (like swordfishes do) or to move the sand on the bottom in search of benthic prey (similar to sawfishes). A putative inioid was described by Montcharmont Zei (1956) under the then new name *Hesperoinia dalpiazzi*. Consisting of a fragmentary mandible from the San Cesario quarry, near Lecce, this record is currently regarded as representative of an odontocete incertae sedis (Fordyce & Muizon 2001). Kentriodontids, early branching relatives of the present-day oceanic dolphins (family Delphinidae), mainly consist of two skulls of *Rudicetus squalodontoides*. This small-sized kentriodontid is based on the holotype of Capellini’s (1878) *Priscodelphinus squalodontoides* from the Orfanotrofia quarries (near Lecce), as well as on a referred specimen from Lower Miocene (Burdigalian) deposits from an unknown locality (Bianucci, 2001). Other more fragmentary remains (isolated ear bones) from the La Signora quarry (near Alessano) and unknown localities have also been referred to kentriodontids (Bianucci & Varola, 1995). The beaked whales (family Ziphiidae) are represented by *Messapicetus longirostris*, which is currently known on the basis of the holotype and one referred specimen,

both from the Late Miocene (Tortonian) of the Cisterna quarry (Bianucci et al., 1992, 1994a, 2016) (Fig. 10f). Differing from most of its extant relatives, which display no erupted teeth except for the 2-4 tusks that characterize all male beaked whales, *M. longirostris* features a full series of functional upper and lower teeth. Such a complete dentition was likely used to grasp prey in epipelagic settings, which contrasts with the deep-water suction feeding habits of most extant ziphiids (Bianucci et al., 2016). Similar considerations may apply to the sperm whales, whose Recent representatives (belonging to the families Kogiidae and Physeteridae) are currently known as deep-marine suction feeders that only bear teeth along their lower jaws. The Pietra Leccese sperm whales include *Zygophyseter varolai*, a killer whale-sized macropredatory stem physeteroid provided with a complete dentition (Fig. 10g). Its holotype and only known specimen consists of an almost complete skeleton from the same locality and time span as *M. longirostris* (Bianucci & Landini, 2006). Biomechanical simulations on the skull and mandibles of *Z. varolai* suggest that its bite strength would have been similar to that of a full-grown white shark, thus allowing for active predation on prey items such as large-sized fishes and diminutive marine mammals (Peri et al., 2022b). Another unnamed, likely macroraptorial sperm whale species is known by a poorly preserved skeleton, featuring taphonomic evidence for scavenging and incrustation, from the same site and strata as the *Z. varolai* holotype (Peri et al., 2020). The Burdigalian portion of the Pietra Leccese quarried in the vicinities of Cursi is home to an incomplete skeleton that was recently described as holotype of *Angelocetus cursiensis*, a crown physeteroid that does not belong to either the Physeteridae or the Kogiidae. The wide temporal fossa, elongated rostrum and slender teeth suggest a diet based on medium to large-sized bony fish that were likely captured by employing a raptorial pierce feeding strategy (Peri et al., 2022a). Besides *A. cursiensis*, the Cursi-Melpignano area also yielded a fragmentary mandible assigned to the closely related crown physeteroid *Orycterocetus* (Bianucci et al., 2004).

Mysticetes from the Pietra Leccese include the holotype of *Archaeoschrichtius ruggieroi*, the geologically oldest member of the grey whale subfamily Eschrichtiinae (Bisconti & Varola, 2006). This specimen comes from the Tortonian strata of the Cisterna quarry and consists of a partial mandible that bears an unambiguously eschrichtiine architecture of the coronoid region. The same quarry and deposits are also home to the geologically oldest remains of the right whale family Balaenidae from the Mediterranean Basin, which consist of an undescribed fragmentary skeleton (Bianucci & Varola, 2014). In addition, fragmentary specimens of Cetotheriidae (a family of mostly diminutive mysticetes that was especially successful in Late Miocene times and may include the extant pygmy right whale) are also known from the Pietra Leccese (Bianucci & Sorbini, 2014).

The fossil record of sirenians (sea cows) in Italy is mainly represented by various specimens of the genus *Metaxytherium*, an extinct relative of the extant dugong (family Dugongidae) that used to inhabit the warmer-than-today Mediterranean Sea until the Pliocene. Remains of *Metaxytherium* are found at different stratigraphic heights of the Pietra Leccese succession, including the Tortonian deposits of the Cisterna quarry (Bianucci et al., 2003).

The fossil mammal content of the Pietra Leccese is completed by some specimens of terrestrial mammals (namely, proboscideans) from the Cursi-Melpignano area. They consist of teeth of

Gomphotherium angustidens that were tentatively assigned to the Middle Miocene and witness to the seaward transport of carcasses (or parts thereof) from the nearby emerged lands (Ferretti, 2008).

Vertebrate traces

Body fossils are not the only witnesses of the central Mediterranean marine vertebrate paleodiversity preserved within the Pietra Leccese limestone. The Cursi-Melpignano area has yielded isolated, large clasts of metamorphic and sedimentary rocks that have been interpreted by Tavani (1973) as putative gastroliths of large marine vertebrates. In addition, a large vertebrate (selachian?) coprolite preserving bite marks and grazing traces on its outer surface has also been described (Collareta et al., 2019, 2022).

Concluding remarks

The Pietra Leccese has long been the setting of abundant finds of marine vertebrate remains, most of which have been retrieved as a by-product of quarrying activities in the vicinities of Lecce and in the Cursi-Melpignano area. Such finds are taxonomically diverse and include several type specimens. Overall, this remarkable fossil record provides irreplaceable insights into the composition, ecological architecture, trophic dynamics and paleobiogeographic affinities of the central Mediterranean marine vertebrate faunas over most of the Miocene epoch. Not least, some of the Pietra Leccese fossils significantly contributed to our current understanding of the evolutionary history of various groups of marine vertebrates (mostly toothed and baleen-bearing whales).

Quaternary terrestrial vertebrates from Salento

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The paleontological area of Maglie

The southernmost part of Apulia, namely the Salento Peninsula, is an area that plays a critical role in our knowledge on Quaternary terrestrial ecosystems, owing to a rich paleontological and archaeological record coming mainly either from coastal caves or inland karst deposits, as well as for a long research tradition dating back at least to the 19th century (e.g., Sardella et al., 2018, 2019; Mecozzi et al., 2021).

The first fieldwork activities in the Salento Peninsula aimed at identifying sites of archaeological and paleontological interest, were carried out during the early 1870s, on behalf of the Provincial authority of Terra d'Otranto. These surveys resulted in the discovery of many Quaternary sites, among which Grotta Romanelli and Grotta Zinzulusa, both located along the Ionian coast near the town of Castro (Lecce). During the 1900s, a large number of institutions conducted fieldwork activities in the Salento Peninsula, especially the Italian Institute of Human Paleontology (IsIPU) and the Italian Institute of Prehistory and Protohistory (IIPP), with the crucial logistic support of the Salento Speleological Group (De Lorentiis, 1962; Cardini, 1962a; De Giuli, 1980, 1983).

Whilst several caves rich in archaeo-paleontological content punctuate the coast of the Salento Peninsula, many other Quaternary deposits were discovered in its inland area, being mainly related to intense karst phenomena that led to the development of fracture sets or other karst forms (sinkholes, polje, etc.). A noteworthy example is the Late Pleistocene site of Cardamone (Lecce), whose extensive infilling deposit developed into a Plio-Pleistocene calcarenite, was discovered during the early 1870s (Botti, 1890). The identification of inland fossiliferous deposits is strongly linked to quarry activities, which exposed large fronts, often by cutting karst cavities.

The presence of vertebrate fossils in the karst cavities of Salento is well known, especially in the area around Maglie (including Melpignano and San Sidero), where these structures are called *ventarole*. Mirigliano (1941) reported for the first time the occurrence of mammal remains in the ventarole near the town of Melpignano. During the 1950s, the fieldwork activities in the area of Maglie continued under the direction of Luigi Cardini, member of IsIPU, leading to the identification of fossils from the ventarole of Cava Motta (Melpignano) and Sant'Isidoro (San Sidero) (Cardini, 1962a). One of the most important works conducted in this territory was carried out by Claudio De Giuli (University of Florence), who described the paleontological material recovered from Cava L (also known as "S.S.3") of San Sidero (Fig. 11).

By the early 1990s, the fossiliferous area of Maglie has been investigated by paleontologists of Sapienza University of Rome and University of Turin (e.g., Bologna et al., 1994; Petronio & Pandolfi, 2008; Iurino et al., 2013; Pandolfi et al., 2017; Mecozzi et al., 2021).

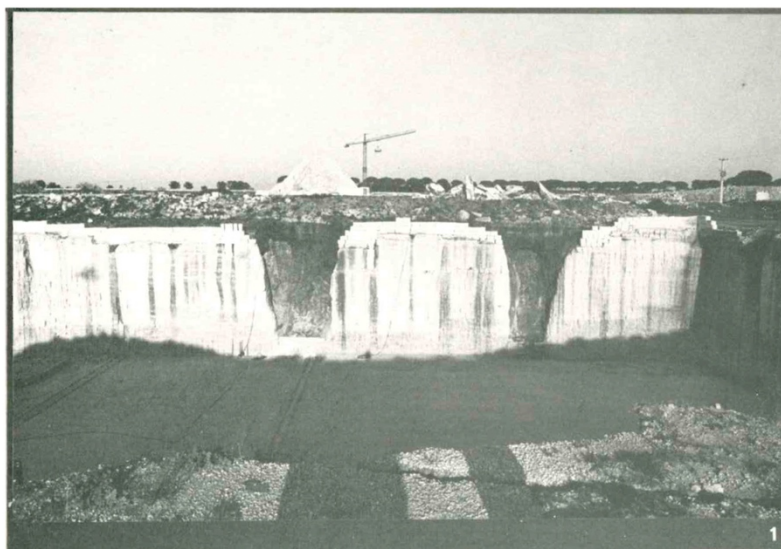


Fig. 11 Karst fissures of San Sidero (modified from De Giuli, 1983).

In the fossiliferous area of Maglie, the bedrock is represented by the 600 m-thick Altamura limestone (Upper Cretaceous; Ricchetti et al., 1988), made up of well-bedded limestone, dolomitic limestone and dolostone. This unit is overlaid by the widespread Pietra Leccese formation (Miocene). Its thickness is about 35 m in the Cursi-Melpignano area (Sansò, 2017), where it has been and still is extensively quarried. Many ventarole develop in the Pietra Leccese, being commonly sub-vertical or funnel-shaped fissures. Average width and height of the cavities are <1 m and 10 m, respectively; only in rare cases, up to 5-6 m-wide cavities were recognized (Pandolfi et al., 2017; Mecozzi et al., 2021). These cavities are filled in the lower part by reddish sediments, generally known as *terre rosse*, and in the upper part by brownish sediments, also called *terre brune* (De Giuli, 1983; Di Stefano et al., 1992; Bologna et al., 1994; Pandolfi et al., 2017; Mecozzi et al., 2021). Mammal remains have been found both in the *terre rosse* and *terre brune* (Figs 12-13). The fossil remains collected from the *terre rosse* of Melpignano and San Sidero karst fissures have long been considered chronologically homogeneous and attributed to the earliest Late Pleistocene (MIS 5) (Mirigliano, 1941; De Giuli, 1983; Bologna et al., 1994), while those recovered from the *terre brune* have been referred to the latest Pleistocene or early Holocene (De Giuli, 1980; Pandolfi et al., 2017).

Considering the fragmentary nature of the stratigraphical contexts of the karst infilling deposits of the Maglie area, their age has been mainly estimated based on correlations with other Quaternary deposits known in the Salento Peninsula, which preserved longer and more articulated successions. Among them, a key reference is Grotta Romanelli, where, at first sight, a similar stratigraphical context, including *terre rosse* in the lower part and *terre brune* in the upper part, has been described since the

early 1900s (see Sardella et al., 2018, 2019; Pieruccini et al., 2022); however, the inferred correlations between the terre rosse and terre brune from different sites were often based on a simplistic color-based repartition. Paleontologically speaking, the material recovered from Melpignano and San Sidero has been described in a number of papers (see references above), while the only data available for Grotta Romanelli has long been a faunal list reported by Blanc (1920).



Fig. 12 Skeleton of *Dama dama* from San Sidero exhibited in the Museum of Natural History of the University of Florence, section of Geology and Paleontology.

Recently, a geological and paleontological revision of the Melpignano and San Sidero karst fissures was published (MecoZZi et al., 2021). The textural and mineralogical analyses performed on the infilling sediments of the ventarole carried out in this work indicate no clear separation between terre rosse and terre brune sediments, the only difference detected being in the organic carbon content. Therefore, the simplistic color-based correlation should be abandoned. On the other hand, the paleontological revision of the collections stored at the Paleontology Museum of the University of Naples Federico II (Melpignano), IsIPU (San Sidero), PaleoFactory laboratory, Department of Earth Sciences, Sapienza University of Rome (Melpignano, San Sidero), Paleontology Museum of the University of Turin (San Sidero), and Museum of Geology and Paleontology of the University of Florence allowed to realize that the mammal remains from the terre rosse of different ventarole encompass a long chronological time span and that are not necessarily coeval (MecoZZi et al., 2021). In other terms, as proposed by Cardini (1962a), the faunal content of each karst fissure should be analyzed and discussed separately. The results of the revision carried out by MecoZZi et al. (2021) indicate that, based on their

faunal content, some ventarole deposits are referable to the Late Pleistocene (MIS 3) while others to the late Middle Pleistocene (MIS 9-8). The faunal assemblages recovered from the terre rosse of Melpignano and San Sidero testify to a long deposition from the late Middle Pleistocene to the Late Pleistocene, (Mecozzi et al., 2021). The age of the lower levels of Grotta Romanelli, which has similarly long been stressed as correlative to MIS 5, has also been recently backdated to the late Middle Pleistocene (Pieruccini et al., 2022).



Fig. 13 Skeleton of *Equus mosbachensis* from San Sidero exhibited in the Museum of Natural History of the University of Florence, section of Geology and Paleontology.

Grotta Zinzulusa

Along the Ionian coast of the Salento Peninsula, the Regional Natural Park Costa Otranto-Santa Maria di Leuca and Bosco di Tricase is located, being one of the most important areas of Apulia for archaeological and paleontological research. The Park hosts, especially in the stretch between Otranto and Tricase (Lecce), several localities that are renowned for their archaeo-paleontological content, such as Grotta Romanelli and Grotta dei Cervi, as well as many other caves, among which Grotta Zinzulusa (Fig. 14). Of all the caves that punctuate this coast, Grotta Zinzulusa is arguably the least known for the Quaternary infilling deposits, but undoubtedly the most famous for the karst landforms, including impressive stalactites, stalagmites and columns, attracting more than 70,000 visitors per year. Grotta Zinzulusa is indeed one of the largest caves of Apulia, long about 120 m and hosting several saloons and two lakes (Lazzari, 1958; Blanc, 1962). On the other hand, few people know that inside the cave infilling deposits preserving Pleistocene and Holocene paleontological and archeological remains were present.

Grotta Zinzulusa was firstly described by Francesco Antonio Del Duca, bishop of the diocese of Castro, in a letter to Ferdinando IV, king of the Kingdom of the “Due Sicilie” in 1793. The archaeological and paleontological record of Grotta Zinzulusa was studied for the first time by Ulderigo Botti, after a century from its discovery (Botti, 1874). During the 1950s and 1960s, the infilling deposits of the cave have been completely excavated, as described by several authors (Lazzari, 1958; Blanc, 1962; Morelli, 1968). Six stratigraphical sequences were recognized, called Vestibolo, Antro B, Antro C, Antro D, Antro E, and Duomo (Blanc, 1962; Cardini, 1962b; Morelli, 1968). Although of limited extent, Grotta Zinzulusa yielded evidence of human occupation, spanning from the Middle Paleolithic to the Neolithic, or Late Pleistocene to middle Holocene in geological terms (Blanc, 1962; Cardini, 1962b; Morelli, 1968).

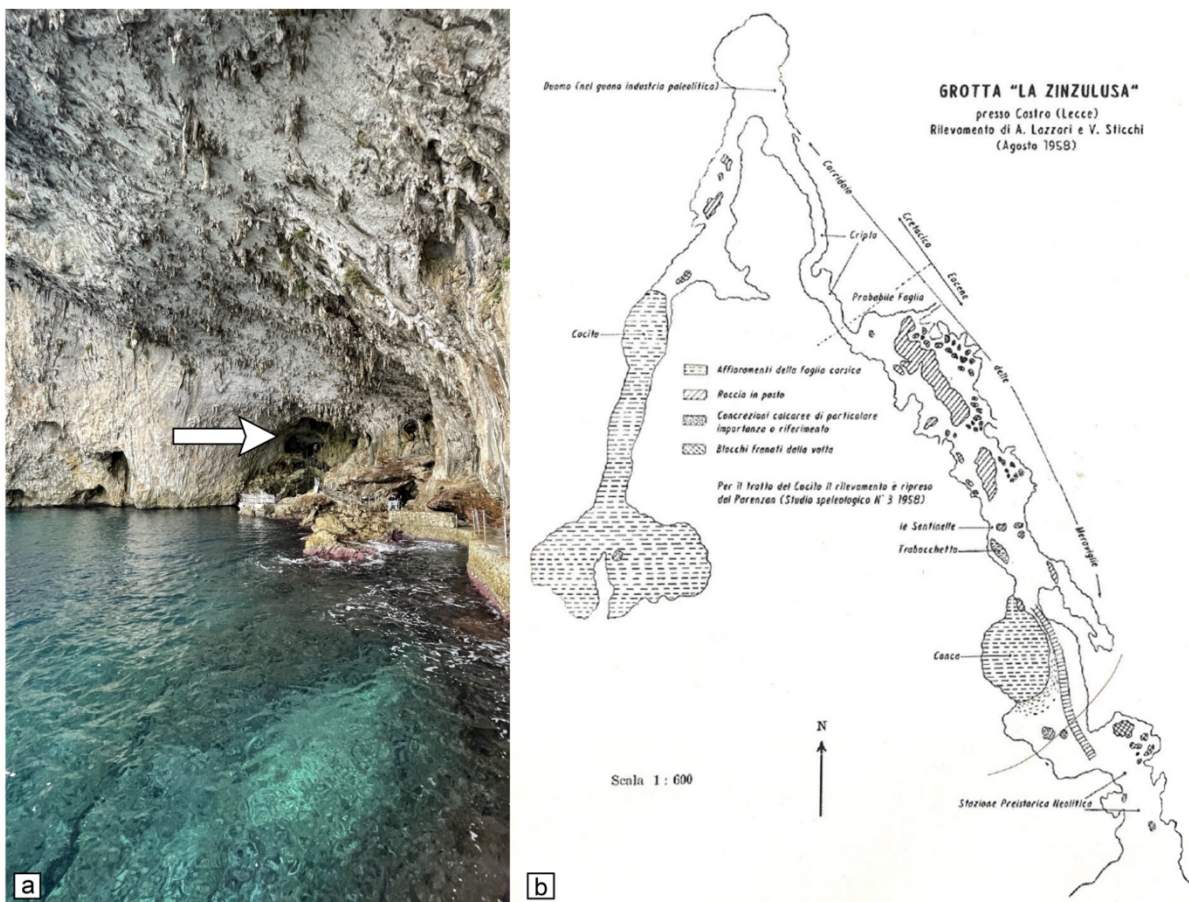


Fig. 14 Grotta Zinzulusa: panoramic view (a) and planimetry of the cave (b; modified from Lazzari, 1958).

The stratigraphic section at the former bauxite mine near Otranto (southern Apulia)

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The Late Cretaceous–Quaternary stratigraphic successions of southern Salento (Apulia, southern Italy) mainly consist of shallow marine, transitional and – more rarely – continental deposits, arranged in unconformity-bounded formations corresponding to sedimentary cycles (Bosellini et al. 1999). These include the Chattian Galatone Fm (Bossio et al. 1992, 1998; Esu et al. 1994), which is composed of sediments representing a nonmarine to brackish environment. This unit, encompassed between the Upper Oligocene Porto Badisco Calcarenites and the Lower to Upper Miocene Pietra Leccese, is exposed at different sites in southern Salento (Fig. 15) (Bossio et al. 1989, 1991; Iannone 1999; Ricchetti et al. 1999; Margiotta & Ricchetti 2002). Eighteen gastropod and five bivalve species are taxonomically described from an Upper Oligocene succession (Fig. 16) cropping out near Otranto (southern Salento, Apulia, Italy).

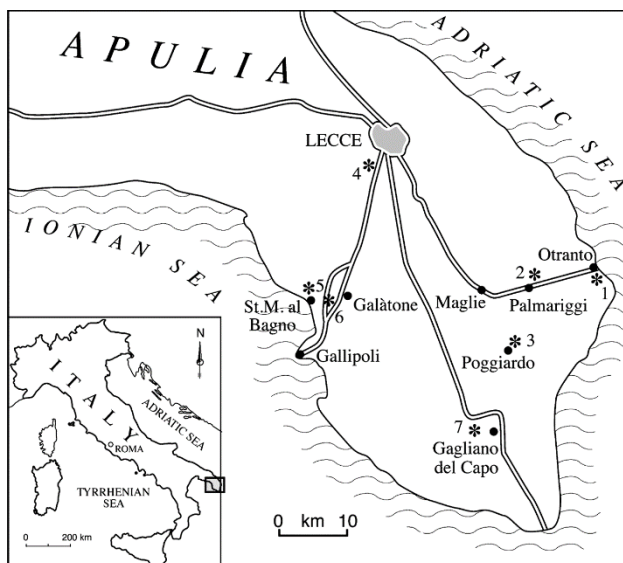


Fig. 15 Location map of the Upper Oligocene transitional deposits of the Galatone Fm in southernmost Apulia (Italy): 1, Otranto bauxite quarry; 2, Monte Vergine; 3, Serra di Poggiardo; 4, Surroundings of Lecce (informal Lecce formation); 5, St. Maria al Bagno; 6, Galatone; *, bauxite outcrops (from Esu et al., 2005).

Among these, *Tectarius (Echininus) japigiae*, *Hydrobia dubuissoni hydruntina*, *Pseudamnicola messapica*, *Pseudamnicola palmariggi*, and *Stenothyrella salentina* have been described as new taxa. Nonmarine and lagoonal environments characterize almost the whole succession, as testified by species-poor assemblages that are rich in specimens of freshwater and oligo- to mesohaline prosobranchs (Neritimorpha and Caenogastropoda), such as Neritidae, Hydrobiidae, Stenothyridae, Thiariidae, Potamididae, Batillariidae, pulmonates (Heterobranchia) including Planorbidae, and bivalves as Dreissenidae and Cyrenidae. The genera *Theodoxus*, *Hydrobia*, *Melanoides*, *Potamides*, *Terebralia*, *Batillaria*, *Granulolabium*,

Mytilopsis, and *Polymesoda* alternately dominate. Littoral marine elements, such as *Tectarius*, *Turritella*, *Barbatia*, *Anadara* and *Chama*, are scatteredly present in the succession, but some prevail towards the top. The Otranto section is composed of nonmarine, brackish and marine strata that are separated from the underlying and heavily weathered Cretaceous limestone by several meters of thick bauxitic paleosol, reddish-yellowish in color, and rich in bauxitic nodules and pisoliths (Fig. 16). Above the paleosol, the well-bedded succession, almost 14 m thick, was subdivided following beds, labelled from the bottom (Tab. 1):



Fig. 16 The stratigraphic section of the Otranto bauxite mine. The person near the black bar is suggestive of the outcrop thickness. The topmost red cover consists of quarrying material.

1-2	20-30 cm	bauxitic pisoliths dispersed in a black, clayey (level 1), coaly (level 2) matrix
3	15 cm	dark grey barren clay
4	10 cm	massive lignite
5	10 cm	grey marl, very hard, rich in oligohaline gastropods (<i>Neritidae</i> , <i>Hydrobiidae</i> , <i>Planorbidae</i>)
6	15-20 cm	massive lignite
7	200 cm	dark grey marl, rich in fossils (dominant <i>Potamididae</i> , <i>Batillariidae</i> , <i>Stenothyridae</i> , bivalves, foraminifers, ostracods); in the topmost cm, the fossil content decreases
8	3-4 cm	marl with gypsum and rare fossils (<i>Hydrobiidae</i> and <i>Corbiculidae</i>)
9	30 cm	15 cm of black clay with gypsum, barren of fossils, followed by 15 cm of lignite, rich in freshwater gastropods (<i>Neritidae</i> , <i>Hydrobiidae</i> , <i>Planorbidae</i>)
10	15 cm	clay, with thin coaly laminations, containing abundant freshwater and brackish gastropods and bivalves (<i>Neritidae</i> , <i>Hydrobiidae</i> , <i>Thiaridae</i> , <i>Dreissenidae</i>) and foraminifers

- | | | |
|----|----------------|--|
| 11 | 130 cm | thin (3-5 cm) pavement of Littorinidae (<i>Tectarius</i> shells) packed in a clayey-marly matrix lies at the base of grey marls (11a) rich in gastropods (Littorinidae, Potamididae, Batillariidae), bivalves (Corbiculidae) and foraminifers; at the top (11b), about 30 cm of laminated and carbonaceous clay with several deformed freshwater mollusks (Neritidae) |
| 12 | 35-40 cm | indistinctly bedded marl with poorly preserved moulds of Corbiculidae (<i>Polymesoda</i>) |
| 13 | 200 cm or more | only in part accessible; marls or clays alternating with more calcareous beds with mainly <i>Polymesoda</i> and foraminifers |
| 14 | 45 cm | a mixture of reworked bauxitic nodules with abundant crab remains, foraminifers, moulds of Hydrobiidae, Potamididae and Corbiculidae in grey and yellow marly matrix; the topmost 15 cm are represented by a <i>Polymesoda</i> limestone crust |
| 15 | c 100 cm | marl and limestone, with very abundant <i>Polymesoda</i> (unsampled because of the steepness of the outcrop) |
| 16 | 150 cm | yellow pseudogley paleosol (16a) with abundant root traces, often carbonaceous; at the top, 10-12 cm of laminated lignite (16b) with abundant freshwater taxa (Neritidae, Hydrobiidae, Dreissenidae) |
| 17 | 30 cm | yellowish-whitish marl with reddish oxidized laminae, with abundant Hydrobiidae, fragmentary Potamididae and <i>Theodoxus</i> , which is more frequent in the lowermost 10 cm; bottom and top are hardened crusts, the latter with cracks (mud cracks?) and casts of mollusks |
| 18 | 120 cm | reddish, cleft clayey (pseudogley?) paleosol, barren of fossils (18b); the base (18a) and the uppermost 2 cm (18c) are coaly, with freshwater taxa (Neritidae, Thiaridae, Dreissenidae) |
| 19 | 10 cm | yellow, fossiliferous marl containing a mixture of crushed, brackish mollusks and foraminifers |
| 20 | 10 cm | barren paleosol cut by a normal fault |
| 21 | 100 cm | yellow calcareous marl with brackish-marine gastropods, fragmentary marine bivalves and foraminifers |
| 22 | 70 cm | yellow marl containing corals, echinoid spines, crushed marine bivalves, gastropods, ostracods and foraminifers |

The Otranto succession can be interpreted as a complex transgressive sequence deposited after a long period of emergence, in which thick bauxitic soils developed. It ranges from freshwater lignitic seams and brackish lagoonal deposits to littoral marine sediments. The strata are referred to the Chattian Galatone Formation like some other successions of Salento based on the lithological and palaeontological content. The benthic foraminifers of the Otranto sections do also suggest an Oligocene

age (Esu et al., 2005), but the precise biostratigraphic attribution of the uppermost, littoral marine part remains unclear. The mollusk and foraminiferal faunas from the uppermost samples do not contain age-diagnostic taxa, but the ostracods may suggest an Early Miocene affinity (A. Bossio, pers. comm. 1998). Therefore, we conclude that the Otranto transgressive sequence should be referred to the latest Oligocene and, only for the topmost part of the Otranto section, possibly to the lowermost Miocene. Palaeobiogeographically, the species of the brackish-marine molluscan fauna of southern Apulia (Tab. 1) are spread into various European basins. Similar assemblages prevail in the Chattian of the German Mainz and Bavaria basins, in the Aquitanian of the Aquitaine Basin, and characterize the Oligo-Miocene deposits of the Piedmont, Hungary, Greece, Turkey and Iran basins. Some taxa show an endemic character, namely, *T. (E.) japgigiae*, *H. dubuissoni hydruntina*, *P. messapica*, *P. palmariggi*, and *S. salentina*. The Late Oligocene fauna of southern Apulia can be included in the Mediterranean-Iranian Biogeographic Province as defined by Harzhauser et al. (2002).

Tab. 1 Relative abundance (percentage) of mollusk species along the Otranto bauxite quarry section. X, percentage not defined; md, mould; fg, fragments. Lithology: B, bauxitic soil; C, clay; CM, calcareous marl; L, lignite (grey-marked levels); M, marl; P, paleosol.

metres	levels	lithology	GASTROPODS																BIVALVES				foraminifers	environment		
			<i>Theodoxus hassiaticus</i>	<i>Neritina picta</i>	<i>Tectarius japgigiae</i>	<i>Hydrobia dubuissoni hydruntina</i>	<i>Pseudamnicola messapica</i>	<i>Stenothyrella salentina</i>	<i>Gilbertiella</i> sp.	<i>Turritella thetis</i>	<i>Melanoides winkleri</i>	<i>Potamides margaritaceus</i>	<i>Potamides papavraceus</i>	<i>Terebralia subconrigata</i>	<i>Batillia pupaeformis</i>	<i>Granulobulum plicatum</i>	<i>Planorbarius</i> sp.	Planorbidae indet.	<i>Barbatia</i> sp.	<i>Anadara</i> cf. <i>A. aquilatica</i>	<i>Chama gryphoides austriaca</i>	<i>Mytilopsis</i> sp.			<i>Polymesoda convexa</i>	
13	22	M																						X	marine	
	21	M			36														fg	fg	fg			X	meso-polyhaline littoral	
	20	P																							emersion	
	19	M	4.9	fg		61																		X	oligo-mesohaline fresh swamp	
	18c	L	X							X													X			
	18b	P																							emersion	
	18a	L	9.5							3.5													87		fresh swamp	
	17	M	0.8			96								1.6	1.6									X	oligothaline lagoon	
	16b	L	20			30																50			fresh swamp	
9	16a	P																							emersion	
8	15	M																					100		oligothaline lagoon	
7	14	C																						X	mesohaline lagoon	
6	13	CM																						X	oligothaline lagoon	
5																										
	12	M																						md	oligothaline lagoon	
	11b	L	X																						fresh swamp	
	11a	M				21				0.5	2	1	29	15	28									3	X	meso-polyhaline open lagoon
	10	C	6.6	2.5	2.5	37				15			fg										36	X	oligothaline swamp	
	9	L	36			49	1.2										1.2	12							fresh swamp	
3	8	M				79											fg						20		restr. oligohaline	
2	7	M					8			1	50				31			0.5	0.4	0.6			8	X	meso-polyhaline open lagoon	
1	6	L																							swamp	
	5	M	15	7.6		51												26							oligothaline lagoon swamp	
	4	L																							swamp	
	3	C																							emersion	
0	1-2	B																							emersion	

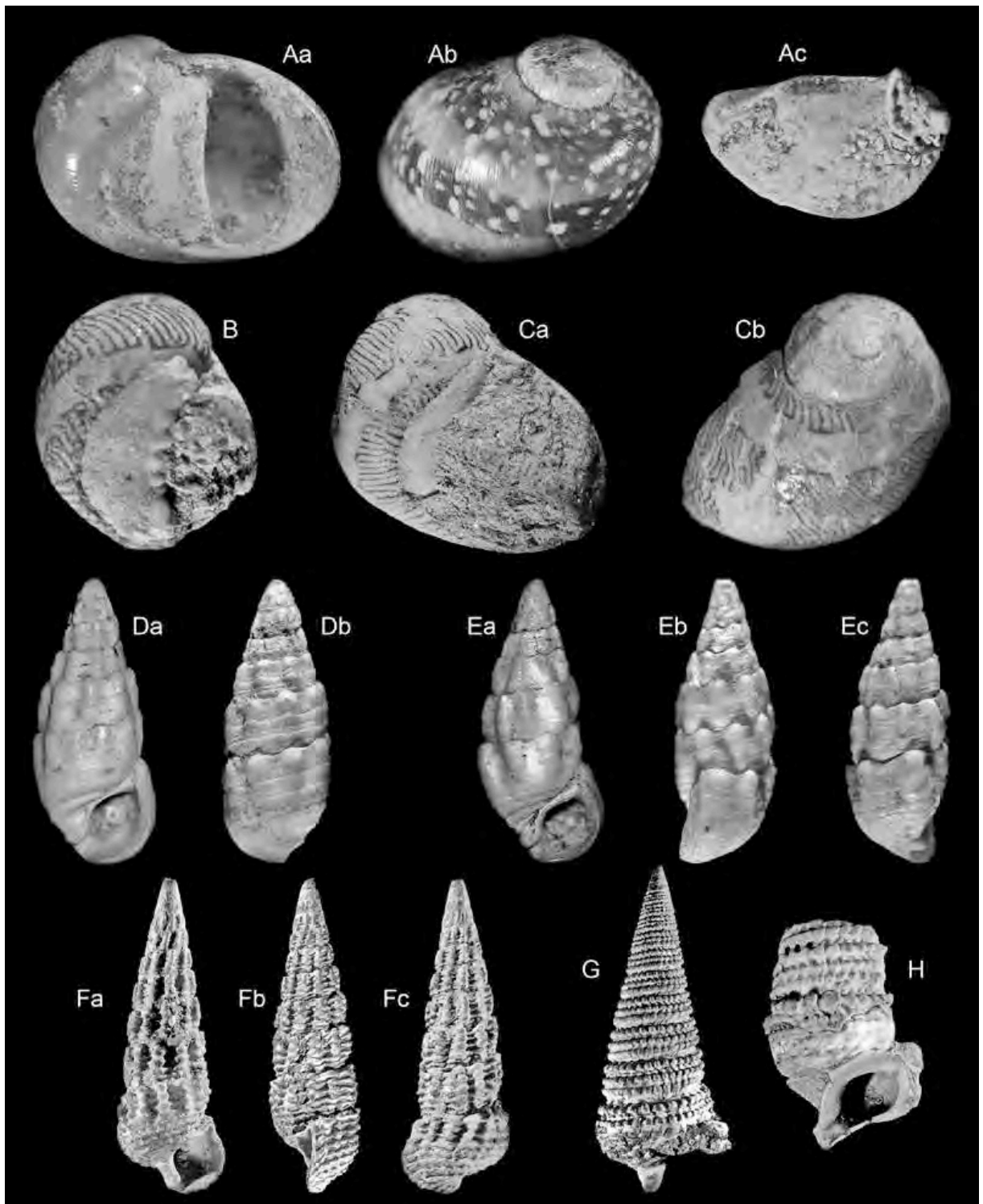


Plate 1 A) *Theodoxus subangularis* (Sandberger, 1860), H = 6 mm, apertural and apical views Ac: operculum with two apophyses, H = 2.5 mm. B-C) *Vitta picta* (Férussac, 1823), B: H = 3 mm, apertural view with denticulations; C: H = 4.5 mm. D-E) *Batillaria pupaeformis* (Basterot, 1825), H = 7 mm; D: frontal and posterior view; E: apertural, lateral and postero-lateral view. F) *Granulolabium plicatum* (Bruguière, 1792), H = 22 mm, apertural, lateral and posterior view. G-H) *Mesohalina margaritacea* (Brocchi, 1814), G: H = 45 mm, apertural view; H: specimen with preserved aperture.

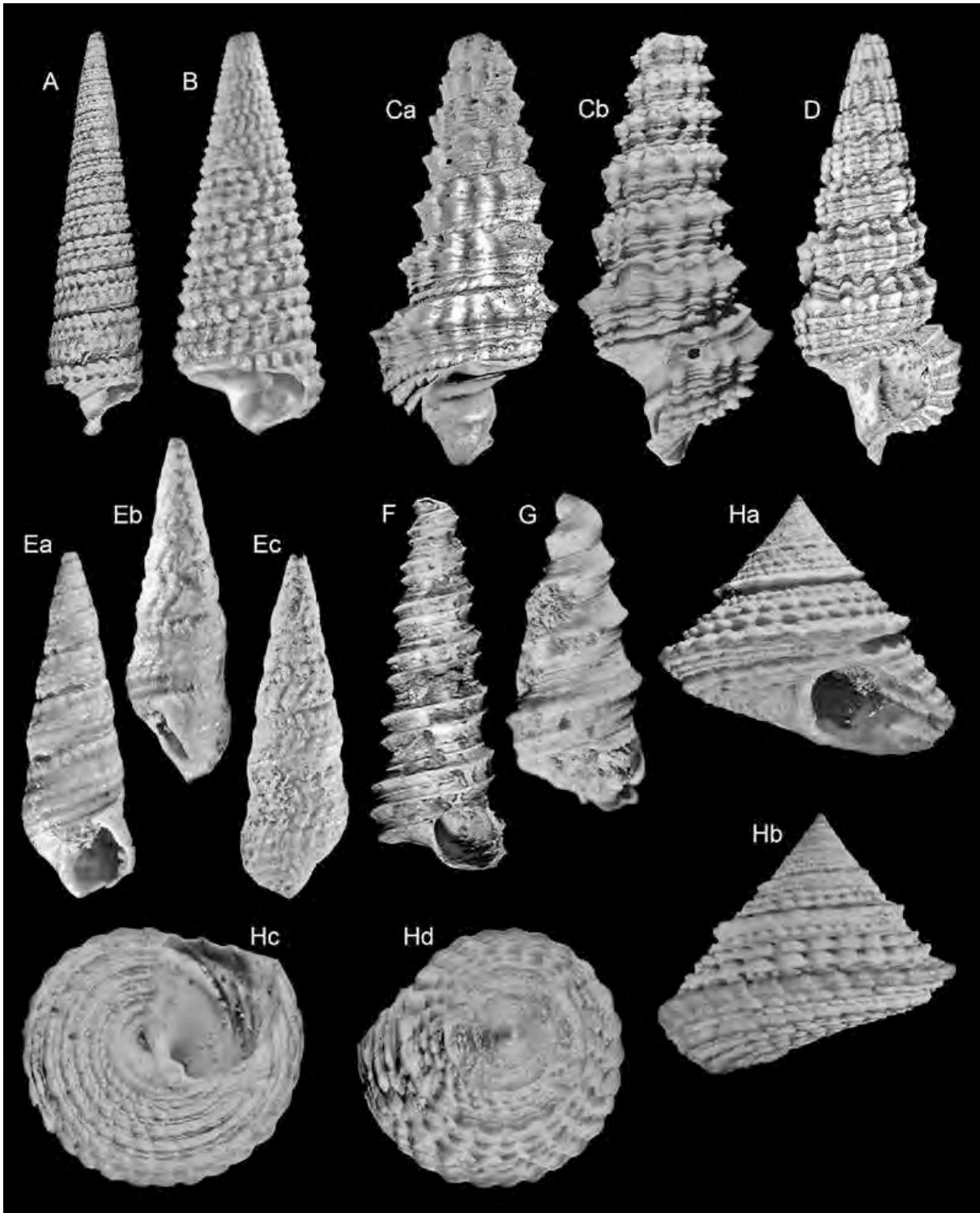


Plate 2 A-B) *Potamides papaveraceus* (Basterot, 1825), A: juvenile, H = 32 mm; B: H = 16 mm. C-D) *Terebralia subcorrugata* (d'Orbigny, 1852), H = 34 mm, apertural, lateral and frontal views. E) *Melanoides winkleri* (Mayer, 1861), H = 16 mm, apertural, lateral and posterior view. F-G) *Turritella thetis* d'Orbigny, 1852, F: H = 18 mm, apertural view; G: juvenile, H = 5 mm. H) *Tectarius (Echininus) japigiae* Esu & Girotti, 2010, H = 10 mm, paratype, apertural, posterior, umbilical and apical views.

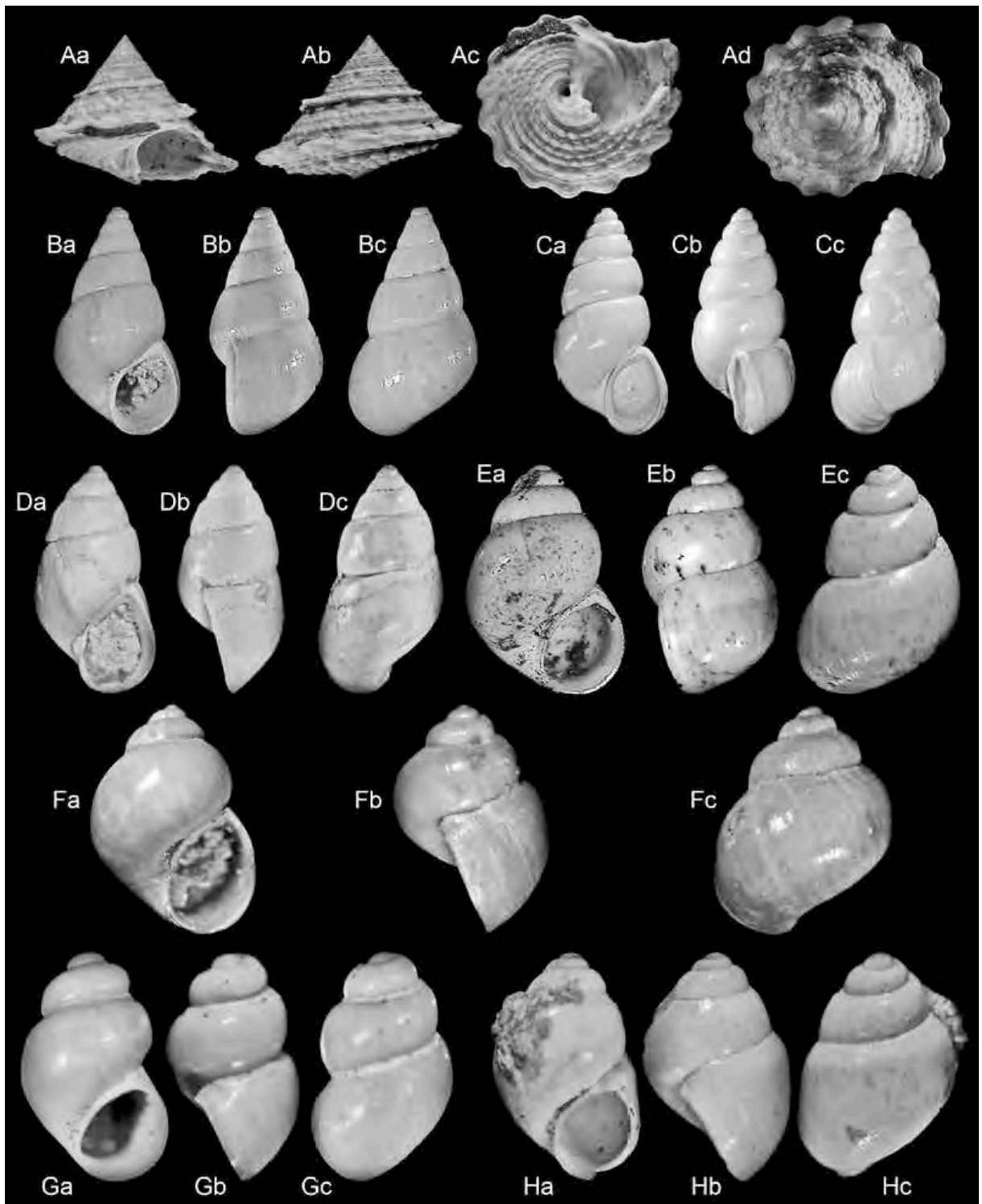


Plate 3 A) *Tectarius* (*E.*) *japigiae* Esu & Girotti, 2010, H = 8 mm, paratype, juvenile, apertural, posterior, umbilical and apical views. B) *Hydrobia* (s.l.) *dubuissonii hydruntina* Esu & Girotti, 2010, H = 4 mm, holotype, apertural, lateral and posterior views. C) *Hydrobia* (s.l.) *galatoniana* Esu & Girotti, 2019, paratype, H = 4.5 mm, apertural, lateral and posterior views. D) *Hydrobia* (s.l.) *ionica* Esu & Girotti, 2019, holotype, H = 4 mm, apertural, lateral and posterior views. E) *Pseudammicola messapica* Esu & Girotti, 2010, H = 3 mm, holotype, apertural, lateral and posterior views. F) *Pseudammicola palmariggii* Esu & Girotti, 2010, H = 3.5 mm, holotype, apertural, lateral and posterior views. G) *Stenothyrella salentina* Esu & Girotti, 2010, H = 0.8 mm, holotype, apertural, lateral and posterior views. H) *Stenothyrella* sp., H = 2.5 mm, apertural, lateral and posterior views.

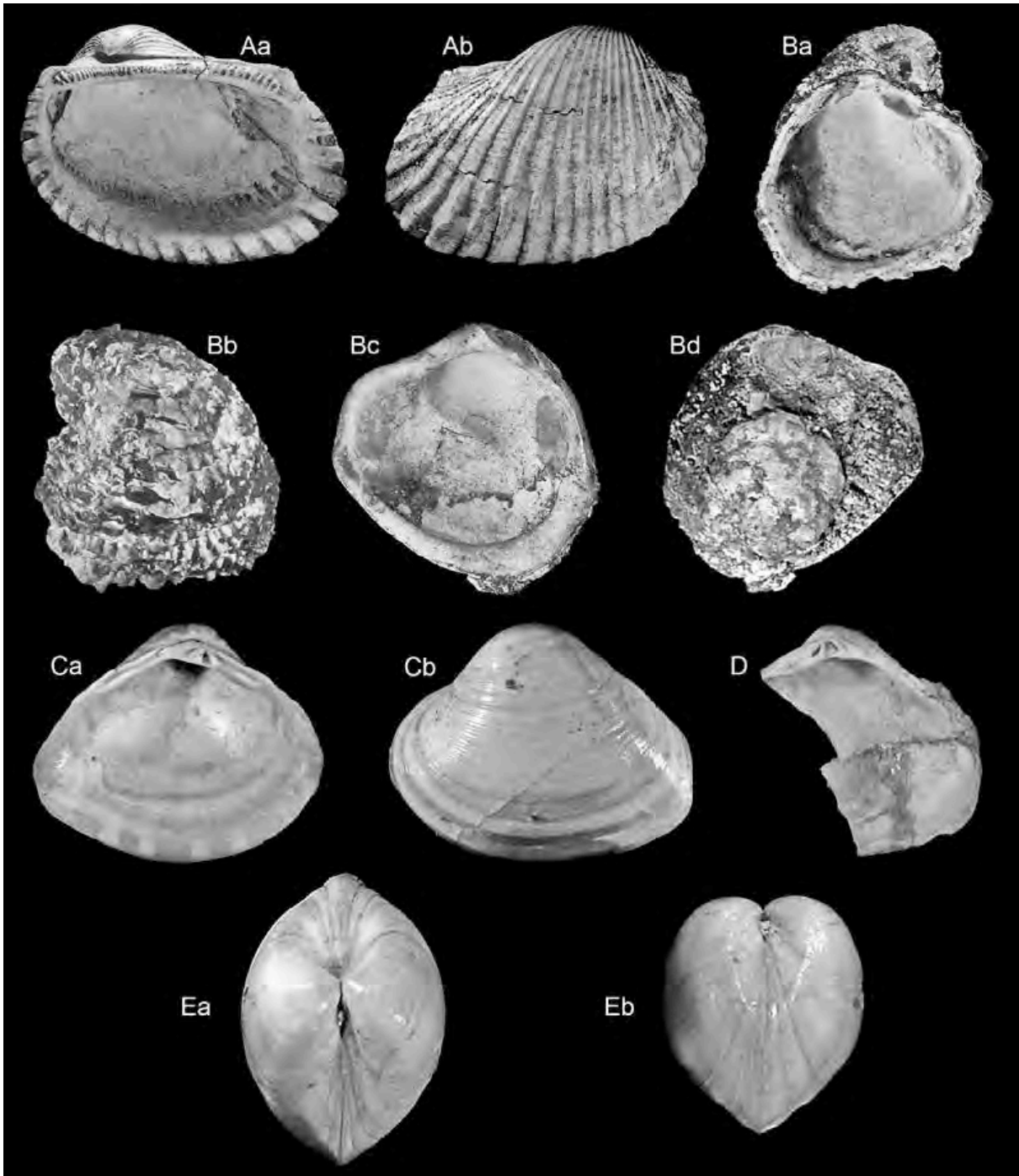


Plate 4 A) *Anadara* cf. *A. aquitana* (Mayer, 1861), H = 14 mm, right valve, internal and external views. B) *Chama gryphoides austriaca* Hörnes, 1870, H = 19 mm, complete specimen; Ba, Bb: lower valve, internal and external views; Bc, Bd: upper valve, internal and external views. C-E) *Polymesoda convexa* (Brongniart, 1822), H = 14 mm; Ca, Cb: left valve, internal and external views; D: right valve, internal views; Ea, Eb: complete specimen, umbonal and lateral views.

The rhodolith facies of the Oligocene Porto Badisco Calcarenite

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Introduction

The Porto Badisco Calcarenite is a rhodalgal/larger foraminiferal-dominated unit exposed along the southeastern coastline of the Salento Peninsula and deposited during the late Oligocene on the southern part of the Apulia Carbonate Platform (Parente, 1994; Bosellini et al., 1999). In contrast with other carbonate units exposed along the coastline that are mainly represented by clinostratified deposits (see next chapter), the Porto Badisco Calcarenite is horizontally bedded, onlapping the underlying formations and infilling pre-existing depressions, like in its type locality at the Porto Badisco cove where it reaches its maximum thickness of about 50-60 m (Bosellini et al., 1999). Scattered outcrops document the original distribution of the Porto Badisco Calcarenite from Capo d'Otranto to the Ciolo cove to the south.

The base of this formation is everywhere characterized by a clear erosional unconformity and marked by a spectacular 1-1.5 m thick horizon rich in rhodoliths (Bosellini & Russo, 1992; Bosellini et al., 1999; Brandano et al., 2010). The upper contact, visible at the Ciolo cove and west of the Porto Badisco cove, is analogously represented by an unconformity that is overlain by the Serravallian-Tortonian phosphatic hardground known as the “*Aturia level*” (Vescogni et al., 2018).

As regards the depositional setting, the Porto Badisco Calcarenite has been interpreted as an homoclinal ramp, gradually passing from a landward shallow-water euphotic environment towards a more distal, oligophotic setting (Brandano et al., 2010; Pomar et al., 2014; Tommasetti et al., 2018).

The age of the Porto Badisco Calcarenite has been clearly redefined recently by Parente & Less (2019). According to these authors, the concurrent range of the larger foraminiferal species and in particular the presence of *Spiroclypeus margaritatus* and of *Miogypsinoides complanatus-formosensis* indicate the late Oligocene Shallow Benthic (SB) 23 Zone defined by Cahuzac & Poignant (1997). In addition, strontium isotope stratigraphy gives an age of 23.6 ± 0.5 Ma for the lower part of the Porto Badisco Calcarenite, thus assigning the age of this formation to the latest Chattian.

The rhodolith facies at Porto Badisco cove

The Porto Badisco Calcarenite is very well exposed along the NE side of the Porto Badisco cove, its type locality, where it is hosted within a paleoembayment cut into the underlying Castro Limestone and Cretaceous basement (Fig. 17). Above the discontinuity, two main facies can be distinguished:

- Lepidocyclinidae calcarenites (Fig. 18). This facies rests directly on the basal erosive surface and comprises the largest part of the Porto Badisco section. It consists of bedded deposits basically

represented by a larger benthic foraminiferal rudstone to floatstone in a packstone-grainstone matrix. The larger foraminiferal assemblage is dominated by *Eulepidina*, *Heterostegina* and *Spiroclypeus*. *Nummulites*, *Operculina* and *Nephrolepidina* make a subordinate but significant contribution. Coralline red algae, represented by crusts, nodules and small rhodoliths, are also common, associated with echinoids and small benthic foraminifera. This deposit fills a shallow channel-like depression inherited from the substrate and its thickness decreases laterally down to 1 m at the extremities.

- Rhodolith accumulation (Fig. 19). This facies consists of a lensoid horizon characterized by a dense accumulation of rhodoliths and surrounded by *Lepidocyclinidae* calcarenites. It also fills the depression inherited from the substrate, with a thickness of about 1.4 m in the central portion that decreases to 20 cm at the margins over a lateral distance of 40 m (Fig. 19). A rudstone to floatstone texture prevails, with a grainstone-packstone matrix rich in fragments of coralline algae, larger foraminifera, small benthic foraminifera and echinoid remains.



Fig. 17 Photo-mosaic of the basal part of the Porto Badisco Calcarenite, Porto Badisco cove (modified from Brandano et al., 2010).



Fig. 18 Detail of the larger foraminiferal rudstone rich in lepidocyclinids (Porto Badisco cove).



Fig. 19 Overview of the spectacular accumulation of rhodoliths of the Porto Badisco Calcarenite (Porto Badisco cove).

This spectacular accumulation of rhodoliths has been the subject of a detailed study carried out by Brandano et al. (2010). In particular, two subfacies have been recognized based on textural features: rhodolith rudstone and rhodolith floatstone.

The rhodolith rudstone can be observed in the central portion where rhodoliths exhibit either an ellipsoidal or subspherical shape, with a maximum diameter of about 3.5 to 8 cm. They are characterized by a laminar, rarely columnar inner arrangement, and the nuclei, up to 1.5 cm in size, consist of medium-grained skeletal grains. These rhodoliths are multispecific, with melobesioids that dominate the algal assemblages and usually occur in the external portion of the coating sequence, together with subordinate mastophoroids in the inner portion and sporolithaceans. Melobesioids include the genera *Lithothamnion*, *Phymatholiton* and *Mesophyllum*. Mastophoroids are represented by *Spongites*, *Lithoporella* and *Karpathia*. *Sporolithon* is the genus recognized among sporolithaceans.

The rhodolith floatstone occurs mainly at the margins of the lentoid horizon. Here, rhodoliths are mainly ellipsoidal, with the maximum diameter that varies between 4.5 and 9 cm. These rhodoliths are also multispecific and are dominated by sporolithaceans and melobesioids.

Considering that fossil coralline algal assemblages can be used as paleodepth indicators (Aguirre et al., 2000), the taxonomic composition of the rhodoliths of the Porto Badisco Calcarenite suggests a growth at water depths below 30-40 m, thus in the oligophotic zone (Pomar et al., 2014). Warm tropical conditions are also inferred by the dominance of the tropical genera and abundance of larger foraminifera (Brandano et al., 2010).

According to Brandano et al. (2010), the channel-like depression inherited from the substrate topography controlled the formation of the rhodolith accumulation, acting as a trap for rhodoliths formed at shallower depth as suggested by the changes in taxonomic composition and inner structure from the first to the final growth stage. The abundance of mastophoroids and the dominance of the laminar growth-structure in the inner portion of the rhodoliths in the rudstone subfacies indicate an

initial growth in a shallower, high-energy setting. In contrast, the dominance of the columnar structure and the dominance of melobesioids in their external portions suggest that the final growth-stage occurred in a deeper, lower energy environment. Moreover, the dominance of rhodoliths with a laminar/columnar structure in the floatstone subfacies indicates moderate to low-energy conditions, thus suggesting a clear change of the hydrodynamic regime across the channel.

Finally, as the rhodolith horizon is bounded by a flat surface above which rhodoliths are absent and beds are tabular, it has been inferred that the rhodolith accumulation ended as soon as the channel depression was totally filled (Brandano et al., 2010).

The Oligocene coral reef complex of the Castro Limestone

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Introduction

The coral reef complex of the Castro Limestone Fm is one of the best-preserved Oligocene coral reefs of the Mediterranean paleobiogeographic province, thus representing a valuable model for those coral reefs that formed during the Oligocene, which is considered worldwide the apex of Cenozoic reef growth.

The Castro Limestone crops out for about 28 km along the southwestern coastal strip of Salento, from the Leuca cape to Otranto, as an alignment of discontinuous outcrops. It overlies, through a disconformity surface, the Cretaceous substrate and discontinuous Eocene carbonate deposits. It is overlain by the Porto Badisco Calcarenite Fm. The most spectacular outcrops of the Castro Limestone, where stratigraphic, sedimentary and palaeontological features can be observed in detail, are located in the area between Castro and S. Cesarea (Fig. 20a). The maximum width is about 3 km and the thickness, ranging from a minimum of 5 m to a maximum of about 80-100 m near Castro and the Zinzulusa cave, is related to the physical accommodation space available during deposition, which was minimum on the platform and maximum along the slope (Bosellini & Russo, 1992; Bosellini et al., 1999).



Fig. 20 A) Location map of the main Castro Limestone Fm outcrops; B) Succession of the different reef paleoenvironments projected along a NW/SE oriented transect (modified from Bosellini et al., 2021).

First briefly described by Rossi (1969), the Castro Limestone has been repeatedly studied since the 1990s until very recently. The studies of Bosellini & Russo (1992) and Bosellini (2006) provided important information about its stratigraphic setting and facies pattern, together with a preliminary characterization of the coral assemblages. In particular, these authors interpreted this unit as a fringing reef complex, with a well-developed E-W oriented paleobathymetric profile including a back reef environment, a bioconstructed coral margin and clinostratified slope deposits.

Bosellini & Perrin (1994) provided a further description of the Castro Limestone coral assemblage by means of qualitative and quantitative analyses focusing on the back reef environment. Quite recently, the fringing reef depositional model has been questioned by Pomar et al. (2014), who interpreted the Castro Limestone as a meso-oligophotic, distally steepened ramp. According to these authors, the coral fauna was mainly confined to the mesophotic belt, forming scattered mounds but with no evidence of a wave-resistant framework.

More recently, Bosellini et al. (2021) revisited the Castro Limestone, combining facies analysis with the first detailed characterization of its coral fauna. Results show that the Castro Limestone is characterized by a rich coral fauna and a large reef volume, representing a luxuriant fringing reef formed within the euphotic zone in clear water conditions facing the open sea.

A paleobathymetric profile of the Castro Limestone depositional system (Fig. 20b) has been reconstructed projecting along a NW/SE oriented transect (Fig. 20a) the positions, geometries and stratigraphic features of the five studied sections, coupled with sedimentary data and the palaeoecological constraints of the biotic assemblages (Bosellini et al., 2021). It is thus possible to show, over a distance of about 2.4 km, the succession of different paleoenvironments and related facies ranging from the shallow back reef to the fore reef slope, similar to the previous interpretation by Bosellini & Russo (1992).

The confirmed fringing reef interpretation is largely based on physical stratigraphic relationships that are directly observable in the field, among which are: 1) the occurrence of a rocky escarpment (Cretaceous limestone, with scattered Eocene cover) mantled by the clinostratified breccia and megabreccia of the Castro Limestone (Zinzulusa section); 2) the occurrence, 2-3 km from the present shoreline, of a “Cretaceous highland”, higher than the adjacent Oligocene sediments; 3) the occurrence of a well-developed coral framework (S. Cesarea section) and of thin sandy facies, horizontally bedded and with scattered corals (Vitigliano and La Scogliera sections), landward of the clinostratified slope deposits (Fig. 20b).

As regards its age, the Castro Limestone has been firstly dated to the early Chattian on the basis of the larger foraminifera association (Bosellini & Russo, 1992; Parente, 1994). According to the Shallow Benthic (SB) Zones defined by Cahuzac & Poignant (1997), this age corresponds to the SB 22B zone. More recently, Bosellini et al. (2021) assigned the Castro Limestone to the middle-late Chattian on the basis of the recognition of *Miogypsinoides* that appeared at the base of the SB 23 Zone.

As regards the coral fauna of the Castro Limestone, the numerous studies have produced a large collection represented by a total of 223 specimens (and 146 thin sections) that are currently housed at the Department of Chemical and Geological Sciences of the University of Modena and Reggio Emilia.

Through the study of this collection, 25 genera and 41 species have been identified, illustrated and described (Bosellini et al., 2021) (Fig. 21). These results underline a remarkable high taxonomic richness for the Castro Limestone coral fauna that, coupled with the high values of coral cover (up to the 64% in the S. Cesarea section), testify to local/regional physiographic conditions suitable for coral reef growth along the SW margin of the Apulian carbonate platform during a period characterized by warming conditions (Late Oligocene Warming Event) and reduced pCO₂ values.

CASTRO LIMESTONE Taxa	EOCENE									OLIGOCENE										MIOCENE								extant genera																										
	Spain	Paris Basin (France)	Veneto, Friuli (N Italy)	Bavaria (Germany)	Croatia	Bosnia	Bulgaria	Hungary	Libya	Sulawesi (SE Asia)	Spain	Aquitaine (France)	Veneto (N Italy)	Liguria (NW Italy)	Salento Peninsula (NW Italy)	Bavaria (Germany)	Austria	Slovenia	Romania	Greece	Bulgaria	Hungary	Libya	Iran	United Arab Emirates	Somalia	Spain		Aquitaine (France)	Provence (S France)	Piedmont (N Italy)	Slovenia	Hungary	Romania	Greece	Turkey	Libya	Egypt	Iran	Pakistan	Tanzania													
<i>Acropora proteacea</i>		x													x																														x									
<i>Acropora salentina</i>															x																																							
<i>Actinacis rollei</i>		x	x										x	x	x	x	x	x	x					x	x	x	x																											
<i>Agathiphyllia apenninica</i>													x	x	x									x																														
<i>Alveopora cf. daxensis</i>											x			x														x																										
<i>Alveopora rudis</i>		x	x									x	x	x	x	x			x																																			
<i>Antiguastrea ingens</i>												x	x	x																																								
<i>Antiguastrea michelottina</i>	x	x	x				x	x				x	x	x									x	x																														
<i>Astreopora decaphylla</i>	x	x										x	x	x	x							x	x																															
<i>Astreopora meneghiniana</i>		x	x									x	x	x								x						x	x																									
<i>Astrocoenia bistellata</i>			x								x			x													x																											
<i>Caulastrea pseudoflabellum</i>	x	x	x									x	x	x	x	x	x	x	x						x																													
<i>Cyathoseris</i> sp.1															x																																							
<i>Cyathoseris</i> sp.2															x																																							
<i>Diploastrea adscita</i>													x	x																																								
<i>Diploastrea multisepta</i>												x	x	x														x																		x?								
<i>Dipsastraea cylindracea</i>													x	x																																								
<i>Favites neglecta</i>												x	x	x								x				x																												
<i>Goniastrea profunda</i>															x													x	x	x	x																							
<i>Goniopora microsidera</i>		x	x									x	x	x	x	x			x																																			
<i>Goniopora nummulitica</i>		x	x									x	x	x	x																																							
<i>Goniopora rotundata</i>															x																																							
<i>Goniopora rudis</i>	x	x	x									x	x	x	x							x					x																											
<i>Hydnophora pulchra</i>													x	x																																								
<i>Hydnophyllia costata</i>													x	x	x	x																																						
<i>Hydnophyllia scalaria</i>		x											x	x	x	x						x	x?				x																											
<i>Leptomussa variabilis</i>	x	x				x						x	x	x	x								x			x																												
<i>Montastraea hilarionensis</i>		x				x							x	x																																								
<i>Montastraea incrustans</i>												x			x																																							
<i>Montastraea irradians</i>		x	x	x								x	x	x												x																												
<i>Pachyseris exarata</i>															x																																							
<i>Pavona minuta</i>															x	x																																						
<i>Pavona paronai</i>													x		x	x																																						
<i>Porites cf. collegniana</i>													x															x	x	x	x																							
<i>Siderastrea pulcherrima</i>															x	x																																						
<i>Stylococenia taurinensis</i>	x	x	x			x	x	x				x	x	x	x								x	x			x																											
<i>Stylophora conferta</i>		x		x								x	x	x																																								
<i>Stylophora thyrsoformis</i>												x	x	x	x												x	x																										
<i>Stylophora tuberosa</i>													x		x																																							
<i>Tarbellastraea russoi</i>															x																																							
<i>Tarbellastraea salentinensis</i>															x																																							

Fig. 21 Stratigraphic and geographic distribution of the Castro Limestone coral species (from Bosellini et al., 2021).

The fore reef facies at the Zinzulusa Cave

The reef slope represented by the distal and deeper fore reef facies crops out along the seashore NE of the town of Castro, next to the karstic cave named Zinzulusa (Fig. 20). It is here represented by a 12 m thick succession of clinostratified, massive beds (Fig. 22) characterized by a E/SE dip between 20° and 30° and hosted within a 400 m long paleoembayment cut into the Cretaceous substrate.



Fig. 22 Overview of the clinostratified beds of the Castro Limestone reef slope, Zinzulusa section.

The most significant characteristic of this facies is the abundance of corals, which are represented by large fragments and whole colonies, sometimes in growth position, forming discontinuous rudstone and floatstone accumulations. Prevalent textures are packstone and grainstone, with abundant fragments of corals, coralline red algae and larger foraminifera (large *Nephrolepidina* tests associated with *Heterostegina*, some rotaliids, small nummulitids, rare miliolids and alveolinids). Planktonic foraminifera are also common together with fragments of echinoderms, mollusks and bryozoans. Some rudist fragments have been recognized, witnessing the contemporaneous dismantling of the underlying Cretaceous bedrock.

About 15 scleractinian coral genera and 20 species have been identified by Bosellini et al. (2021), with the most common genera being represented by massive and tabular colonies of *Actinacis*, *Antiguastrea*, *Astreopora*, *Goniopora*, *Porites*, *Hydnophora*, *Favites*, *Astrocoenia* and *Agathiphyllia* (Fig. 23). Within the branching coral rubble, fragments of *Stylophora* and *Acropora* have been recognized. The Zinzulusa outcrop is also the type locality of a recently erected species of the genus *Acropora*, *A. salentina*, which was described by Wallace and Bosellini (2015). Massive colonies that have been measured range in size from 30 to 85 cm in length and to 20 to 80 cm in height. Several solitary corals are also present.

Typical of the slope facies is also the common occurrence of a fine-grained, geopetally laminated glauconitic sand filling intercoral cavities and small fractures (Fig. 24). Microfacies analysis of this sediment revealed its close similarity to the phosphatic deposits of the “*Aturia level*” (Vescogni et al., 2018), a Serravallian/Tortonian hardground from which this material could have filtered by a series of fractures and through the primary porosity of the Castro Limestone reef slope.

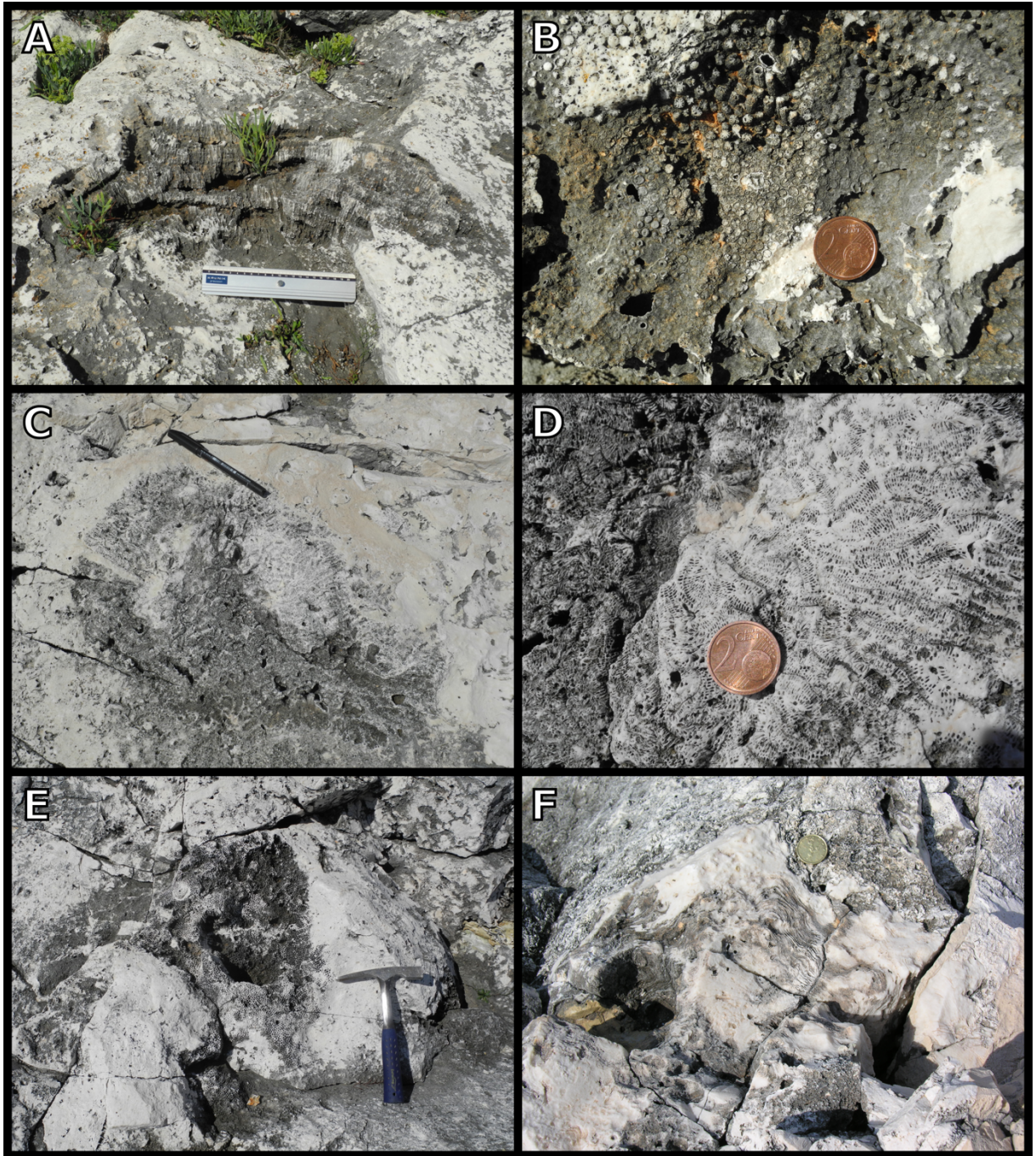


Fig. 23 Some scleractinian coral colonies, Zinzulusa section. A) *Montastraea incrustans* (Osasco); B) *Astreopora decaphylla* Reuss; C) *Hydnophora pulchra* Michelotti; D) detail of *Hydnophora pulchra* Michelotti; E) *Antiguastrea michelottina* (Catullo); *Actinacis rollei* Reuss.



Fig. 24 Glauconitic sand pocket within the Castro Limestone reef slope, Zinzulusa section.

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