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PALAEONTOLOGICAL AND SEDIMENTOLOGIC CRITERIA FOR HIGH RESOLUTION ENVIRONMENTAL ANALYSIS: THE PLEISTOCENE SUCCESSION AT TORRE OVO (SALENTO, SOUTH ITALY)

Assunta D'Alessandro, Francesco Loiacono
Dipartimento di Geologia e Geofisica, Università di Bari
Corresponding author: A. D'Alessandro <tina@geo.uniba.it>

ABSTRACT: D'Alessandro A. & Loiacono F., *Palaeontological and sedimentologic criteria for high resolution environmental analysis: The Pleistocene succession at Torre Ovo (Salento, South Italy).* (IT ISSN 0394-3356, 2010).
The about 15 m thick middle and upper Pleistocene succession outcropping near Torre Ovo (south of Taranto, Salento), contains diverse assemblages of body and trace fossils. The assemblages are sensitive indicator of environmental parameters and allow to recognize stratigraphic key surfaces and infer sedimentation dynamics. The lower unit (1) is a marine faintly layered muddy fine sand, that may be attributable to the middle Pleistocene. The following unit (2) is a marine calcarenite, possibly deposited during M.I.S. 5.5. Blocks of algal calcarenite included in the basal transgressive lag are reworked from inferred M.I.S.7 deposits. The succession ends with a continental unit subdivided into sub-units 3A and 3B, which are late Pleistocene or Holocene in age. Unit (1) includes rare trace fossils in paramoudra-preservation. During a phase of subaerial exposure in a hot, semi-arid climate, the deposit was subjected to intense vadose diagenesis. Unit (2) can be subdivided into four sub-units: 2A and 2B represent the trangressive systems tract, 2C records the condensed maximum flooding zone, and 2D the regressive systems tract. Greyish calcarenite (3A), laps onto the basal part of unit 2. Its upper part includes pebbles and blocks of sub-unit 2D. The sediment is pervasively bioturbated (*Camborygma* shafts). This ichnogenus is indicative of a terrestrial environment, firm substrate and is influenced by the ground water level. Sub-unit 3B, partly coeval to sub-unit 3A, is a reddish terrigenous conglomerate including few *Camborygma* shafts in rare sand lenses. Tentatively, the deposit has been attributed to M.I.S 3.

RIASSUNTO: D'Alessandro A. & Loiacono F., Criteri paleontologici e sedimentologici per un'analisi ambientale ad alta risoluzione: la successione pleistocenica di Torre Ovo (Italia meridionale, Salento). *(IT ISSN 0394-3356, 2010).*
Lungo la costa ionica del Salento, nell'area di Torre Ovo (a sud di Taranto), affiora una successione, attribuibile al Pleistocene medio e superiore, di spessore variabile (al massimo circa 15 metri) che contiene diverse associazioni di fossili in senso stretto ed icnofossili. Le associazioni sono indicatori di parametri ambientali e permettono di riconoscere importanti superfici stratigrafiche nonché di dedurre le dinamiche deposizionali della sedimentazione. La successione è divisibile in tre unità. L'unità inferiore (1), composta da una alternanza di straterelli siltosi fangosi e di livelletti sabbiosi più sottili (generalmente inferiori a 2 cm), include rare tracce fossili con conservazione paramoudra *e disperse impronte esterne di nassariidi nel sedimento più fangoso. Può essere correlata a depositi affioranti in prossimità di Taranto ed attribuiti al Pleistocene medio. La sovrastante unità (2) è una calcarenite marina, i cui sedimenti furono depositati probabilmente durante MIS 5.5. L'unità 2 è stata suddivisa in quattro sotto-unità: 2A e 2B rappresentano il system tract trasgressivo, 2C ricorda la zona condensata del* maximum flooding*, e 2D il* system tract *regressivo. La successione termina con una unità continentale divisibile nelle sotto-unità 3A e 3B del Pleistocene superiore o dell'Olocene. La calcarenite grigiastra (3A) si addossa sulla parte basale della unità 2. La sua parte superiore include ciottoli e blocchi della sotto-unità 2D. Il sedimento è pervasivamente bioturbato (*Camborygma shafts*).Questo icnogenere è indicativo di ambienti terrestri, substrato compatto ed è influenzato dal* ground water level*. La sotto-unità 3B, in parte coeva alla sotto-unità 3A, è un conglomerato terroso che include lenti sabbiose contenenti rare* Camborygma*. Tentativamente, il deposito è stato attribuito a M.I.S. 3.*

Key Words: Environmental changes, Paramoudra, *Camborygma*, Quaternary.

Parole-chiave: Cambiamenti ambientali, Paramoudra, Camborygma, Quaternario.

INTRODUCTION

Marine terrace deposits outcropping along the coastal area of western Apulia have been repeatedly investigated. Geomorphologic and stratigraphic descriptions and chronologic reconstruction of the deposits near Taranto were provided by different authors (i.e. Dai Pra & Hearty, 1992; Belluomini & *alii,* 2002; Caputo, 2007), but the age of the coastal deposits, their palaeogeography and local uplift history have yet to be elaborated. The study area (Fig.1) was chosen for the presence of different sedimentary bodies and trace fossil assemblages that may allow us to infer sequences and depositional environments. The primary purposes of this study are thus (1) to examine biotic changes and interpret their probable causes, and (2) to infer from ichnofossil assemblages some factors biasing the depositional environments.

GEOLOGICAL SETTING

The Ionian coast of Salento peninsula is located on the eastern flank of the Taranto Valley, considered to be the present foredeep area of the Southern Apennines Chain-Bradanic Trough-Apulian foreland system (Pescatore & Senatore, 1986).

The Apulian unit is characterized by Mesozoic limestones unconformably covered by Pliocene and Quaternary deposits more than 500 m thick in the Gallipoli Basin (well Lieta 1, Agip, 1977) (Fig. 1). The Pliocene deposits are represented by a calcarenite unit containing fossils that belong to the early Mediterranean Pliocene Molluscan Units (MPMU1) (D'Alessandro *et alii*, 2004), i.e. to a tropical unit that disappears about 3.0 Ma ago (Monegatti & Raffi, 2001, 2007). This unit is transgressed by a lower Pleistocene calcarenite with boreal immigrants, or by greyish muds attributed to the "Argille Subappennine" Formation (Upper Pliocene-Middle Pleistocene). From the Middle Pleistocene onwards the regional uplift and glacio-eustatic sea-level changes produced several marine terraces, some characterized by calcarenite or mixed deposits or by coastal calcarenitic/calciruditic bodies (communication of F.L.), others represented by abrasion surfaces. In particular, transgressive episodes, dated 125-85 ka, are recognized in the Taranto area (Hearty & Dai Pra, 1985; Dai Pra & (Hearty, 1992).

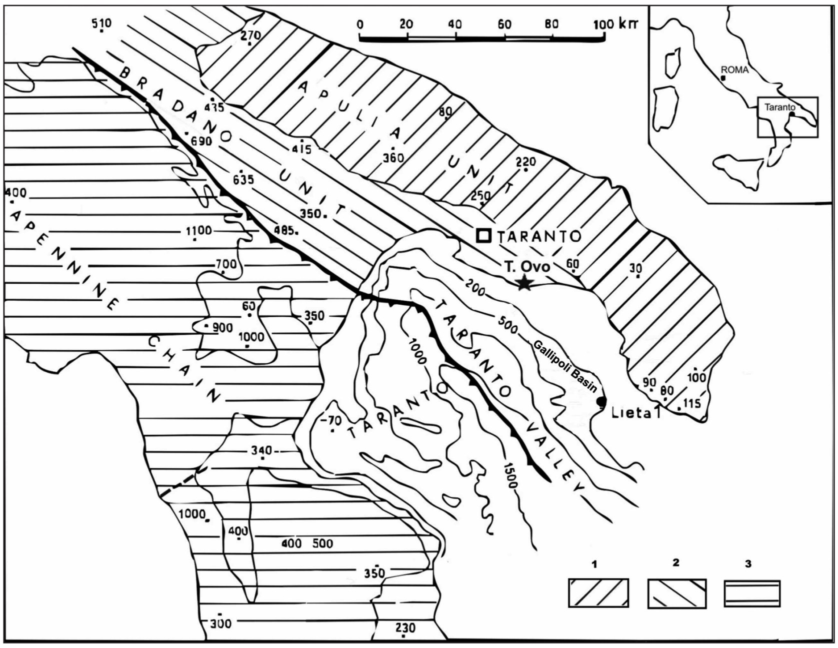

Fig. 1 - Location map of study area and recent bathymetry (in metres) of Taranto Gulf. The toothed line corresponds to the front of the allochthonous trust sheets of the Apennines (modified from Pescatore & Senatore, 1986). 1: Apulian foreland, 2: Bradanic Foredeep, 3: Southern Apennines Chain unit.

Localizzazione dell'area studiata e batimetria attuale (in metri) del Golfo di Taranto. La linea dentellata corrisponde al fronte delle falde di sovrascorrimento alloctone dell'Appennino (modificato da Pescatore & Senatore, 1986). 1: Avanpaese apulo, 2: unità della Fossa Bradanica, 3: unità della Catena Appenninica.

Belluomini *et alii* (2002) present results regarding the ages of different units on the basis of morphological evidence and palaeontological characteristics. Different tectonic settings have been inferred for the Taranto coastal area. The evidence suggests tectonic uplift also in post-Tyrrhenian times, even though certain indicators of past sea-level stands are lacking (Ferranti *et alii*, 2006).

Recent offshore research reveals a present-day shelf-slope system (Pescatore & Senatore, 1986) characterized by a shelf of varying widths, cut by several channels, and by terraces linked to recent transgression. Rapid sedimentation and catastrophic failures are the main processes affecting this depositional system, which is connected to the deep Taranto canyon.

THE LOCAL SUCCESSION

The stratigraphic succession, displaying an overall thickness of about 18 m, crops out along the sides of a low hill, on top of which a coastal medieval tower stands (Torre Ovo, Fig. 2). In vertical succession, a variably exposed greyish muddy fine sand is transgressed by a marine biocalcarenite (exposed for about 11 m). Pervasively bioturbated yellowish bioclastic sand, locally preserved as brownish biocalcarenite, lay in disconformity against the older deposits. The basal part of this last unit is locally included in a reddish terrigenous conglomerate. Two measured sections are schematically drawn in Fig.3.

Fig. 2 - The Pleistocene succession near Torre Ovo hill: marine muddy silt (1), marine calcarenite (2). The unit 3, laying in disconformity on Units 1 and 2, is composed by a brownish calcarenite (3A), and a reddish terrigenous conglomerate (3B).

La successione pleistocenica affiorante presso la collinetta Torre Ovo: silt fangosi marini (1), calcarenite marina (2); l'unità 3, trasgressiva sulle precedenti unità, è composta di una calcarenite brunastra (3A) e da un conglomerato terroso rossastro (3B).

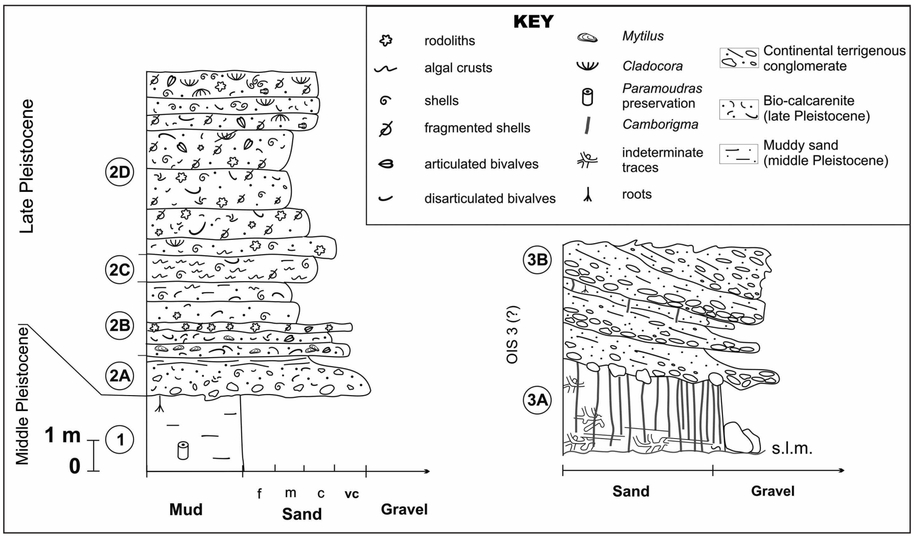

Fig. 3 - Log of two studied sections.

Log di due sezioni studiate.

UNIT DESCRIPTION AND INTERPRETATION

UNIT 1

The exposed part of the unit is composed of gently layered greyish muddy fine sand (Pl. 2, 7) which coarsens upwards and is mainly composed of angular quartz grains and minute plant debris. The layers, 2-4 cm thick, are normally graded from fine sand to silt. The shelly macrofauna is represented only by dispersed external moulds of *Nassarius* cf. *limatus*, whilst aragonite shells have disappeared. In the present-day Mediterranean, this species is considered preferential of Muddy Detritic Bottom (DE) and of Coastal Detritic Bottom (DC) biocoenoses (CALDARA *et alii*, 1989). The ichnofossils are represented by minute sinuous galleries (≈1 mm wide, bioturbation index (BI) = 3-4, locally), associated with few scattered galleries (around 5-6 mm wide), passively filled with red sand, some meniscus structures and rare large burrows up to 30cm wide (BI =1) in paramoudra-preservation (Pl. 1, 1-3). The trace fossils, therefore, suggest reworking by meiofaunal organisms, mobile worms, burrowing echinoids, and crustaceans. The upper surface of the unit is irregularly erosional and is underlain by a concentration of pedogenic chalky nodules (Pl. 1, 5) and by few clasts reworked from older deposits occurring below and on the erosional surface of unit 1 (Pl. 1, 4; Pl.2, 6).

On the basis of general features, the unit has been correlated to nearby deposits attributed to Middle Pleistocene by BELLUOMINI *et alii* (2002).

Interpretation. The biotope, dominated by burrowing organisms, was possibly located in a protected zone of the deep inner shelf. The fossil community could be compared to a facies of the Recent Muddy Sand (SE) biocoenosis under stressing conditions. The development of shelly benthic fauna was probably hampered by the high frequency of physical disturbance and, maybe, by amensal relationships. The disappearance of aragonite shells and the presence of numerous chalky nodules, some of which can be attributed to rhizoliths, suggest emergence and sub-aerial exposure of the deposit during a warm and dry period. During this period an intense, vadose diagenesis, was possibly responsible for *paramoudra*-preservation. BROMLEY *et alii* (1975), in deeper deposits, partially anoxic, suggest an early diagenesis for *paramoudras.*

UNIT 2

Unit 2, about 11 m thick, is mostly represented by calcarenite and secondarily by calcirudite beds, and may be subdivided into four sub-units (2A to 2D):

Sub-unit 2A

This interval about 120 cm thick consists of calcirudite grading upwards into medium-grained calcarenite. The basal surface is sharp and irregular. The lowermost bed (20 cm in thickness) is composed of granules (around 2-3 mm) and pebbles (2-3 cm) including a few rounded blocks of *paramoudras* (on average 6-7 cm, occasionally up to 20 cm in diameter) and sub-angular clasts of algal calcarenite (up to 25 cm), reworked from the older units (Pl. 1, 5, Pl. 2, 6). Upwards the deposit gradually changes into coarse calcarenite with a few allochthonous shells and, at the top, into fine calcarenite characterized by hummocky cross-stratification.

In the coarse calcarenite, some shells of *Patella aspera, Gibbula varia, Monodonta turbinata, Columbella rustica, Arca noae, Conus mediterraneus, Cerithium vulgatum, Lima lima, Exaplex trunculus* and *Mitrella scripta* occur either dispersed or forming lenses of randomly oriented, sparse shells.

Removal and dragging of shells from fossil communities comparable to those of the present-day Mediterranean sea (*sensu* PÉRÈS & PICARD, 1964) of nearshore and inner shelf biotopes, i.e. GI (Infralittoral Gravels), HP (*Posidonia* Meadows) biocoenoses in the coarse calcarenite and SGCF (Coarse Sand and Fine Gravel under Bottom Current), SFBC (Fine Well Sorted Sand) biocoenoses in the fine calcarenite, may be deduced, in agreement with the physical structures which suggest a shoreface setting (the acronysms are those used by the same AA).

Sub-unit 2B

This sub-unit is a package of beds about 250 cm thick. The lower interval is composed of normally graded (rudite to medium-grained calcarenite) composite beds, bounded by planar-parallel surfaces. A single massive biocalcirudite bed is composed of coarse bioclasts and bounded by wavy surfaces (Fig. 4). The subrounded clasts are mostly calcareous algae, bryozoans, and mollusc shells which are commonly bioeroded (mostly *Entobia geometrica*). These are included and seat in a mixed quartz-bioclastic matrix.

The lowermost bed of this unit is characterized by a thin discontinuous sedimentologic concentration of densely packed, convex-up and imbricated, complete valves of *Mytilus galloprovincialis* (Pl. 2, 2) with indeterminable gastropod fragments encrusted by calcareous algae. The following layer includes discontinuous flat concentrations of loosely packed convex-up mytilid valves, replaced upwards by *Glycymeris glycymeris*, mostly in small concentrations with valves chaotically oriented or nested (Pl. 2, 9). Rarely shells of *Cerithium vulgatum*, disarticulated *Ostrea edulis* valves bearing *Entobia laquea*, and *Emarginula elongata* have been observed. Dispersed and randomly oriented disarticulated shells are less common upwards; rarely, complete valves occur nested and grouped in flat lenses. Most abundant are specimens of *Bolma rugosa* and ellipsoidal rhodoliths, followed by a few valves and shells of *Chlamys* and *Aequipecten*, rare mytilids, *Venus verrucosa, Spondylus gaederopus, Glycymeris glycymeris,* and *Cerithium vulgatum*. In this part of sub-unit 2B the fauna is represented by allochthonous and parautochthonous components.

Fig. 4 - Sub-unit 2B. To note the bed (1), 20cm thick, bounded by wavy surfaces.

Sotto-unità 2B. É evidenziato uno strato (1), spesso 20cm, limitato superiormente ed inferiormente da superfici ondulate.

The upper 50 cm of the interval is composed of whitish, poorly compacted, medium-grained bioclastic sand with some dispersed *Bolma* shells and rare *Manupecten pesfelix, Chlamys multistriata*, and *Pecten jacobaeus* valves; locally this deposit is more fossiliferous and includes nested and stacked valves and sparse gastropods (mainly *B. rugosa)*. Upwards, a few crusts of calcareous algae are added.

The fossil assemblages, composed of typical elements of different Recent biocoenoses (AP – Photophilous Algae -, SFBC, SGCF) suggest that a certain percentage of the shells were transported and accumulated by storm-induced flows on a soft substrate of the inner shelf. Upwards, the autochthonous and parautochthonous fossils indicate a transition to a deeper paleocommunity located in the middle shelf, comparable to a shallow facies of the Recent-day DC biocoenosis. The appearance near the top of crusts of calcareous algae denotes a transition toward a new facies of the palaeocommunity.

Sub-unit 2C

The massive interval is made up of a bio-calcirudite bed (80 cm thick), white (greyish when weathed) due to the abundance of irregular crusts of Peyssonnellaceae included in a bioclastic mud matrix. A discontinuity surface, indicated by an abrupt compositional change (from poorly fossiliferous sand to compacted algal calcarenite), marks the base. The bioclasts are represented by large (on average 5÷6 cm in diameter) crusts of calcareous algae, with dispersed molluscan and bryozoan fragments. Unbroken fossils are dispersed, mostly belonging to *Bolma rugosa*, whose shells are normally encrusted by calcareous algae, and secondarily to *Manupecten pesfelis* and *Neopycnodonte cochlear* (Fig. 5).

This association is comparable to the Recent "*Coralligène de plateau*" biocoenosis (Pérès & Picard, 1964), recently considered a low-energy facies of the Coastal Detritic biocoenosis. The development of the free Peyssonnellaceae facies needs alternate periods of whirling by storm-induced currents and of decantation in a quiet sea (Pérès, 1967).

Fig. 5 - Detail of sub-unit 2C.

Dettaglio della sotto-unità 2C.

Sub-unit 2D

This interval is a whitish medium- to fine grained biocalcarenite, about 600 cm thick. It is predominantly made up of composite beds, 1 m thick on average, formed by 2÷3 sub-layers individually grading upwards from calcirudite into fine calcarenite. The calcirudites are composed of abundant rounded rhodoliths, mollusc fragments of variable sizes, celleporiform bryozoans, *Cladocora*, and rare unbroken macrofossils.

In general, composite beds increase in number upwards. The laminar-foliose algal crusts and *Manupecten pesfelis* decrease and disappear upwards, the former more rapidly than the latter. *Bolma rugosa* shells decrease in abundance but increase in size, whereas rhodoliths with closely spaced short branches, celleporiform fragments, *Glycymeris valves*, and deeply bioeroded valves of *Spondylus gaederopus* increase. A few large fragments of *Cladocora coespitosa* or complete colonies of it, albeit not in life position, appear in the upper part. The upper 40 cm are characterized by biogenic concentrations made up of densely packed to dispersed fossils mostly represented by a flat and large morphotype of *Cladocora* colonies in life positions (Pl. 1, 8), locally encrusted by tubes of *Petaloconchus subcancellatus* , and accompanied by organisms preferring shallow biotopes such as *Arca noae, Spondylus gaederopus, Cardita calyculata, Chama* sp., *Striarca lactea*, and shells of *Diodora* cf. italica, *Patella caerulea, Conus mediterraneus*, and rare *Ocenebra erinaceous*. Large-sized dispersed shells of *Bolma rugosa* occur in the fine calcarenite.

Taphonomic features, gradual taxonomic changes and growth forms of corals and calcareous algae provide evidence of palaeoenvironmental changes fostered by a trend towards lower net rate of sedimentation, increase in water energy, and higher luminosity probably linked to shallowing upward trend.

Interpretation. Unit 2 is thought to represent a depositional sequence. Lack of sediments deposited during the middle Pleistocene, and presence, in the basal lag of sub-unit 2A, of rare sub-angular clasts of algal calcarenite (possibly reworked from M.I.S.7 deposits), suggest that a ravinement surface was cut when the sea level rose during a successive late Pleistocene highstand which may be attributed to M.I.S.5.5, even though Senegalese faunal elements are lacking. This erosion is recorded by an unconformity surface covered by the lag with reworked components. The retrogradational sequence is composed of sediments deposited during the transgressive systems tract (sub-units 2A-B). During the interval of minimum rate of sedimentation (maximum flooding) characterized by a particular hydrodynamic condition, a paleocommunity comparable to the Recent "Coralligéne de plateau" biocoenosis was able to flourish (2C). The thickness of sub-interval 2C suggests a relatively long period of stillstand (in agreement with Forsström, 2001; Caputo, 2007). The succession ends with sediments (2D) deposited during the relative fall of the sea level (FSST) as suggested by the biotic changes in the fossil assemblages indicative of shallower habitats, by the taphonomic features of skeletal elements, and by the depositional features of the composite beds.

Unit 3

Sub-unit 3A.

In three outcrops, each a few hundred meters apart, dark greyish calcarenite, weathered into yellowish barren lime sand by oxidation, downlaps against the base of Unit 2, and crops out above sea level for a thickness of 2-3 metres. The quite well sorted sediment is composed of comminuted bioclastic debris and subordinately of sub-rounded quartz grains. It is pervasively bioturbated (BI = 5-6) by unwalled, passively filled, indeterminate complex burrows which in the lower part of the unit locally show gentle laminations. Long shafts (BI = 3-4) attributed to *Camborygma,* postdate the primary burrow systems. Due to differences in preservation, the deposits present variable appearances. In the northern locality the sand is compacted but not hardened, so that the ichnofossils are partly destroyed by waves; usually the shafts (Fig. 6) have been passively filled by sand, lack walls, and rare horizontal galleries of the same size can be observed. If the shafts are preserved in calcarenite, they are empty and the boundaries are thickened by diagenesis. In one outcrop, *Camborygma* shafts are absent near the sea level.

Many rounded blocks from sub-unit 2D occur in the upper part of unit 3 and completely or in part cover the *Camborygma* shafts (Pl. 2, 5). The blocks are larger landwards and disappear towards the sea.

A cross-section exposed below the tower shows the calcarenite partially lying on a small "tongue" of terrigenous conglomerate of sub-unit 3B. This calcarenite in proximity of the slump scar is thinner, more yellowish, with long shafts that rapidly decrease and disappear, so that only the indeterminate complex burrow systems are seen (Pl. 1, 6).

Fig. 6 – Subunit 3A: *Camborygma* shafts preserved in cohesive sands.

Sotto-unità 3A: colonne attribuite a Camborygma presenti nelle sabbie coesive.

Sub-unit 3B.

The subunit is only locally present and is partly coeval whit 3A. Reddish deposits, some metres thick, cut directly, the muddy silt (unit 1) or the marine calcarenite (unit 2), with a strong angular unconformity. They are composed of massive terrigenous sediments with sub-angular calcarenite pebbles and include rare large lenses of coarse sand thinning landwards (Fig. 7). The intercalated coarse sands are crossed by dispersed *Camborygma shafts* (Pl. 2, 4) with thick diagenetic walls that cross numerous tangled networks (as in unit 3A).

Interpretation. The well sorted, subrounded grains, the high density of complex boxworks, and the presence of a faint oblique stratification in the lower part of the deposits suggest an intertidal environment, possibly transitional to backshore. The presence of *Camborygma*, attributed to the continental, low-diversity *Scoyenia* ichnofacies (*sensu* Buatois *et alii*, 2002), suggests events of colonisation by continental crabs (that is crayfish) in alluvial environments with a deep and oscillating water table (Hasiotis & Mitchell, 1993; Kowalewski et alii, 1998, Buatois & Màngano, 2007). Abundance and length of shafts are related to the depth of the water table.

Large rounded blocks from unit 2 indicate that the deposits of that unit had become lithified during a phase of subaerial exposure. Moreover the absence of bioeroding and encrusting organisms suggests that the blocks underwent gravity flows along steep cliffs or coastal gullies. Thus, detrital deposits of sub-unit 3B are inferred to infill topographic depressions due to erosion and gravity failure.

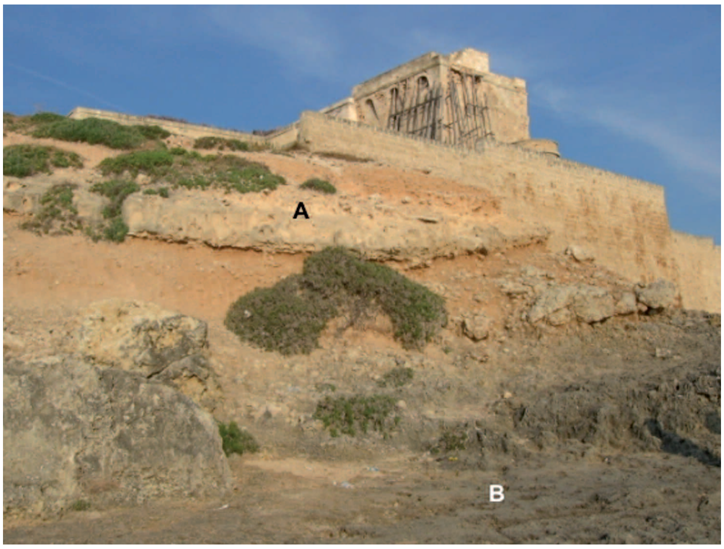

Fig. 7 - Unit 3: (A) a coarse lens of sand thins landwards; (B) abrasion surface cutting the calcarenite of sub-unit 3A.

Unità 3: (1) una grossa lente di sabbia che si assottiglia verso terra; (2) superficie di abrasione che taglia la calcarenite della sotto-unità 3A.

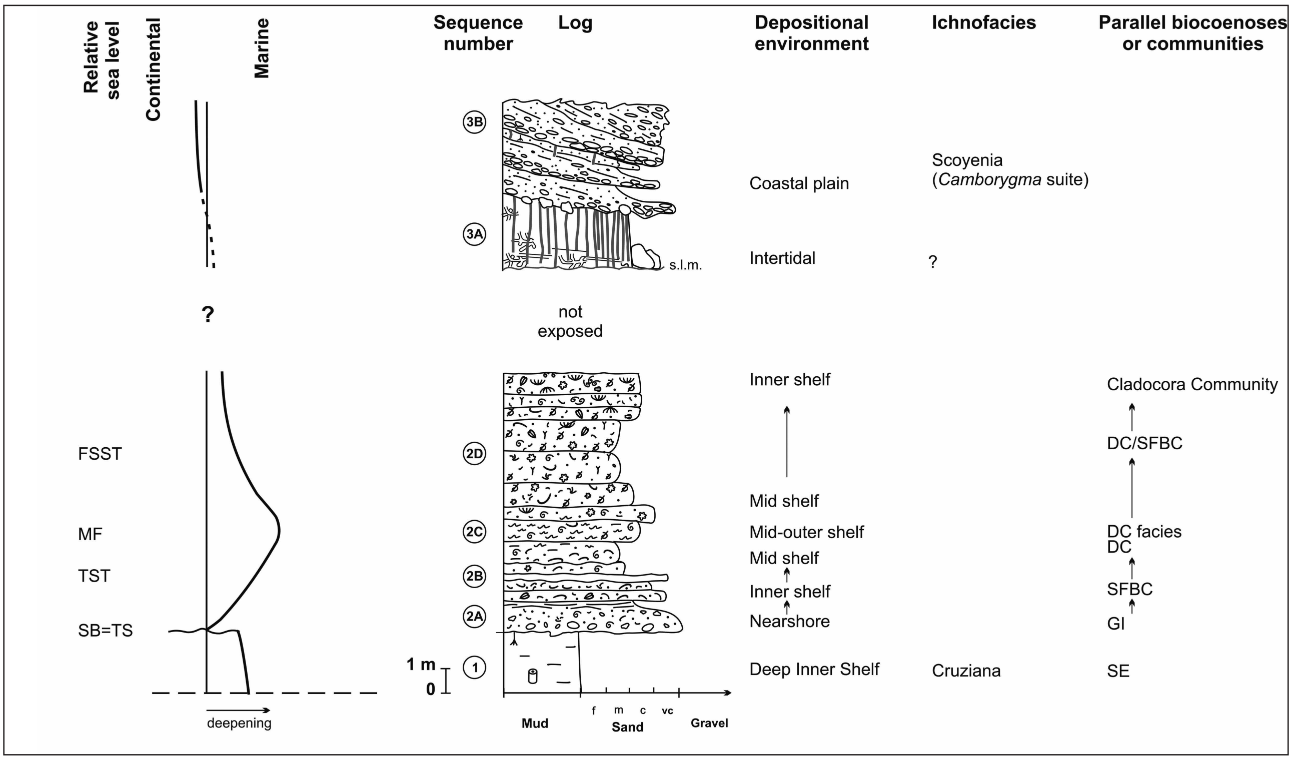

Fig. 8 - Inferred sequence stratigraphy of the succession (synthetic log) with inferred variation of the sea level. SB = sequence boundary; TS = transgressive surface; ecotone between biocoenoses are linked wish slash mark; arrows indicate trends between community changes.

Supposta sequenza stratigrafica della successione (log sintetico) con le variazioni dedotte del livello del mare. SB = limite di sequenza; TS = superficie di trasgressione; gli ecotoni fra le biocenosi sono collegati con slash mark; le frecce indicano le tendenze dei cambiamenti di comunità.

The sub-unit 3B is similar to pinkish/red deposits cropping out south of Taranto and referred by Belluomini *et alii* (2002) to M.I.S 3.

DISCUSSION AND CONCLUSION

The integrated analysis of the Torre Ovo stratigraphic succession is a contribution to reconstruct the sedimentary evolution and the controlling factors during the Middle-Late Pleistocene in this stretch of Salento coast. The sequences recognized and correlated in the studied sections (Figs. 3, 8) allow to distinguish the following events: deposition of marine muddy fine sand (Unit 1, inferred age middle Pleistocene) was followed by a drastic relative sea-level fall. This lead to subaerial exposure and erosion in a hot, semi-arid climate of both unit 1 and an algal calcarenite (possibly middle Pleistocene, M.I.S.7), as indicated by the presence of reworked paramoudras and calcarenitic blocks into the lag of the overlying marine unit (Unit 2). The latter can be regarded as a depositional sequence. The transgressive systems tract, represented by calcirudite and calcarenite beds, is followed by a fossiliferous facies that records condensation. The succession ends with sediments deposited during the falling stage system tract. A sea-level fall or local uplift of the area caused the subaerial exposure of Unit 2.

Younger deposits (Unit 3) downlap against part of units 1 and 2. Features of the unit suggest a transition from quasi-marine to continental settings characterized by periodically subaerial exposure as confirmed by the freshwater ichnofacies. The deposit of sub-unit 3A is pervasively bioturbated. The long shafts record an event of opportunistic colonisation by crayfishes, on firmgrounds characterized by a fluctuating freshwater table. Subsequent erosion of the top of sub-unit 3A, sub-rounded blocks from sub-unit 2D found on the erosive surface, deposition of massive, terrigenous sediments and gravity flows all agree with the suggested evolution.

Finally, an abrasion surface, about 30 cm above the present coastline (Fig. 7), cuts the deposits of sub-unit 3A, thus suggesting a new phase of sea level highstand.

SYSTEMATIC ICHNOLOGY

Ophiomorpha-like structures
in paramoudra-preservation

(Pl. 1, 1-3)

Description - In a yellow-greenish muddy silt unit, rare solitary sub-cylindrical structures sub-vertical and transversal occur. Commonly large parts of fallen down “cylinders” are piled up at the foot of the sections and allow a precise description of the structures. The large “cylinder” is composed of one central, apparently unbranched tube, 3-4 cm. wide, passively filled with rarely preserved brown, compacted muddy sand. The tube is surrounded by a thick wall of yellow siltstone lithologically similar to the enveloping sediment, hardened by vadose diagenesis in form of “paramoudras”. The diameter of the complete structure can be up to 30 cm (Pl. 1, Fig.3). The biogenic central tubes may represent the ichnogenus *Ophiomorpha*; the interpretation is doubtful because of the poor visibility of the ichnotaxonomic features. The transverse galleries commonly are weakly deformed or flattened (Pl. 1, 1-2). The central tubes are usually enlarged by water circulation, and appear as empty galleries 8-9 cm wide.

Comparison - These solitary structures differ from *Okinawatubus cylindricus* Noda in features of the external tube, which in our specimens are produced by cementation of the enclosing silty mud.

PLATE 1
TAVOLA 1

Figs. 1-3 - *Ophiomorpha* like in paramoudra-preservation. (1, 3) two large fragments crashed down: 1) is a vertically flattened specimen, 3) it is about 30 cm. wide; (2) a vertical exposition: the central gallery is surrounded by an incompletely formed and deformed paramoudra.

Gallerie simili a quelle di Ophiomorpha con conservazione paramoudra. (1,3) due grossi frammenti crollati: 1) esemplare appiattito trasversalmente, 3) diametro di circa 30 cm. (2) esemplare in posto visibile su una parete verticale: la galleria centrale è circondata da una struttura paramoudra non completamente consolidata e deformata.

Fig. 4 - Unconformity surface between the muddy silt (Unit 1) and the lag of sub-unit 2A. To note the numerous chalky nodules into the muddy silt, suggesting diagenetic alteration of roots.

Superficie di inconformità fra i silt fangosi (Unità 1) e il lag della sotto-unità 2A. Notare la presenza di numerosi noduli carbonatici nel silt fangoso che suggeriscono una alterazione diagenetica di radici.

Fig. 5 - Basal part of sub-unit 2A transgressive on Unit 1. Pebbles and reworked components of older units are present into the lag.

Parte basale della sotto-unità 2A trasgressiva sulla Unità 1. Il lag contiene ciottoli e componenti rimaneggiati delle unità più vecchie.

Fig. 6 - Below the slump scar, the calcarenite of sub-unit 3A is yellowish and bioturbated by indeterminate boxwork systems that replace the lateral ichnoassemblage characterized by the long shafts.

Sotto la nicchia di distacco, la calcarenite della sotto-unità 3A è giallastra e bioturbata da indeterminati sistemi biogenici tridimensionali che sostituiscono l'icnoassociazione laterale caratterizzata da lunghi shafts.

Fig. 7 - Oblique section of sub-unit 3A showing densely packed *Camborygma* shafts.

Sezione obliqua della sotto-unità 3A mostrante l'alta densità dei Camborygma shafts

Fig. 8 - Sub-unit 2D: *Cladocora coespitosa* in life position.

Sotto-unità 2D: Cladocora coespitosa in posizione di vita.

PLATE I

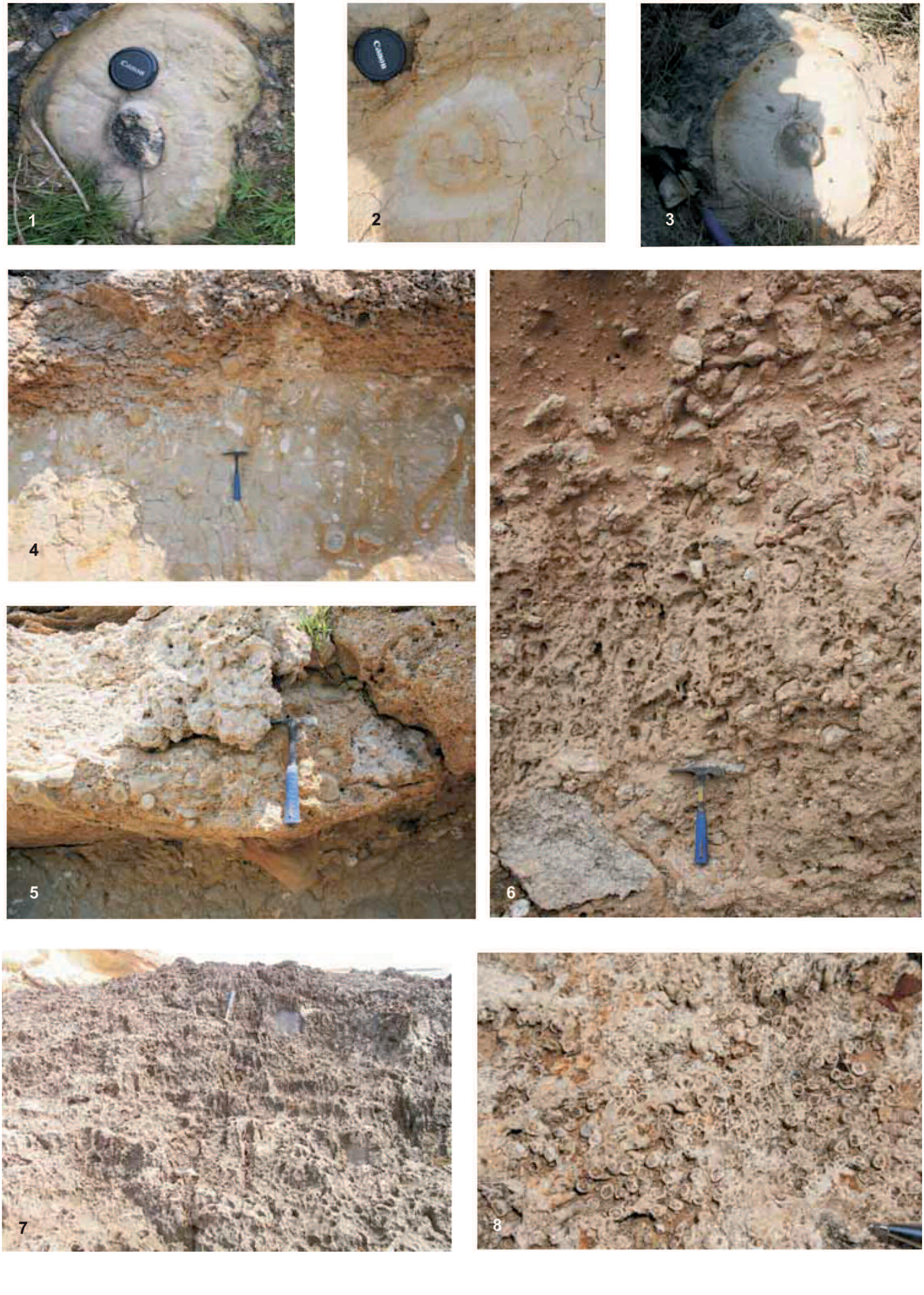

PLATE II

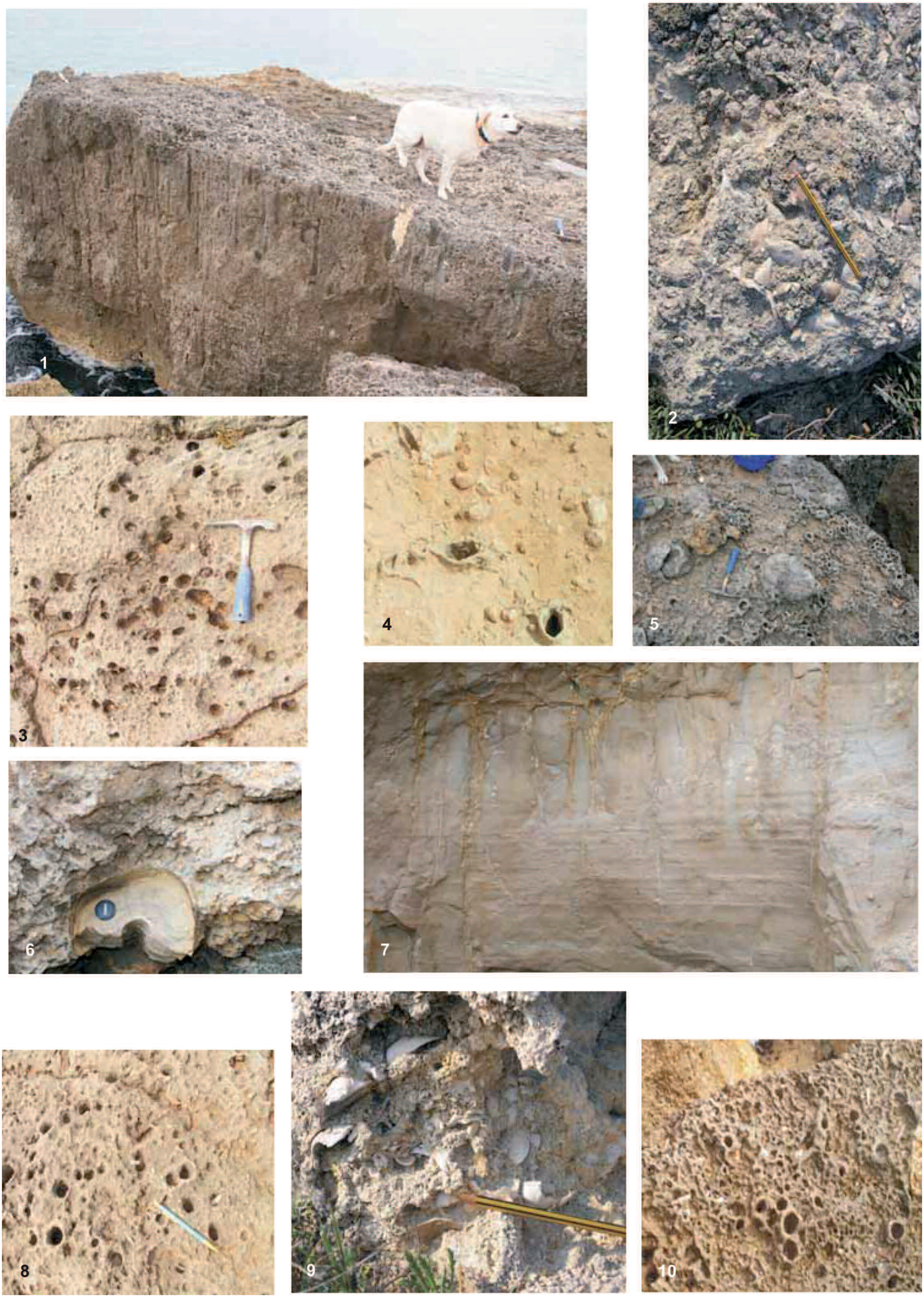

PLATE 2
TAVOLA 2

Fig. 1 - *Camborygma* shafts preserved in sub-unit 3A.

Camborygma shafts fossilizzati nella sotto-unità 3A.

Fig. 2 - Sedimentological concentration of densely- to loosely packed disarticulated valves of *Mytilus galloprovincialis*. Top view.

Concentrazione sedimentologica di valve disarticolate di Mytilus galloprovincialis la cui densità varia da densely- to loosely packed (sensu Kidwell, 1991). Veduta dall'alto.

Figs. 3, 5, 8, 10 - *Camborygma shafts* in sub-unit 3A. Note the different dispositions of the shafts. Figure 5: blocks from unit 2 failed in the calcarenite sub-unit 3A, partly cover shafts of Camborygma. Hammer for scale.Top view.

Camborygma shafts nella sotto-unità 3A. Notare la differente disposizione degli shafts. Nella figura 5 si può notare che la formazione delle tracce è precedente alla deposizione dei ciottoli i quali ricoprono i Camborygma shafts. La scala è indicata dal martello. Veduta dall'alto.

Fig. 4 - The dispersed shafts in the subunit 3B show thicker "burrow lining" and somewhat larger diameter (6-7cm) compared with those of sub-unit 3A.

Le tane della sotto-unità 3B sono molto minori e dispersed rispetto a quelle della sotto-unità 3A; inoltre hanno "pareti" più spesse e in alcuni casi un diametro superiore (6-7cm).

Fig. 6 - Large fragment of "paramoudras" in the lag of sub-unit 2A.

Frammenti di grandi dimensioni di paramoudras nel lag della sotto-unità 2A.

Fig.7 - Unit 1, detail of the layered muddy silt and muddy fine sand. The vertical structures can be mud craks filled by sediment of overlying unit 3A.

Unità 1, dettaglio dell'alternanza degli straterelli di silt fangoso e di sabbie fini fangose (straterello più esile e più chiaro). Le strutture verticali sono probabilmente fratture da disseccamento, riempite dal sedimento dell'unità 3A.

Fig. 9 - *Glycymeris glycymeris* valves chaotically oriented and nested or convex-up in small pavements.

Valve di Glycymeris glycymeris orientate caoticamente e "annidati" o disposti con le convessità in alto, in esili concentrazioni.

Camborygma cf. eumekenomos Hasiotis and Mithchell

(Pl. 1, 7, Pl. 2, 1-3-4-8-10)

Description - Sub-unit 3A: Straight shafts, more than 2 m long (Pl. 1, 7, Pl. 2, 1), range in diameters from 2 - 6 cm occur empty in calcarenite and passively filled in firm sand. In horizontal thin-sections the shaft boundary shows compaction of adjacent sediment. Where sand infilling is preserved (presumably in the basal part) horizontal galleries of the same size as the shafts are present and can be interpreted as corridors described in *C. eumekenomos.* The superficial morphology, poorly preserved due to present-day erosion, is an array of irregular, minute knobby structures. The shafts commonly are loosely to densely packed (Pl. 2, 3-8-10). Where occasionally two of them are in contact they have an oval-shape being partly fused.

The rare and dispersed shafts that occur in the sand bed of *sub-unit 3B* are those with a large diameter (6-7 cm) and somewhat thicker "burrow linings" due to diagenetic mineralization (Pl. 2, 4).

In both *sub-units* the shafts never cross each other.

Comparisons - Skolithos linearis, commonly shorter and thinner, is similar for in also having a simple, vertical shape. Dense burrows of *Skolithos* have been recorded from freshwater and terrestrial settings (e.g. Boutois and Mángano, 2004; Melchor *et alii*, 2006;) although Skolithos ichnocoenosis is more typical of lower littoral to infralittoral, moderate to high-energy conditions (Frey *et alii*, 1990). However, features of the Torre Ovo traces, palaeontological and granulometric features of sub-unit 3A, as well as their occurrence in the undoubtedly terrestrial sub-unit 3B suggest an attribution to *Camborygma* burrows made by continental crabs in firm sediments.

Psilonichnus upsilon, which in modern environments is typically present in the uppermost foreshore and backshore of beaches, dunes, washover fans and tidal flats, is morphologically quite different. *Psilonichnus tubiformis* can reach lengths of over 200 cm, but is characterized by short side branches at irregular intervals; the Y- or U-shaped tube continues downward as a straight to slightly curved or somewhat twisted tube (Nesbitt and Campbell 2002). Cylindrical burrows up to 2 m in length, abundant in coastal muddy deposits, were attributed by Nara and Kotake (1997) to *Psilonichnus* isp. However the morphology of the surfaces of the burrows and their location in continental sand (sub-unit 3B) suggest different origin of our ichnofossils.

Remarks - The burrows have been attributed to *Camborygma* cf. *eumekenomos* mostly for their size and surface features, even though the presence of basal corridors is uncertain. The absence of chimney structures in the upper reaches of burrows can be ascribed to erosion. The burrows probably originated at the same palaeosurface. The absence of other ichnospecies of *Camborygma* may further imply that the burrows record a single generation of a monospecific tracemaker. The differences in shaft size and variation in density in the two beds may have been caused by spatial heterogeneity of the groundwater level, soil moisture and vegetation cover (Kowalewski *et alii*, 1998).

The unwalled burrows of the crayfish are well preserved due to their construction in firm substrates often subaerially exposed and pedogenically altered; in this examined case mostly for the rapid burial by terrigenous conglomerate deposits. Ichnotaxonomically, the ichnospecies is characterized by its simple architecture, lack of lining, sharp burrow boundary, and presence of bioglyphs.

The hardened shafts were emptied probably during the renewed rise of the sea level. Burrows not exposed to wave action are still filled by sands.

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