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Edited by

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THE CAPO DI FIUME STRATIGRAPHIC SECTION

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The Capo di Fiume stratigraphic section (Figs. 1, 2.1) has been discussed by many authors (e.g., Bellatalla et al., 1992; Carboni et al., 1992; Patacca et al., 1992; Mazza et al., 1995; Miccadei & Parotto, 1998; Carnevale, 2003) who have described its lithological and paleontological features with different degrees of detail. The section is composed of paralic to open marine mud-dominated Messinian deposits overlying a relatively thick "terra rossa" horizon attesting to a prolonged subaerial exposure. The "terra rossa" soil covers uppermost Cretaceous limestones, but a minor fault has locally obliterated the original stratigraphic contact.

The Cretaceous carbonates below the "terra rossa" deposits consist of medium-grained bioclastic limestones characterized by a pseudo-crystalline texture which explains the name given to this lithostratigraphic unit (Saccharoidal Limestone). Actually, the saccharoidal aspect derives from the nature of the biodetritus almost exclusively composed of abraded and worn *Inoceramus* prisms, echinoid spines and *Pithonella*-like calcisphaerulids. Large scale low-angle planar cross stratification with bidirectional dip (Fig. 2.2) points to offshore marine bars in a ramp-like open-shelf setting. The top of the Saccharoidal Limestone is characterized in the last 10-15 centimetres by a strong bioturbation, expressed by horizontal and oblique large burrows (Fig. 3.1) suggesting a nearshore stressed environment. The groundmass of the overlying red-stained illuvial

soil consists of a fine mixture of red to yellow clay minerals, Fe and Fe/Mn hydroxides, unstained silty-sized eolian quartz-grains and scarce mica flakes. The groundmass also includes isolated and

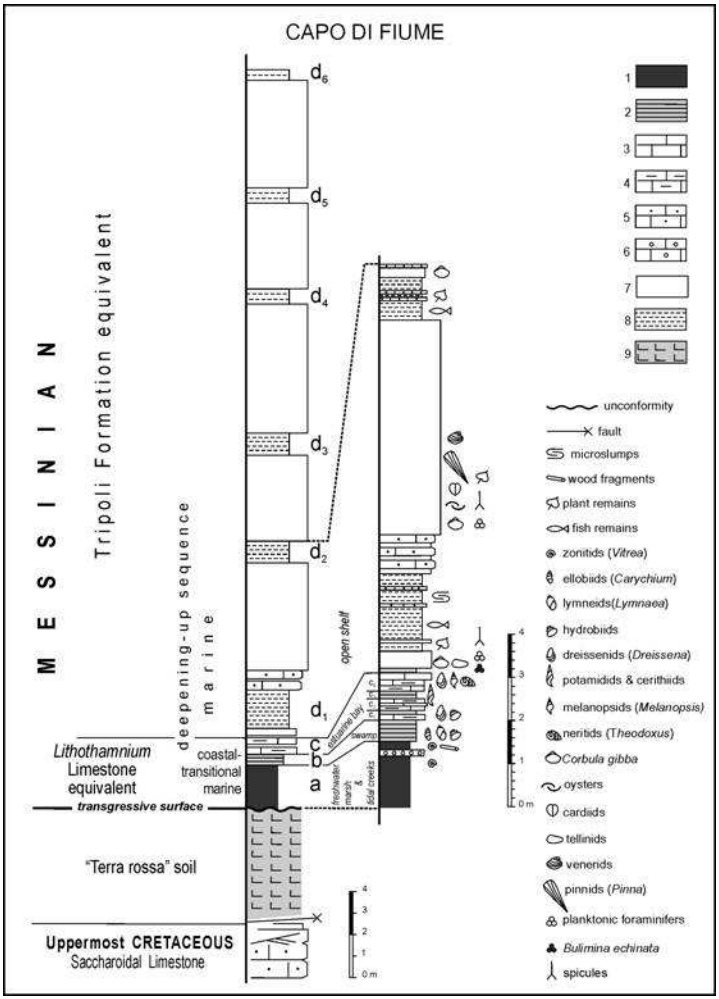


Figure 1. *Capo di Fiume stratigraphic section. Dashed lines delimitate the portion of columnar section (left hand in the picture) that has been zoomed (right hand). 1, mottled grey to dark-brown marls and clayey marls; 2, fissile dark-grey marls and shaly marls; 3, limestones; 4, marly limestones and limey marls; 5, bio-lithoclastic calcarenites; 6, lime conglomerate; 7,*

massive muddy deposit emplaced by mass-flow mechanism; 8, diatomitic marls; 9, "terra rossa" soil.

coalesced calcareous nodules, fine to medium-sand-sized subangular/subrounded carbonate lithoclasts with leached rims, locally abundant ferruginous pisoids and subordinate medium-sand-sized volcanic quartz and calcitized feldspars. The calcareous nodules consist of speckled micrite/microsparite masses precipitated in a vadose zone, frequently surrounded by an iron-enriched clayey red rim. Spar-filled circumgranular shrinkage cracks and complex networks of carbonate rhizoliths are the most common pedofeatures (Figs. 3.2 and 3.3). At places, porosities associated with root activities are partly or totally filled with well-preserved needle-fiber or whisker calcite cement of vadose origin (Fig. 3.4). The Messinian transgressive deposits overlying the "terra rossa" soil are organized into a deepening-up muddy sequence indicative of wetland to estuarine environments (**a-c** intervals in fig. 1, representing an equivalent of the *Lithothamnium* Limestone Formation), which evolves upwards into an open-marine shelf sequence (diatom-rich deposits representing an equivalent of the Tripoli Formation, see fig. 4.1). The lower portion of the sequence consists of paralic deposits represented by about 1.5 metres of grey to dark-brown mottled marls and clayey marls with very thin, lenticular beds of pebbly conglomerates (interval **a** in Fig. 1 and in Figs. 4.2 and 5.1). The pebbles of the conglomerates, characterized by pendant lower coats of white micritic chalky calcite are mainly composed of lower Cretaceous shallow-water limestones referable to a protected inner platform. Bahamian-type protected platforms were widely represented in the central-southern Apennine domains during the early Cretaceous. The marls, almost barren, consist of a micrite-sized pedogenetic carbonate with dispersed organic particles, clay minerals, fine to very fine sand-sized angular quartz grains and

subangular to subrounded calcareous lithoclasts. The pedogenic carbonate with dispersed organic particles, clay minerals, fine to very fine sand-sized angular quartz grains and subangular to subrounded calcareous lithoclasts. The pedogenic nature of these marls is also testified by the common occurrence of vadose whisker calcite inside vugs and cavities created by root activity.

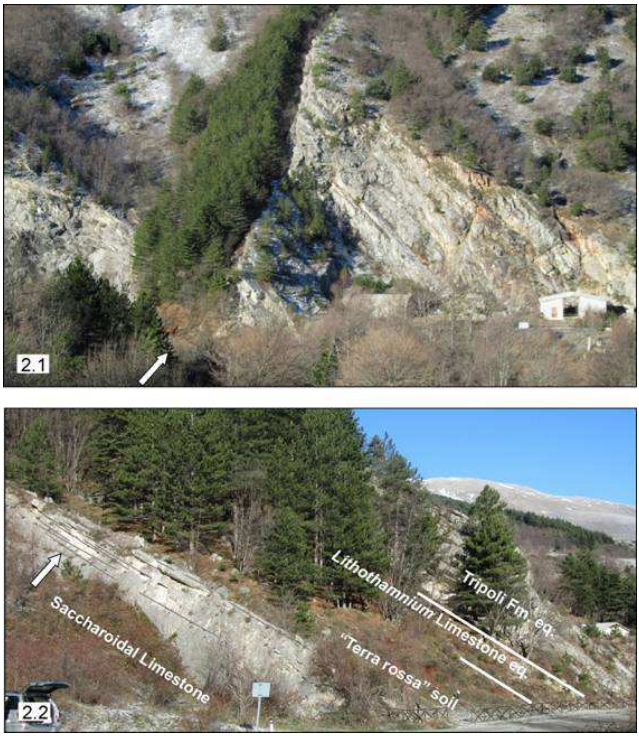


***Figure* 2.1**. *General view of the Capo di Fiume stratigraphic section. The white arrow points to the "terra rossa" soil.* **2.2**. *Capo di Fiume stratigraphic section. The "terra rossa" soil overlies upper Cretaceous ramp carbonated belonging to the Saccharoidal Limestone Formation. The white arrow indicates large-scale low-angle cross-stratification (emphasized by*

line drawing). The "terra rossa" soil is in turn overlain by Messinian deposits representing the equivalents of the upper portion of the Lithothamnium *Limestone Formation and of the entire Tripoli Formation. White lines mark stratigraphic contacts between the different lithostratigraphic units.*

The mottled appearance is actually related to the presence of a faint network of subtle root tubules stained by dispersed organic particles or filled with black microaggregates of pyrite framboids (Figs. 6.1 and 6.2), s well as to the occurrence of light-coloured carbonate rhizoliths (Figs. 6.2 and 6.3). The dark colour, the pyrite concentration, the pervasive root burrowing and the common occurrence of circumgranular cracks (Figs. 6.2 and 6.3) are all hydromorphic features indicating a moist soil formed in a humid, strongly reducing environment in which long periods of saturation allowing Fe mobility alternated with periods of intense drying causing Fe concentration. The uppermost portion of interval **a** (Fig. 5.1 above the conglomerate) is constituted of grey marly clays alternating with organic-rich black shales containing plant remains and rare fragmented shells of *Vitrea* (terrestrial pulmonate gastropod of the *Zonitidae* family, see also Carboni et al., 1992).

The **a** interval grades upwards into about 50 cm of fissile and foetid dark-grey marls and shaly marls commonly assuming a whitish colour on weathered surfaces (**b** interval in Fig.1; see also Figs. 4.2, 5.1 and 5.2). The shaly marls are characterized by thin lumachella layers made up of a species-poor assemblage of aquatic or strongly hygrophilous land gastropods referable to ellobiids (*Carychium*), lymneids (L*ymnaea*) hydrobiids and vertiginids, associated with ostracods. The gastropods are indicative of stagnant freshwater ponds (*Lymnaea*), of brackish-water environments with salinity fluctuating from hypohaline to oligohaline conditions (hydrobiids) and of a humid densely vegetated land (*Carychium* and vertiginids). In the lower portion of the **b** interval the shell marls

alternate with dark-brown to black euxinic layers rich in wood fragments displaying lighter current-driven wavy to lenticular detrital laminae (Fig. 6.4) composed of bioclastic ash, silt-sized quartz grains, diffuse organic particles, sporomorphs and very fine sand-sized calcareous lithoclasts with well-rounded shape.

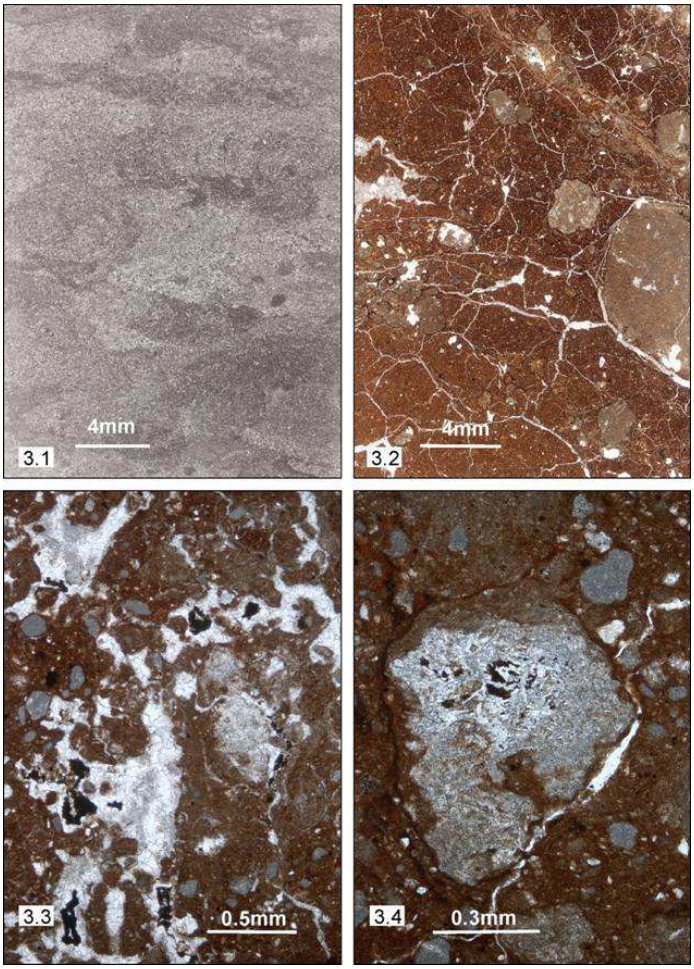
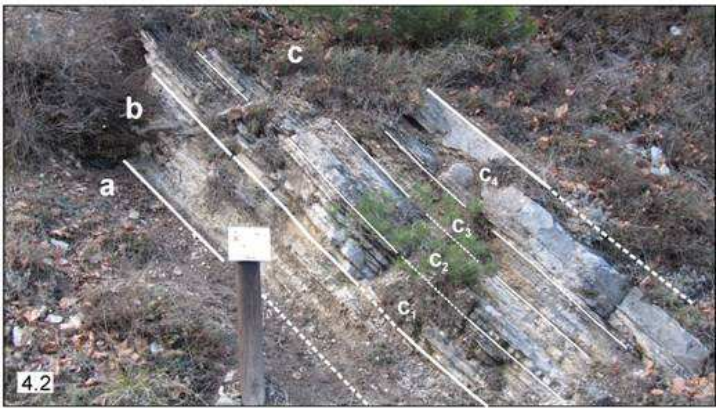


Figure 3.1. *Striated to oblique burrows at the top of the upper Cretaceous Saccharoidal Limestone.* ***3.2***. *"Terra rossa" soil. Spar-filled shrinkage cracks and carbonate nodules. In the left side of the picture, cluster of small nodules coated by a red rim of iron-enriched aluminous clays.* ***3.3***. *"Terra rossa" soil. Compound pedofeature consisting of spar and microspar-filled root channels and tubules (root residues still visible as black patches) crossed by a spar-filled discontinuous subtle network of syneresis cracks. Small calcareous lithoclasts are dispersed in the groundmass.* ***3.4***. *"Terra rossa rossa" soil. Vugs partially filled with vadose "whisker calcite" cement. The central porosity has been loosely occluded by a coarse meshwork of calcite crystal laths.*

Figure 4.1. *Capo di Fiume stratigraphic section. The picture shows the stratigraphic contact between Messinian paralic deposits equivalent to the upper portion of the Lithothamnium Limestone Formation and marine deposits equivalent to the Tripoli Formation.* $\boldsymbol{d_1}$ *and* $\boldsymbol{d_2}$ *are diatomitic levels (same label as in figure 1).* ***4.2***. *Capo di Fiume stratigraphic section. Enlarged view of the Messinian deposits equivalent to the upper portion of the Lithothamnium Limestone Formation.*
a*: top of anoxic freshwater marsh deposits;* ***b****: foetid thinly laminated swamp deposits;* ***c****: brackish-water estuarine calcareous muddy deposits. Labels* $\boldsymbol{c_1}$-$\boldsymbol{c_4}$ *indicate the lithologic intervals separated in figure 1 and described in the text.*



Both molluscs and lithofacies indicate a permanently flooded area in highly vegetated wetlands temporarily subject to feeble oscillations of salinity and to periodic slow-flowing water currents. This suggests

the existence of swamps connected to marine environments under warm temperate or subtropical climatic conditions.

The **b** interval is overlain by a more calcareous interval 1.20 m thick represented by marls, limey marls, marly limestones and subordinate limestones organized into a quite complex stratal package (interval **c** in fig. 1; see figs. 4.2 and 5.2). The heterogeneity of the lithofacies architecture is mirrored by an equivalent heterogeneity of the fossil assemblage which reflects a schizohaline environment with rapid salinity fluctuations from hypohaline to oligohaline conditions. According to the facies associations, the **c** interval can be subdivided into four portions represented by:

c_1. 30 cm of thinly laminated foetid grey shaly marls, marls and subordinate marly limestone with *Dreissena* and *Hydrobia* together with ostracods and very rare, evidently reworked planktonic foraminifers (*Globigerinoides obliquus*, *Globigerinoides trilobus*, *Globoquadrina altispira globosa* and *Orbulina universa* in Carboni et al., 1992);

c_2. 30 cm of marls and limey marls with thin intercalations of marly limestones. The fossil assemblage, mainly represented by *Dreissena*, *Melanopsis* and small neritids belonging to the genus *Theodoxus*, together with abundant cerithiids, indicates a brackish-water environment with an overall increased salinity with respect to the underlying deposits. The microfacies (Figs. 7.1 to 7.4) is dominated by very abundant calcareous calcisphaerulids representing sporomorphs or resting cysts of algae, disarticulated valves of ostracods and thick-walled *Ammonia* associated with sporadic reworked planktonic foraminifers;

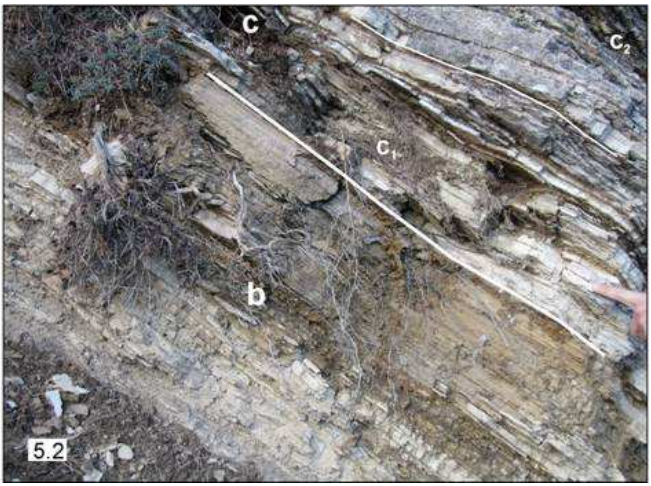


Figure 5.1. *Capo di Fiume stratigraphic section. Particular of figure 4.2 showing the uppermost portion of the freshwater marsh deposits* ***(a)*** *containing a tidal-creek pebble conglomerate and the lower portion of the overlying swamp deposits* ***(b)*** *represented by laminated foetid marls. Note the gradual transition from the lower to the upper lithofacies.* ***5.2***. *Capo di*

*Fiume stratigraphic section. Gradual transition from the laminated swamp deposits (**b**) to the overlying brackish-water estuarine-bay deposits (**c**). **c**$_1$ and **c**$_2$ intervals are characterized by mollusk assemblages indicating an overall upward increase in the salinity, in concomitance with the upward increase in carbonate content.*

c$_3$. 20 cm of grey marl and silty marls with thin beds of marly limestone intercalated in the lower portion and thin layers of black shales rich in organic matter and plant remains intercalated in the upper portion. The fossil assemblage is dominated by rich assemblages of potamidids and cerithioids of the families Cerithiidae, Diastomidae and Litiopidae, alternated with nearly monospecific associations of *Dreissena* concentrated in thin lumachella layers (Fig. 8.1). The occurrence of anoxic black horizons, the potamidid-cerithioid-*Dreissena* assemblages suggest a further increase in salinity with respect to the underlying deposits; the presence of hygrophilous terrestrial gastropods (vertiginids), even though vert rare, may be related to episodic lowering of the salinity;

c$_4$. 40 cm of limey marls and marly limestones with a limestone bed at the top. The fossil association characterizing this interval is dominated by *Dreissena*, *Melanopsis*, *Theodoxus*, cerithiids and small marine bivalves apparently belonging to the semelids associated with rare specimens of *Corbula*. The microfacies of the **c**$_4$ portion is characterised by a groundmass

c$_4$. 40 cm of limey marls and marly limestones with a limestone bed at the top. The fossil association characterizing this interval is dominated by *Dreissena*, *Melanopsis*, *Theodoxus*, cerithiids and small marine bivalves apparently belonging to the semelids associated with rare specimens of *Corbula*. The microfacies of the **c**$_4$ portion is characterised by a groundmass of calcareous sporomorphs with dispersed disarticulated valves of ostracods and very rare displaced planktonic

foraminifers. The appearance of the first marine mollusks indicates a brackish-water environment in proximity of an open-marine shelf possibly represented by an estuarine bay. open-marine shelf possibly represented by an estuarine bay.

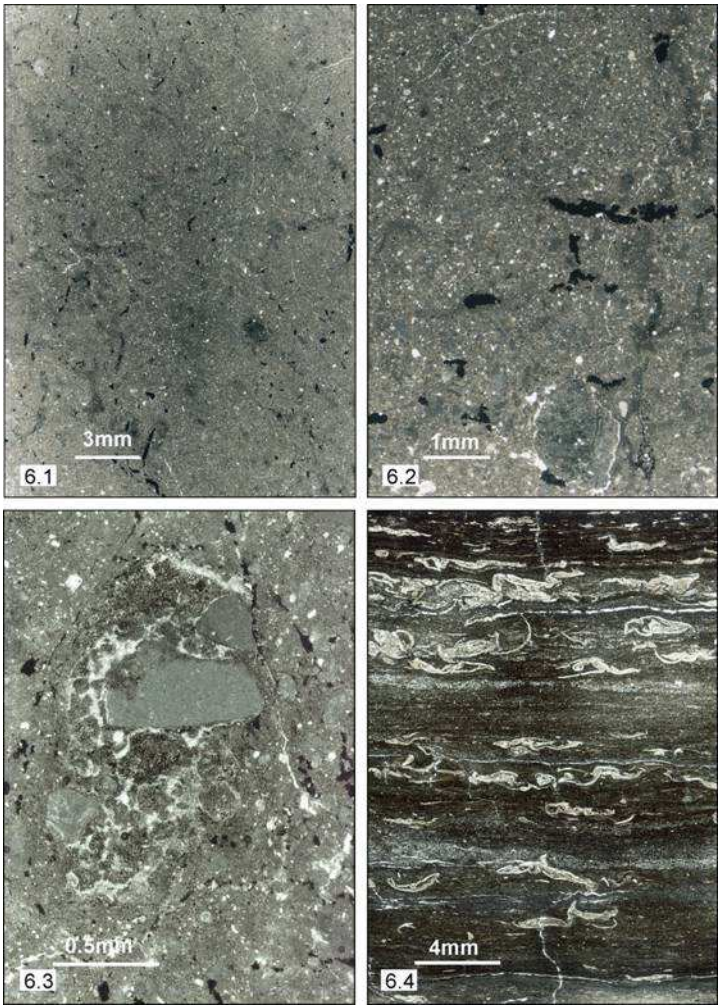


***Figure 6.1**. Capo di Fiume stratigraphic section. Microfacies of the Messinian freshwater marsh deposits of the interval **a**. Grey to brownish speckled sandy micrite with dark-stained root tubules. **6.2**. Capo di Fiume stratigraphic section. Microfacies of the Messinian freshwater marsh deposits of the interval **a**. Enlarged view of the sandy micrite showing well-preserved root tubules, some of which filled with a microaggregate of black pyrite framboids. The picture also shows an evident circumgranular crack around a nodule of carbonate rhizolith (lower side of the picture), as well as spar-filled fissures generated by syneresis processes. **6.3**. Capo di Fiume stratigraphic section. Microfacies of the Messinian freshwater marsh deposits of the interval **a**. Pedogenically-reworked carbonate with spar-filled root cavities and syneresis features. **6.4**. Capo di Fiume stratigraphic section. Microfacies of the Messinian swamp deposits of the interval **b**. Laminated black shales showing discontinuous thin lumachella layers with flattened gastropods and wavy to lenticular laminae of very fine calcarenite/calcisiltite with black veneers of wood fragments. Syneresis features are here represented by thin, spar-filled, transversal sinuous fissures and subhorizontal, flat shrinkage cracks.*

The **c** interval is overlain by approximately 30 metres of marine deposits (Tripoli Formation equivalent) represented by at least six cycles of alternating dark-grey calcareous marls and finely laminated diatomitic marls. The first marine cycle exhibits a relatively complex architecture whereas the overlying cycles primarily consist of sharp alternations of calcareous marls and diatomitic marls. In general, the sequence is characterised by a progressive decrease of thickness of the diatomitic marl intervals, which range from about 180 cm in the first cycle to 50 cm in the sixth one (Fig. 1). The sequence starts (base of the interval $\mathbf{d_1}$ in Fig. 4.1) with a moderately thin (10 cm) laminated fissile calcareous marl containing very rare dreissenids and abundant *Corbula* followed by 40 cm of massive grey limey marls. The grey marls are heavily bioturbated and characterised by a relatively abundant bivalve content (primarily *Corbula gibba* with joined valves, but also oysters, cardiids, semelids and tellinids, see Fig. 8.2).

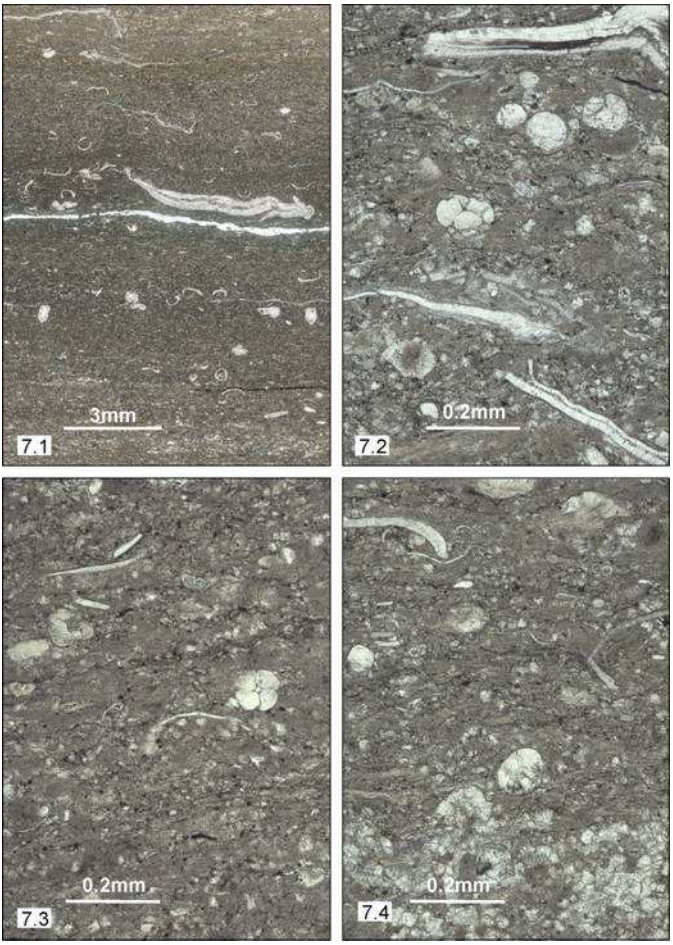


***Figure 7.1**. Capo di Fiume stratigraphic section. Microfacies of the Messinian estuarine-bay deposits of the interval **c**. Calcisphaerulid-rich packstone/wackestone with sparse flattened and crashed gastropods, thin-shelled bivalves and disarticulated thick-walled ostracods. **7.2** to **7.4**. Enlarged view of the calcisphaerulids. These problematic calcareous bodies, interpreted as calcitized sporomorphs or resting cysts of algae, are made up of welded microspheres of radially-arranged fibrous calcite lined by darker*

sutures. In the upper left side of fig. 7.3 the broken wall in one of these sphaerical calcite bodies likely represents an excystation stage.

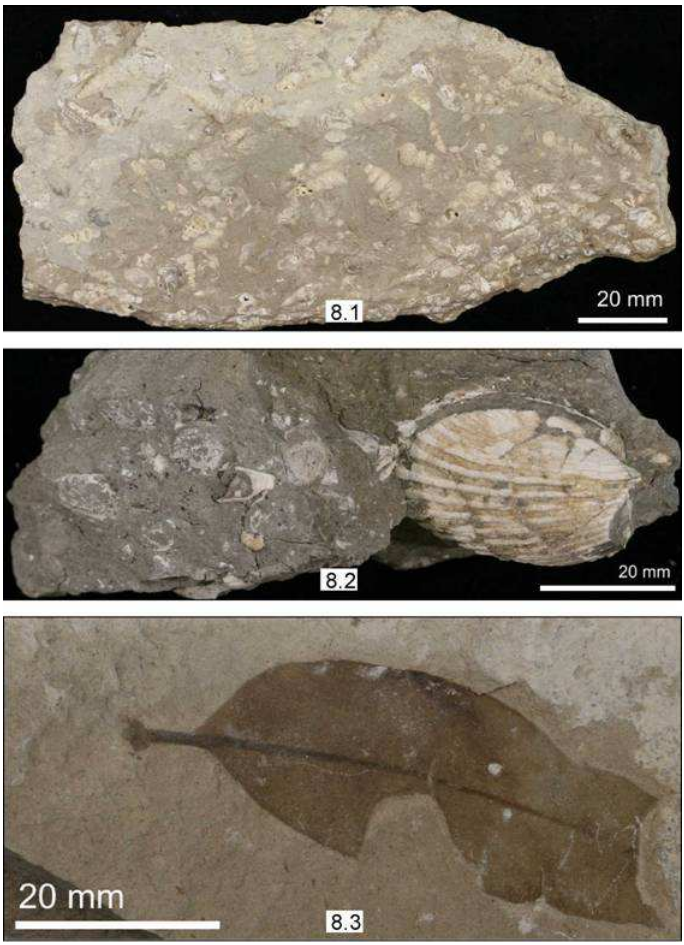


Figure 8.1. *Capo di Fiume stratigraphic section. Messinian estuarine-bay deposits of the interval* ***c3.*** *Lumachella layer containing Dreissena, potamidids, cerithiids, litiopids, and diastomids.* ***8.2***. *Accumulation of*

Corbula gibba and Lima sp. with conjoined valves from the grey marls at the base of the diatomitic interval ***d*****1** *of figure 4.1.* ***8.3****. Leave from the* ***d*****1** *diatomite horizon.*

Carboni et al. (1992) have reported the presence of several taxa of benthic foraminifers (e.g., *Ammonia beccarii*, *Bolivina* sp., *Bulimina echinata*, *Cibicides* spp., *Elphidium crispum*) plus rare globigerinids. A centimetre-thick level of dark-brown clayey marls with mollusks separates the basal laminated calcareous marl from the overlying grey marls. The fossil assemblage of these muddy deposits indicates a marine environment characterised by very turbid waters with a maximum depth of some tens of metres (10-40 metres). The textural homogeneity and the total absence of sedimentary structures related to selective transport by marine currents or coastal drift indicate subtidal conditions in a mud-dominated open coastal flat with scarce or null sand-sized sediment supply from the catchment area. These nearshore to inner-offshore deposits are followed with abrupt contact by 180 cm of thinly laminated diatomitic marls indicative of deeper-water environment (**d1** in Figs. 1 and 4.1). The basal portion of the laminated calcareous marls is characterised by reduced diatom content, abundant plant remains (Fig. 8.3) and a moderately diverse assemblage of planktonic foraminifers (*Globorotalia* spp., *Gobigerinoides trilobus*, *Orbulina universa*). As a whole, the diatomitic marls are represented by a dense series of clastic-biogenic couplets made up of siliceous laminar mats composed of interwined, felted diatom frustules alternating with calcisiltite laminae containing bioclastic ash, abundant siliceous sponge spicules, fish remains, scarce planktonic foraminifers, very rare fine-sand-sized quartz grains and dispersed phosphatic material trapped in a film of loose diatoms (Figs. 9.1, 9.2, ,10.1 and 10.2).
The macrofossil content of this diatomitic interval is relatively rich and includes well-preserved articulated skeletal remains of not less

than 22 taxa of teleost fishes belonging to 14 families, among which the clupeid *Spratelloides gracilis* is by far the dominant element, a single nearly complete articulated skeleton assigned by Mazza et al. (1995) to the ochotonid species *Prolagus* cf. *apricenicus*, bird feathers, rare decapods crustaceans, insects, bivalves apparently in life position and plant remains (leaves, seeds, pine cones, fruits).

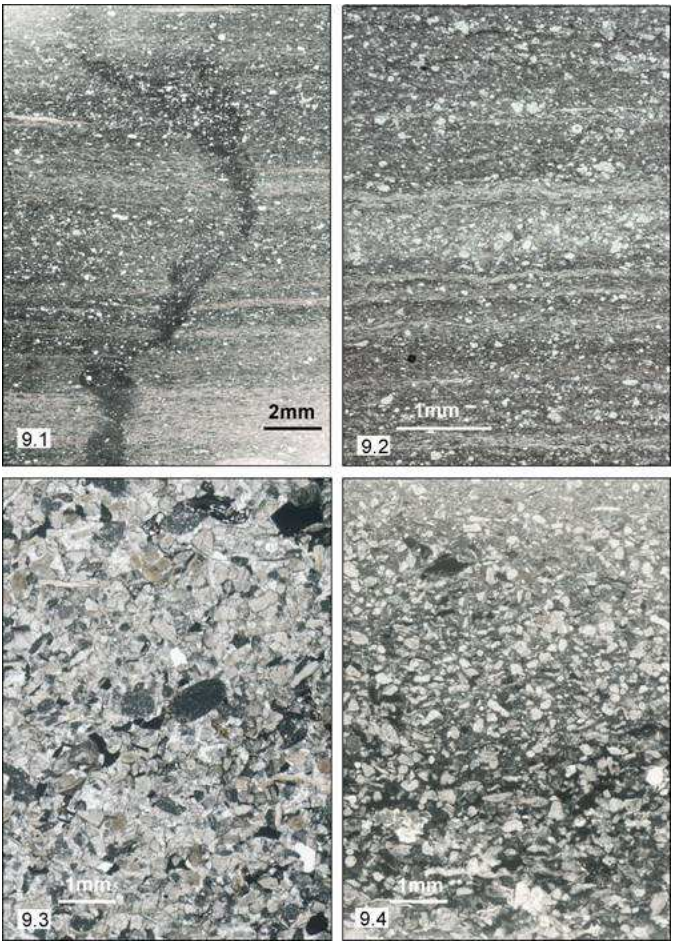
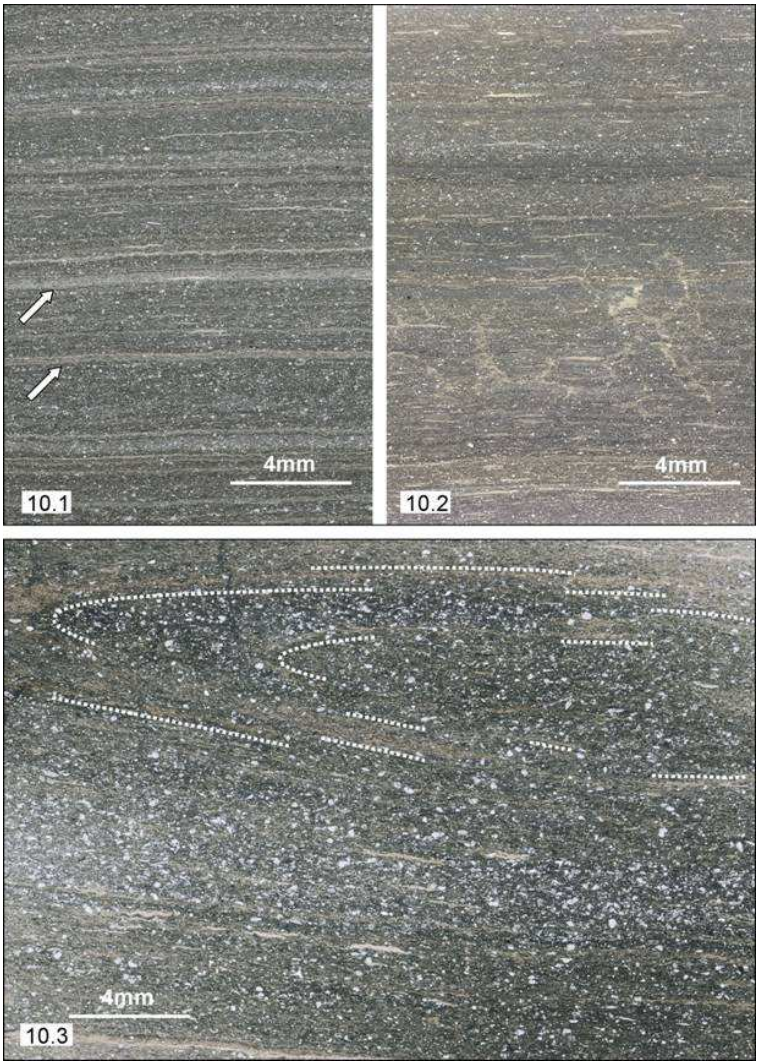


***Figure 9.1**. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation. Diatomitic marl of the **d_1** horizon. Close-up view of a dewatering microstructure preserved as a vertical pipe. Note in the lower part of the image the distinct breaking of the light-yellow diatom-rich laminae. **9.2**. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation. Diatomitic marl of the **d_1** horizon. Enlarged view of the alternating calcisiltite and diatom-rich laminae. The coarser detrital layer in the central part of the picture is indicative of sporadic feeble traction-current processes in deep water. **9.3**. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation. Calciturbidite layer in the upper portion of the **d_1** diatomite horizon. Bio-lithoclastic packstone with very well-rounded lithoclasts. **9.4**. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation. Calciturbidite layer in the Corbula-rich marls overlying the **d_1** diatomite horizon. Bio-lithoclastic calcarenite with well-developed normal grading.*

The rather scarce foraminifers are exclusively represented by ammoniids, bolivinids and rare dwarfed globigerinids (Carboni et al. 1992; Patacca et al. 1992). At about 20 cm from the base of the described diatomitic interval, a thin bed (7 cm thick) of massive mudstone containing a nearly monotypic assemblage of *Corbula gibba* with disarticulated and joined valves (see Fig. 8.2) has been interpreted as a subaqueous gravity-driven mud-flow deposit triggered by seismicity or by a sudden increase in the sediment loading related to a rapid sediment supply from the catchment area determined by an exceptional climatic event. Fluid-escape microstructures (Figs. 9.1. and 10.2) and microslumps (Figs. 10.3, 11.1 and 11.2) determined by seismicity or sediment loading are quite frequent in the upper portion of the diatomitic interval. These

sediment-instability features are associated with centimetric calciturbidite layers commonly outlined by diagenetic black siliceous rims and affected by small-scale slumping (Fig. 11.1). The calciturbidite layers consist of coarse to medium-sand-sized recrystallized bio-lithoclastic packstones containing fragments of crustaceans, serpulids, barnacles, echinoid spines, *Elphidium* sp., fish teeth and scales, as well as abundant, well-rounded lithoclasts derived from upper Cretaceous basinal limestones (Figs. 9.3 and 9.4).



***Figures 10.1** and **10.2**. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation. Diatomitic marl*

of the ***d1*** *horizon with closely spaced even-parallel laminae constituted of calcisiltites alternating with diatom-rich layers. Arrows point to some thicker light-yellow laminae made up of felted diatom frustules. In figure 10.2 an interconnected system of fluid-escape microstructures disrupts the laminae creating a kind of dish and pillar microstructures.* ***10.3****. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation. Upper portion of the* ***d1*** *horizon. Detail of a slump-related syndepositional deformation involving both calcisiltite and diatomite layers (the latter yellowish in the picture).*

Several types of biogenic laminae can be recognized based on chromatic characters, thickness, lateral extension and diatom content. The diatom content is highly variable in these laminae. Laminae characterized by high clastic content often contain a moderately diverse diatom flora (*Actinocyclus* cf. *octonarius*, *Actinoptychus* sp., *Coscinodiscus* spp., *Navicula* sp., *Rhabdonema adriaticum*, *Rhaphoneis* sp., whereas other biosiliceous laminae are characterized by monospecific or oligospecific assemblages of *Coscinodiscus* spp. and/or *Thalassionema nitzschioides* (Fig. 12). The structure and composition of the *Coscinodiscus* laminae are consistent with the so-called "fall dump", a massive sedimentation of diatoms that have grown episodically in the Deep Chlorophyll Maximum during periods of water stratification (Kemp et al., 2000), while the origin of the *Thalassionema nitzschioides* laminae is commonly associated to high productivity, nutrient abundance and bloom events (e.g., Schuette & Schrader, 1981; Sancetta, 1992). Articulated fish skeletons are primarily associated with biogenic laminae dominated by *Thalassionema nitzschioides* and/or *Coscinodiscus* sp. The excellent preservation of the skeletal remains seems to be related to the rapid mineralization mediated by microbial film that proliferated on the mucilage produced by the diatom flocs;

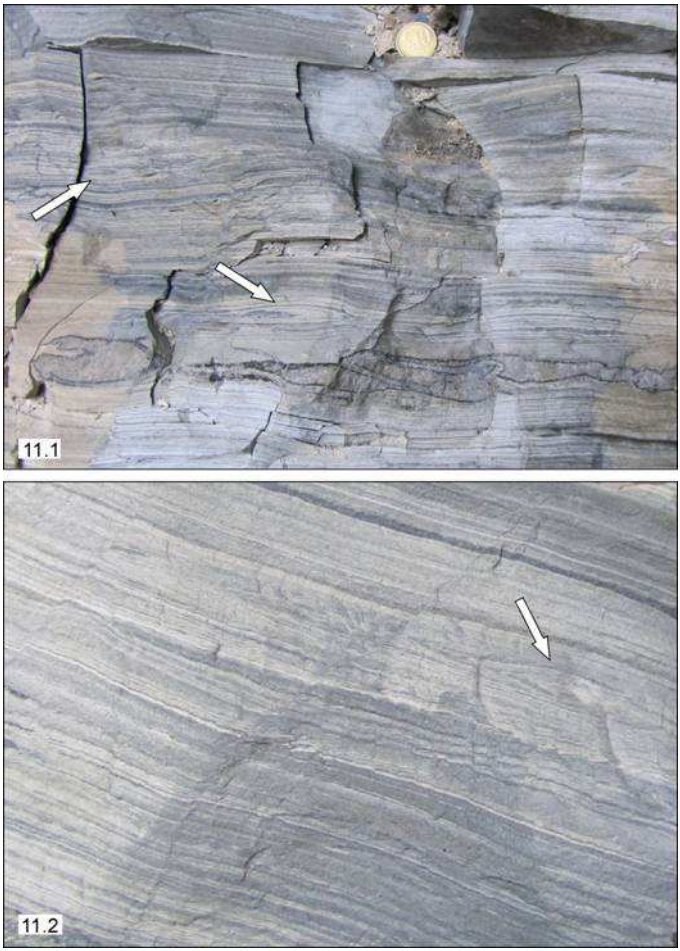


Figure 11.1. *Capo di Fiume stratigraphic section. Lower portion of the Messinian deposits equivalent to the Tripoli Formation. Diatomitic horizon* $\boldsymbol{d_1}$ *showing (see arrows) small-scale soft sediment deformation induced by slump mechanisms. In the lower part of the picture, a thicker slumped bed is evidenced by a diagenetic black siliceous rim.* ***11.2***. *Capo di Fiume stratigraphic section. Lower portion of the Messinian deposits equivalent to the Tripoli Formation. Enlarged view of the diatomitic marls of the* $\boldsymbol{d_1}$

horizon showing small-scale synsedimentary deformation by slump (arrow), as well as younger brittle deformation by microfaulting.

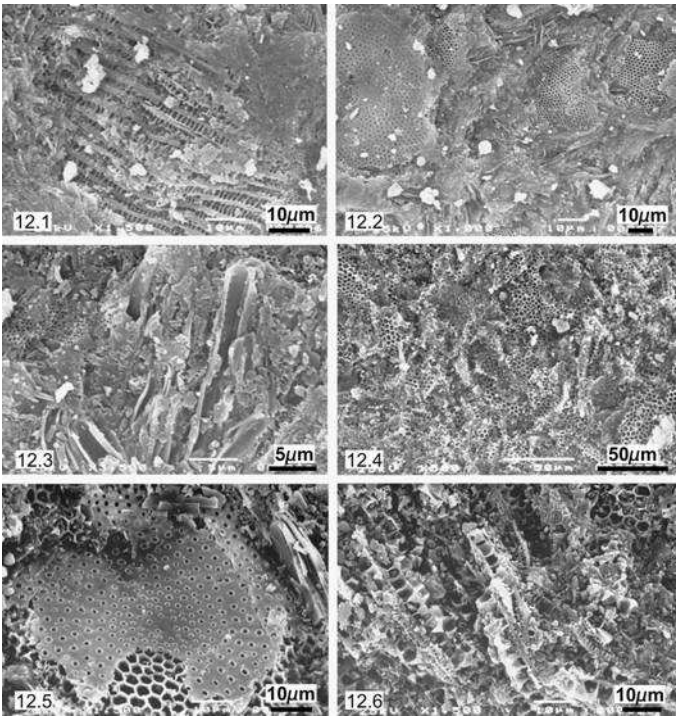


***Figure 12**. Capo di Fiume stratigraphic section. Scanning electron images of diatoms from the d_1 horizon. **12.1**. Rhabdonema adriaticum; **12.2**. Coscinodiscus–Thalassionema lamina; **12.3**. frustules of Thalassionema nitzschiodes; **12.4**. Coscinodiscus lamina; **12.5**. frustule of Coscinodiscus sp.; **12.6**. Coscinodiscus lamina.*

the sedimentary action of the microbial film is manifold since it protected the sediment from erosion enhancing the formation of laminated deposits, inhibited the complete decomposition of the

carcasses, scavenging and endofaunal settling, and promoted the rapid phosphatization of the bones and the mineralization of organic components.

The large part of the fossil fishes are very well preserved and nearly complete (Fig. 13). A few specimens exhibit various degrees of incompleteness, showing evidences of scavenging activity of weak hydrodynamic transport. The only recognized specimen belonging to the Nile perch, *Lates* cf. *niloticus*, exhibits the typical anatomical and biostratinomical characters of a prolonged post-mortem floating. Not less than 22 taxa belonging to 14 families have been identified. The clupeid *Spratelloides gracilis* is by far the dominant element of the assemblage, represented by more than 75% of the recognized specimens. The analysis of the ecological guilds indicates that assemblage primarily consists of demersal neritic and coastal epipelagic taxa, with a subordinate contingent of migratory pelagic and oceanic species. The Nile perch is the only freshwater/paralic taxon recognized in the assemblage. The heterogenous composition of the fish assemblage, characterized by the co-occurrence of coastal and opportunistic pelagic taxa, suggests the existence of rocky reefs and seagrass beds in close proximity to the depositional environment, and the presence of the Nile perch clearly indicates that a river system also contributed to the paleophysiography of the basin.

Overall, the diatom content of the biogenic laminae indicates a depositional marine environment with a water depth up to about one hundred metres. The sudden facies change from estuarine-bay to deeper-marine conditions moving from the **c** interval to the $\mathbf{d_1}$ diatomite horizon suggests a rather narrow shelf connecting coastal and basinal areas and thus favouring the accumulation of large volumes of gravity-driven deposits at a short distance from the coast.

The $\mathbf{d_1}$ diatomitic interval is overlain by about 1 metre of grey marls with intercalated centimetric calciturbidite layers (Fig.

14.1) showing evident normal grading (Fig. 9.4) and locally well-preserved erosional structures at the base. The marls contain nearly monotypic accumulations of conjoined *Corbula gibba*. The shells are evidently displaced from their original position, showing the commissure parallel or sub-parallel to the bedding surfaces.

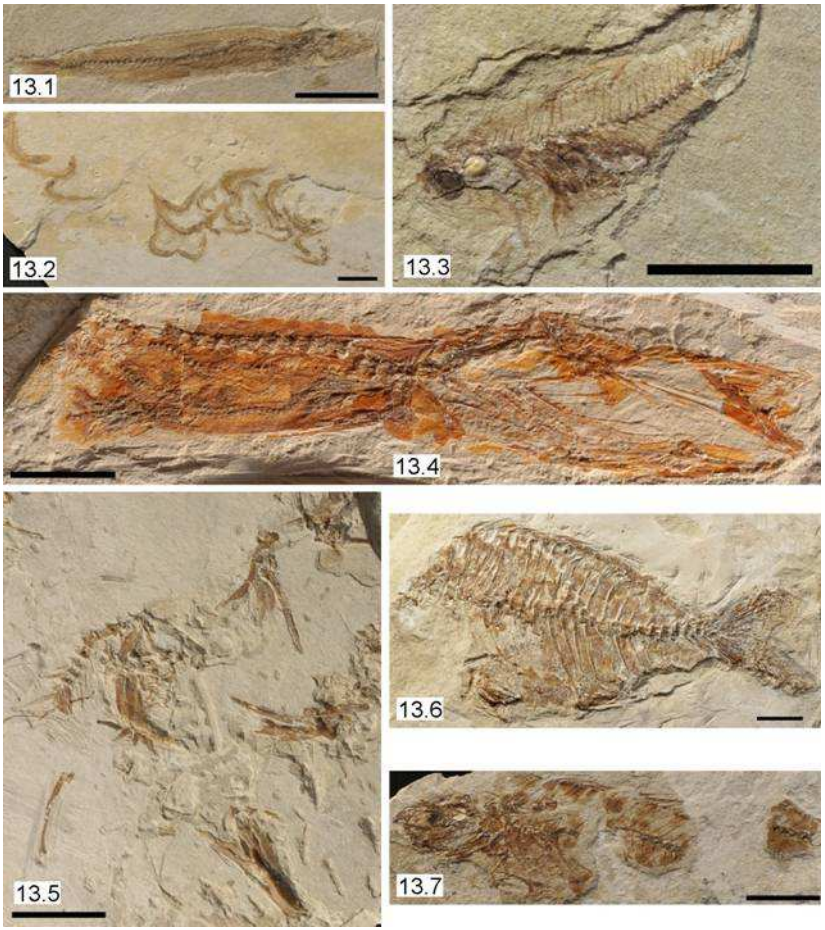


***Figure 13**. Capo di Fiume stratigraphic section. Fishes from the* $\mathbf{d_1}$ *diatomitic horizon.* ***13.1**. Spratelloides gracilis;* ***13.2**. mass mortality of*

juvenile individuals of Spratelloides gracilis; ***13.3****. Diaphus edwardsi;* ***13.4****. anterior portion of the body of Paralepis albyi with swallowed prey specimens of Spratelloides gracilis;* ***13.5****. Lates cf. niloticus;* ***13.6****. Pagrus sp.;* ***13.7****. Boops roulei. Scale bars 20 mm.*

The marls with calciturbidite intercalations are followed by 5 metres of massive grey marls and limey marls (Fig. 4.1) containing abundant and diversified marine bivalves (*Acanthocardia* sp., *Callista* sp., *Cardita* sp., Cardiidae indet., *Circomphalus* sp., *Glans* sp., *Lima* sp., cf. *Megaxinus* sp., *Ostrea* sp., *Paphia* sp., *Pinna* sp., *Venus* sp.), often with joined valves, associated with rare gastropods (*Aporrhais* sp., *Turritella* sp.). The massive aspect of this thick muddy interval, the absence of any internal sedimentary structure, the absence of biogenic reworking and the big volume of sediment involved suggest a gravitational mass-flow mechanism for transport and accumulation, perhaps triggered by seismic activity. The microfacies is characterised by very fine-grained bioclastic wackestones/packstones with dispersed and randomly distributed large mollusk fragments (Fig. 15.1) and rare small-sized *Elphidium*. The fine fraction is composed of buliminids, *Cibicides*, planktonic foraminifers (*Globigerina, Globogerinoides, Globorotalia* and *Orbulina*), abundant very thin siliceous sponge spicules, echinoid spines, unidentified bioclastic ash, abundant phosphatic material and organic particles mixed with very fine sand-to-silt-sized calcareous lithic grains (Fig. 15.2).

About 1.20 metres of finely laminated diatomitic marls lie over the massive grey limey marls. This diatomitic interval, as the previously described one, exhibits different types of indicators of tectonic instability and also contains calciturbidite beds here associated with thicker contourite-like deposits. The microfacies is similar to that of the d1 horizon, with abundant and well preserved thin sponge spicules (Figs. 15.3 and 15.4). The macrofossil content includes articulated fish skeletons, rare bivalves (*Cardita* sp.) and

plant remains, the latter extremely abundant in some biogenic laminae. Trace fossils, generally lying parallel to the bedding, are also present.

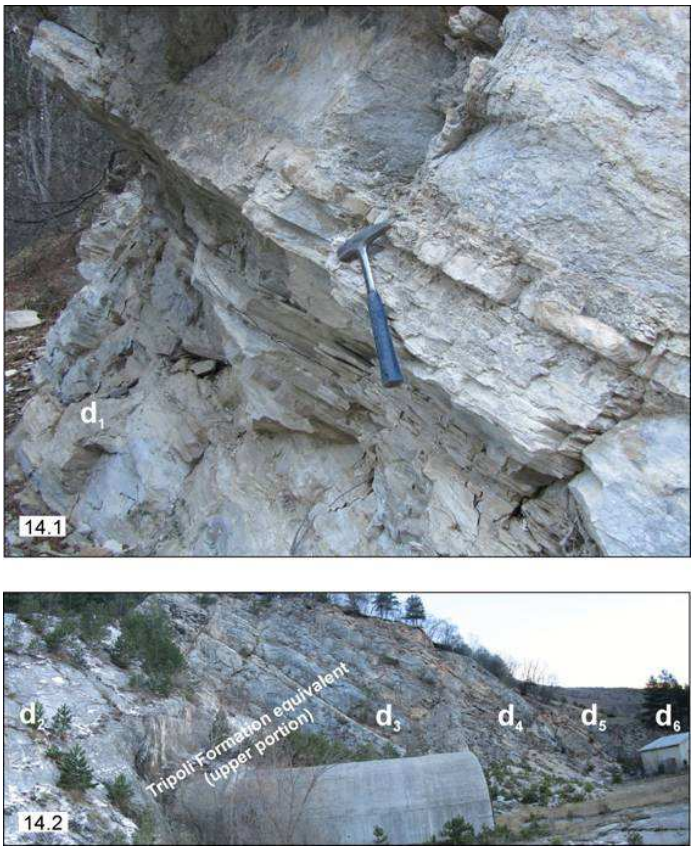


Figure 14.1. *Capo di Fiume stratigraphic section. Lower portion of the Messinian deposits equivalent to the Tripoli Formation. Lower diatomitic horizon (**d_1**) overlain by Corbula marls with intercalated thin calciturbidite layers.* ***14.2***. *Capo di Fiume stratigraphic section. Middle and upper portion of the Messinian deposits equivalent to the Tripoli Formation.* **d_2-d_6** *refer to diatomitic horizons the position of which is indicated in figure 1. The*

diatomite horizons are separated by mud-flow deposits each bed measuring some metres in thickness.

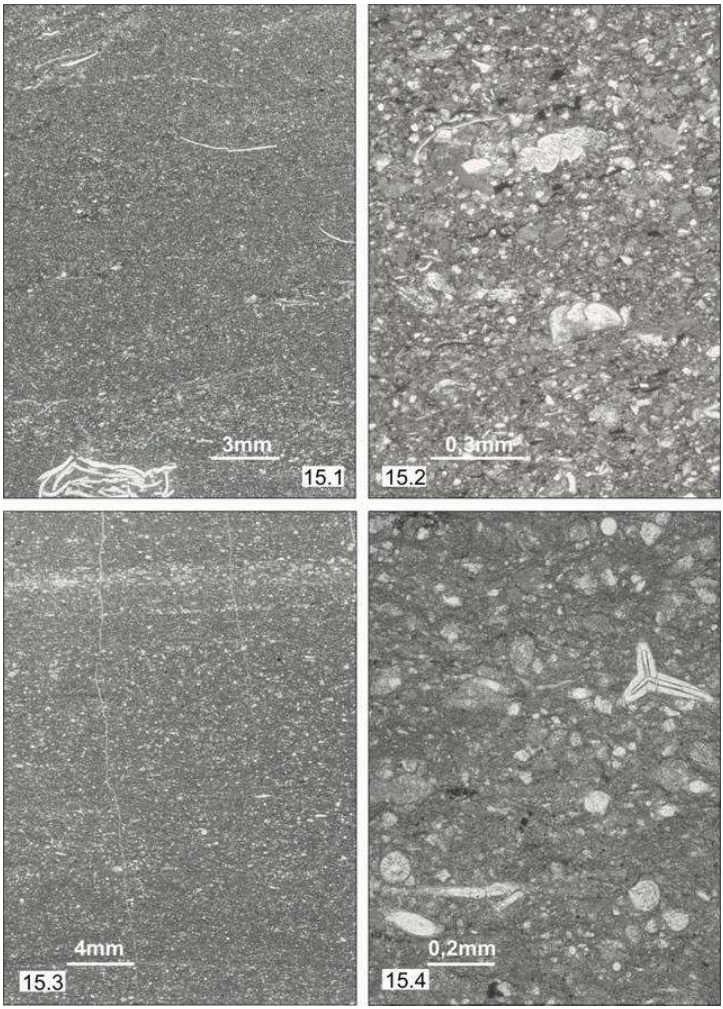


***Figure 15.1**. Capo di Fiume stratigraphic section. Messinian deposits equivalent to the Tripoli Formation. Microfacies representative of the massive muddy deposits overlying the **d_1** diatomite horizon showing randomly distributed thin-shelled bivalves. **15.2**. Capo di Fiume stratigraphic section. Messinian deposits equivalent to the Tripoli Formation. Massive muddy interval overlying the **d_1** diatomite horizon. Bio-lithoclastic wackestone/packstone with crushed buliminids (upper part of the photo). **15.3**. Capo di Fiume stratigraphic section. Messinian deposits equivalent to the Tripoli Formation. Microfacies representative of the **d_2** diatomite horizon. Vaguely laminated spicule-rich packstone. A subtle parallel lamination is evidenced by the iso-orientation of the thin spicules. **15.4**. Capo di Fiume stratigraphic section. Microfacies of the Messinian deposits equivalent to the Tripoli Formation, **d_2** diatomite horizon. Magnification of the microfacies of figure 10.2 showing well-preserved calcareous sponge spicules.*

The succession continues with other four cycles of alternated dark grey calcareous marls and finely laminated diatomitic marls (Fig. 14.2). Each interval of dark grey calcareous marls is characterized at its base by two or three shell beds consisting of nearly monotypic assemblages of conjoined *Corbula gibba* specimens with the commissure parallel or subparallel to the bedding plane alternating with very fine-grained calciturbidites and contourites. The upper portion of the calcareous marl intervals is always characterized by common bivalves, often with joined valves and chaotic distribution, and rare turritellid gastropods. In the uppermost cycle, the dark grey calcareous marls also include a massive accumulation of large ostreids. Planktonic foraminifers are always relatively abundant. The stratigraphic marker *Turborotalia multiloba* appears to be present in the calcareous marls of the sixth cycle.

The diatomitic marls of the upper four cycles show a progressive reduction of the biogenic content and apparently lack the previously abundant indicators of tectonic instability. Articulated

skeletal remains of fishes are rare, mostly represented by poorly preserved specimens of *Spratelloides gracilis*.

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