PLIOCENE AND PLEISTOCENE DEPOSITIONAL ENVIRONMENTS IN THE PESCULUSE AREA (SALENTO, ITALY)

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Riassunto. L'integrazione dei dati paleontologici e sedimentologici ha consentito una elevata discriminazione degli ambienti deposizionali succedutisi fra il Pliocene e il Pleistocene in un'area del Salento meridionale. I cambiamenti fisiografici delle zone ripetutamente inondate nell'intervallo di tempo considerato influenzarono significativamente gli ambienti deposizionali e le paleocomunità marine. In particolare, durante il Pliocene superiore, la presenza di un altofondo calcareo creò un ambiente protetto che permise la conservazione di forme di fondo di eccezionali dimensioni, interpretate come tsunamiti. Dopo una fase continentale, la prima ingressione marina pleistocenica é documentata da sedimenti calcarenitici ("Calcarenite di Gravina", auct.) che evolvono rapidamente in fanghi terrigeni (Argille subappennine, auct.) durante un periodo di instabilità sedimentaria di origine tettonica. Geometria, strutture sedimentarie e associazioni fossili caratterizzanti l'unità sovrastante, provvisoriamente indicata "Calcarenite della Casarana" (Pleistocene medio ?), suggeriscono una deposizione prodottasi essenzialmente in un braccio di mare limitato da bassi rilievi calcarei e allungato in direzione NO-SE. Questa unità è definibile composizionalmente come un "foramol" carbonatico (*sensu lato*) di clima temperato-freddo. La deposizione della successiva unità, detta "Sabbie della Serrazza", avvenne in un' ampia baia articolata in più insenature minori. Entrambe queste unità sono costituite per la maggior parte da corpi progradazionali contenenti ospiti nordici, deposti con ogni probabilità durante fasi di relativo stazionamento o lento abbassamento del livello del mare all'interno di periodi di generale ritiro del mare per cause glacioeustatiche.

Abstract. An integrated sedimentologic and palaeoecologic approach is used to define the evolving Pliocene, Early and Middle Pleistocene depositional environments in the Pesculuse area. Lower Pliocene deposits show evidence of a quiet outer-shelf setting, apparently not affected by the physiography of the transgressed palaeotopography. In contrast, the onlap of Upper Pliocene carbonate deposits onto topographic highs testifies that sedimentation was preceded by a block-faulting event. The Late Pliocene transgression flooded a subaerial karstic landscape. A ridge of Cretaceous limestone created a protected environment, in which wavy bedforms of exceptional scale, which are thought to result from tsunami surges, were generated and preserved. At this stage, different palaeocommunities settled in several shallow-water micro-environments.

After a continental phase, an Early Pleistocene sea-level rise is documented by transgressive coarse calcarenites ("Calcarenite di Gravina") grading upwards into terrigenous mudstones. In the former shallow sublittoral palaeocommunities are recorded. Rapid transition to the terrigenous mudstones took place during a period of tectonically-controlled sedimentary instability that favoured the successful settlement of an Heterogeneous Association. A new biocoenotic equilibrium was achieved in deep circalittoral settings.

The transgression marking the onset of deposition of the Middle (?) Pleistocene "Calcarenite della Casarana" took place within a NW-SE elongated seaway limited by low-relief limestone ridges. A downward shift of the facies tracts at the base of the regressive package points to a definite drop of the relative sea level; the presence of cold-water faunas suggests that the drop was essentially glacio-eustatic. A progradational body of calcarenites with distinct clinoforms, substantially consisting of foramol deposits, formed during the regressive stage, apparently starting from the fault scarps bounding the depression. The calcarenitic body prograded into a current-swept seaway and its accretion was essentially episodic, mainly due to the dispersion of bioclastic debris by storm-induced flows. During the late stage of the infilling, narrowing of the seaway resulted from a relative sea-level fall; this enhanced the flow strength due to strait conditions and produced a train of migrating sand waves along the axis of the seaway.

Deposition of the following unit, the Middle Pleistocene "Sabbie della Serrazza", took place within a wide bay with minor embayments located on drowned palaeovalleys and was preceded by a regional uplift, as indicated by a comparison with the former stratigraphic unit concerning the general depositional depths and shoreline positions.

The progradational units of the "Calcarenite della Casarana" and the "Sabbie della Serrazza" contain cold Atlantic guests and were most probably laid down during stages of relative standstill or very slow fall within general glacioeustatic drawdowns of sea level.

Introduction.

The western coastal strip of the Salento peninsula is characterized by a Mesozoic carbonate basement, partially hidden by Plio-Pleistocene deposits (Fig. 1). During the Early Tertiary to Late Miocene time span, regional vertical movements generated fault-bounded and locally tilted blocks arranged in different ways according to their location, either in monoclinal structures or in a series of steps or small horsts and grabens. Tectonic stresses progressively weakened during the Late Pliocene and Early Pleistocene: block faulting was of little im-

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portance during that period, whereas regional vertical movements were more significant (D'Alessandro et al., 1988). Therefore, the resulting complex topography strongly influenced the Late Pliocene and Pleistocene depositional and ecologic environments.

Landward of Pesculuse (southern Salento, Italy), terraced Pleistocene deposits of different facies and age can be recognized in the landscape features as a series of surfaces descending in a step-like fashion toward the sea. The local stratigraphy has been studied along two small valleys (Canale Fano and Canale Muscio) which cut the whole marine terraced system. Except for the basement of the Cretaceous limestones (Calcare di Altamura Fm.) and the recent beach deposits, the outcrops in this area show evidence of several marine sedimentary cycles, with transgressive basal contacts (Fig. 1B, from D'Alessandro et al., 1988). The first two sedimentary sequences are exposed in erosive windows: the older is represented by Lower Pliocene glauconitic and silty carbonate sands (Leuca Fm., Bossio et al., 1991), the younger is represented by Upper Pliocene limestones (Uggiano Fm., Bossio et al., 1991). Both are unconformably capped by a discontinuous continental conglomerate less than a metre thick. This one, on the other hand, is overlain by massive calcarenite (Calcarenite di Gravina Fm., *sensu* Ciaranfi et al., 1992) that grades upwards into muddy and locally marly deposits (Argille Subappennine Fm., *sensu* Ciaranfi et al., 1992) of Early Pleistocene age. According to D'Alessandro et al. (1988), during the Middle and Late Pleistocene a spectrum of siliciclastic and carbonate sediments were deposited as a series of marine terraces resulting from the interaction of glacioeustatic and tectonic events. These younger formational units are indicated in this paper with informal names, because of the lack, in the literature, of any formal designation.

The aim of this study is to define the evolving depositional environments of the Pesculuse area during the Pliocene, Early and Middle Pleistocene on the basis of an integrated sedimentologic and palaeoecologic approach (*e.g.* Bernasconi & Robba, 1993). The palaeoecologic analysis is based on the assignation of the identified fossil communities to biocoenoses of the past equivalent the modern Mediterranean biocoenoses (*sensu* Pérès & Picard, 1964). In this paper, the term "association" comprises remnants of one or more fossil communities interpreted as facies of a specific biocoenosis of the past. The biocoenoses mentioned in the test and their relative letter codes are summarized in Table 1. For the palaeoecological approach, it must be kept in mind that originally aragonitic skeletons are preserved as moulds and/or casts. Furthermore, in Upper Pliocene deposits, voids left by shell dissolution may remain open, but usually are filled by sparry calcite that greatly impedes the precise identification of the fossils. Samples have been collected from fossil assemblages (*sensu* Russel, 1991) composed of prevalently autochthonous and/or parautochthonous elements, as well as from shell beds manifestly consisting of allochthonous hardparts. All fossils are listed in Tables 2-7, with their relative abundances and ecological requirements.

Lower Pliocene deposits

Greenish Lower Pliocene deposits, about 6 m thick, crop out south-eastwards of Aparo di Valentini locality (Fig. 1). They consist essentially of massive, evenly bioturbated, glauconitic silty sands, whose coarser-grained fraction is composed of unbroken shells of planktic foraminifera (mainly *Orbulina*). The sediment is almost homogeneous, except for a single sandy silt layer, and is locally truncated by a terrestrial conglomerate. Both sediments are capped by a transgressive Lower Pleistocene calcarenite (Calcarenite di Gravina Fm.). The top of the Lower Pliocene deposits is characterized by numerous *Thalassinoides* piping downwards from the Calcarenite di Gravina, coupled with a few whitish shafts truncated at the discontinuity surface (Fig. 2). The shelled macrofauna is represented by rare valves of *Pseudamussium cristatum* (Bronn) and articulated *Neopycnodonte navicularis* (Brocchi), whereas the presence of soft-bodied animals is documented by numerous tiny *Chondrites*.

Interpretation.

A preservational bias alone seems to be inadequate to explain the low diversity of macrofauna as well as the paucity of fossilized skeletons. The rarity of shelly suspension-feeders could indicate low oxygen values at the seafloor, whereas reducing conditions below the se-

Fig. 1   - A: Simplified geological map based on unpublished data kindly provided by G. Ricchetti. B: Idealized scheme of stratigraphic relationships (slightly modified from D'Alessandro et al., 1988). 1) Holocene deposits; 2) foreshore and eolian calcarenites (Upper Pleistocene); 3) shoreface limestone conglomerate (Upper Pleistocene); 4) algal limestone (Upper Pleistocene); 5) Middle Pleistocene calcarenite and silty sand (Sabbie della Serrazza); 6) Middle (?) Pleistocene calcarenite (Calcarenite della Casarana); 7) Lower Pleistocene clayey silt (Argille subappennine Fm.); 8) Lower Pleistocene calcarenite (Calcarenite di Gravina Fm.); 9) Upper Pliocene limestone (Leuca Fm); 10) Lower Pliocene glauconitic silty sand (Sabbie di Uggiano Fm); 11) Upper Cretaceous limestone and dolostone; 12) quarries; 13) dip directions of clinoforms; 14) dip directions of sand-wave foresets. The scattered numbers indicate altitude above sea level.
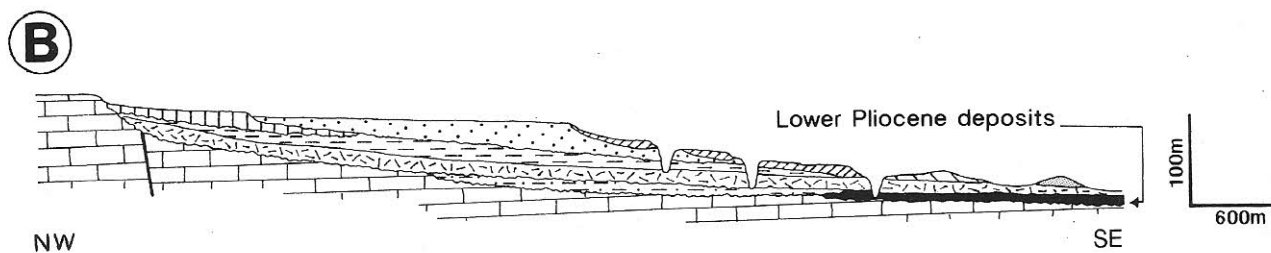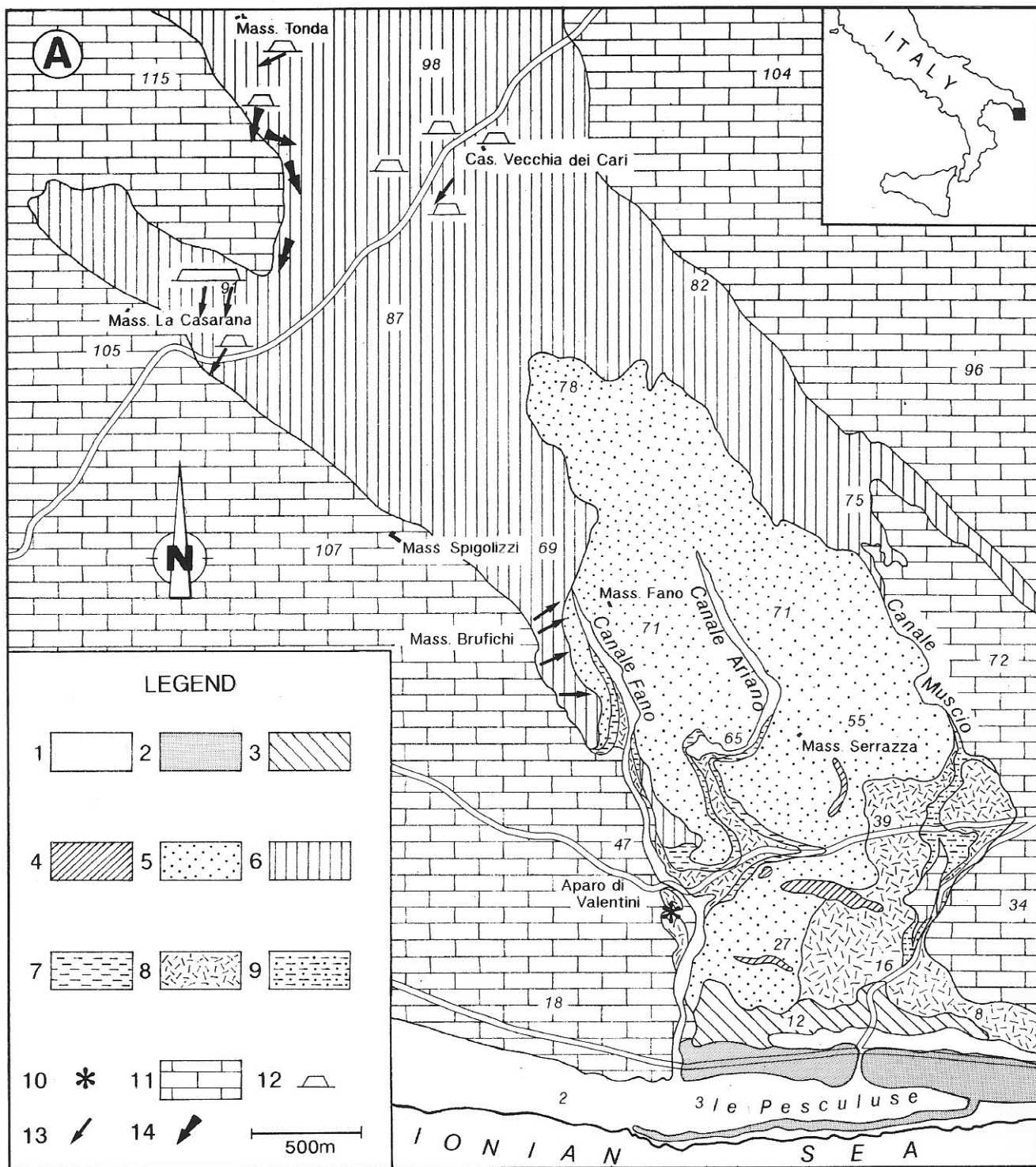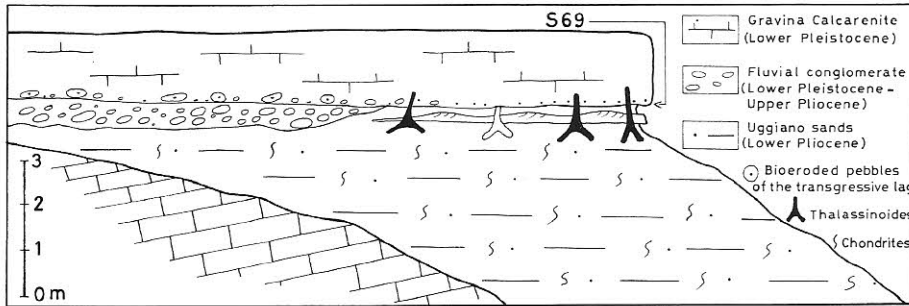
Fig. 2 - Cross-section of sediments exposed SE of Aparo dei Valentini. The Lower Pliocene silty sand records an outer-shelf setting.

diment interface can be inferred both by the monotypic *Chondrites* suite and by the diminutive size of the burrows (Bromley & Ekdale, 1984; Savrda & Bottjer, 1986). The successful settlement of the *Chondrites*-producers, i.e. of a possible chemosymbiotic animal (Seilacher, 1990), probably resulted from low-energy conditions and from an insufficient supply of oxygen to the interstitial water. Furthermore, the activity of such organisms could produce an indistinct interface and entail amensalistic interactions. The grain size of the terrigenous components as well as the primary lack of physical structures, except for a thin layer interpreted as a distal tempestite, are concordant with the inferred low water energy, whereas an unfavourable environment for most of the bottom dwellers is confirmed by the scarcity of epibenthic forms. The abundance of planktic remains points to a prevalently biogenic accumulation by fallout.

In summary, the facies reflects a quiet outer-shelf setting, rarely affected by deposition of thin sandy covers produced by more severe storm events. The *Thalassinoides* systems are clearly related to the Lower Pleistocene transgression, whereas the few whitish shafts could represent remnants of the Upper Pliocene cycle whose ingressive facies is well documented to the east, along the Canale Muscio valley.

Upper Pliocene deposits

Along the small Canale Muscio valley, Cretaceous limestones and/or red palaeosols are overlain by limestones (less than 10 m thick) which record the Late Pliocene transgression. On the basis of facies associations which can be differentiated in the initial stage of the transgression, three segments (inner, intermediate and outer segment) have been distinguished, from north to south (Fig. 3).

In terms of depositional environments they are thought to represent 1) marginal-marine low-energy ponds, 2) protected shallow-marine settings bounded on the seaward side by a submerged ridge of Cretaceous limestone, and 3) open-marine inner shelf environments, respectively. Landward of the ridge in addition of lapping onto the ridge itself, the limestones lap onto the flanks of a palaeo-depression cut within the Cretaceous limestones. The present-day topography seems to be in part a case of partial exhumation of an ancient topography.

Inner segment.

In the northern part of the Canale Muscio, thin- and wavy-bedded, variegated carbonate deposits occur
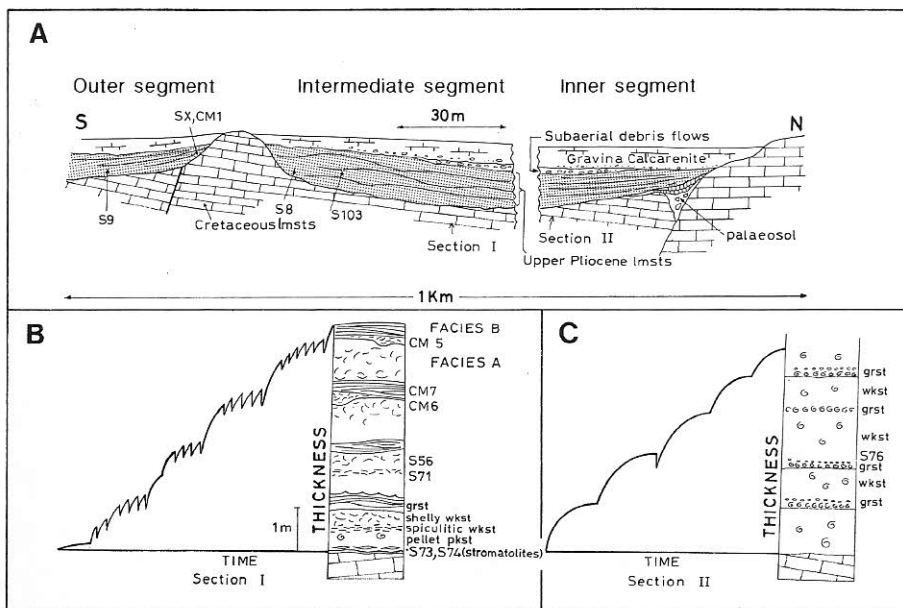
Fig. 3 - Canale Muscio. A. The three segments of the Upper Pliocene deposits are inferred to represent, from North to South, marginal-marine ponds, protected shallow-marine settings and open-marine inner shelf respectively. B, C. Major skeletal concentrations are mostly sedimentologic and rapidly formed; on the wavy bedform surface, and landward of the intermediate interval, mixed (biogenic/sedimentologic) long-term concentrations occur; grst: grainstone; pkst: packstone; wkst: wackestone.

Fig. 4 - Giant bedform with wavelength of 32m in the intermediate segment of the Upper Pliocene deposits. Canale Muscio. Seated person for scale.

above a red palaeosol that includes blocks of the Cretaceous substratum. They grade upwards into thicker-bedded calcisiltites containing scattered, undeterminable moulds of small marine gastropods. The overall thickness is about 4 m. Southwards this facies is missing and the substratum is directly overlain by scattered coquina layers (Fig. 3C) grading into wackestones with dispersed fabric (*sensu* Kidwell & Holland, 1991). Fossil concentrations consist mainly of *Cylichnina* shells (Table 2, S76) in a peloidal matrix composed of abundant ovoid faecal pellets and, subordinately, peloids of unidentified origin, that occur either isolated or aggregated in botryoidal lumps.

Intermediate segment.

As outlined above, along this intermediate segment (Fig. 3) the Upper Pliocene sediments lap onto a ridge of Cretaceous limestones, which also bounds them on their seaward side. To the north, the limestones are covered by a stromatolitic veneer rich in ferruginous nodules, overlain by micritic laminae characterized by birdseyes (S73) and sub-parallel to the bedding. They grade upwards into current-rippled, pelleted packstones (S74), that contain few pellets of recognizable faecal origin and very rare ostracod shells. Locally, the sediment is a bioclastic wackestone consisting of micritized thin-shelled molluscs and benthic foraminifera, mixed with peloids showing thin, vaguely laminated and commonly micritized coatings. About a metre above the transgressive contact two main facies appear to alternate (Fig. 3B). These are:

Facies A - Spiculitic wackestones to shelly wackestones and, locally, packstones form composite beds, with an average thickness of 80 cm. These composite beds show an overall, upward evolution from spiculitic and foraminiferal wackestones to shelly wackestones due to the progressive addition of shells, and then to shelly packstones that can include clusters of mostly small-sized *Neopycnodonte* and *Aequipecten*. The composite character of the beds results from smaller-scale repetitions of this trend, although in most cases it is incomplete, i.e. interrupted at various stages. Fossils are mainly unbroken; bivalves (venerids, ostreids, cardiids) are commonly found in growth position, or slightly shifted and disarticulated, whereas the single valves are randomly orientated. The intensity of infestation of the hardpart by encrusting or bioeroding organisms is low and generally restricted to shells of epifaunal bivalves.

Facies B - Laminated and locally coquinoid grainstone layers alternate with the previous facies providing a clear evidence of stratification to the whole succession. They show a large-scale wavy geometry, characterized by giant convex-up hummocks (Fig. 4) and intervening swales, the latter generally of a smaller radius. The wave length is in the order of 30 m and may reach 32 m; amplitudes range from 30 cm in the case of flattest waves, to more than 1 m and exceptionally up to 2.15 m in the case of highest-relief waves. The flanks of the hummocks and swales dip in all directions, suggesting an isotropic geometry. The giant waves are commonly irregularly asymmetric, with variably inclined flanks (range: 5°-25°). They have been observed for about 250 m in an onshore-offshore direction. A maximum of about 5-6 stacked, out-of-phase bedforms are preserved in the axial area of the palaeo depression, where the deposits reach an overall maximum thickness of roughly 10 m. Bedforms decrease significantly in wave amplitude landwards from the ridge, flattening out progressively in the same direction, and finally grading into subhorizontal planar layers toward the inner segment. Basal erosion is minimal in this area, increasing the preservation potential of the underlying sediments. As a consequence, the changes in packing and composition of fossil hardparts, described in facies A, are best recognized in this area.

The thickness of the laminated layers ranges between 25 and 75 cm, and commonly shows a gradual variation along the length of the wave, but without a clear repetitive trend: along the section of the Canale Muscio, both landwards and seawards, thickening may occur. The base of the beds is locally characterized by distinct scours infilled with densely packed, randomly oriented and poorly sorted molluscan shells. These concentrations, dominated by cardiids and venerids, are composed of the same taxa as those in the shelly packstones of facies A. The internal structures of the laminated beds are represented by local normal grading and low-angle hummocky cross-bedding (Fig. 5) with wave length of 0.7 - 2.8 m. In the lower part of the bed thick laminae grade upwards into increasingly finer-grained and better defined laminae; each lamina commonly shows inverse grading. Wave- or

Fig. 5 - Detail of the giant bedform of Fig. 4 (facies B) showing hummocky cross stratification. Hammer for scale.

combined-flow ripples may occur at the top of the bed with their crest direction trending N 70°-250° (on average). Rare, isolated sets of high-angle cross-bedding, about 30 cm thick, are locally present in the lower part of the succession. They dip either landwards or seawards.

The laminated beds are mostly composed of peloids, mainly faecal in origin, tiny shells, benthic foraminifera and, in places, delicately aligned sponge spicules. They can be replaced by coquinas near the ridge, as well as landwards (inner segment). Seawards, coquinoid cm-thick laminae, or flat lenses, commonly alternate with finer-grained, generally barren, grainstone laminae. Bioclasts show a clear sorting of size and shape, and are dominated by virtually unbroken gastropods (rissoids and cerithiids) (Table 2, S8). Concave-up stacked disarticulated *Spisula* shells locally occur in the lower part of the finer-grained laminae. The lower part of the coquina beds may also contain relatively large-sized unworn skeletons, such as single oyster valves, occasionally heavily covered by long tubeworms, shells of cerithiids, *Bittium*, as well as small, rounded, masses of corallinacean algae encrusting or encrusted by multilamellar bryozoans, or bored by clionids. Carapaces of crabs were also observed. Few bioclastic layers consist of oriented fragments of polychaete tubes mixed with spicules, and grade upwards into spiculitic wackestones. Fossil remains are commonly associated with well-rounded molluscan bioclasts and composite grains occasionally including ooids.

Outer segment.

Sediments characterizing this segment lap onto the seaward side of the ridge, which locally shows poorly preserved bioerosion traces, and are mainly composed of fine-grained calcarenites, commonly laminated, containing both scattered and clustered fossils. The latter are represented by bivalves (mainly *Glycymeris*), with closed or slightly rotated valves, or gastropods (Tab. 2, S9). Only locally, near the ridge, clumps of chaotically orientated *Strombus,* spicules and a few small colonies of corals (samples SX, CM1), together with lenses of cardiids, were found. The same taxonomic composition characterizes also the uppermost part of the succession on the landward side of the ridge.

Interpretation

Inner segment.

The onlap of the Pliocene beds on the topographic high, as well as the small-scale lateral and vertical changes of the biofacies, testify that the Pliocene transgression flooded a landscape characterized by a complex karstic relief, with red soils locally preserved in small depressions. Indeed, the carbonates underlain by the red palaeosols in the innermost area, could represent deposits of a coastal sabkha, originally accumulated in a small karstic depression episodically flooded by marine water and subjected to intense evaporation under warm, dry climatic conditions. The landward shift of the shoreline and the establishment of low energy environments, which evolved from marginal-marine (probably lagoonal) to open marine, is testified by sedimentologic features and by the poorly preserved fossils. Southwards, the monotypic *Cylichnina* coquinas, composed of skeletal remains of a palaeocommunity comparable to the SVMC biocoenosis, would record the settlement of an upper infralittoral community in a sheltered zone.

Intermediate segment.

Facies A.

Taphonomic features suggest that the fossil remains did not suffer any significant transport and that they represent autochthonous and parautochthonous relics of the original communities. However, biocoenotic anomalies reveal the presence of exotic elements within the sampled assemblages. Taking into account that the taphofacies suggests background conditions of a low sedimentation rate in a low-energy setting (*sensu* Brett &

Baird, 1986), the mixing can be attributed to biological and physical agents such as active transport by hermit crabs, passive accumulation from cliffs by gravity and weak currents that possibly gently reworked the bottom.

Among the bivalves (Table 2), few taxa dominate and are almost exclusively represented by infaunal suspension-feeders (burrowers of soft substrates). *Timoclea ovata* is common throughout the facies, but it is more abundant in some layers, together with small-sized *Acanthocardia mucronata* (preferential of DC biocoenosis), *A. paucicostata* (characteristic of SFBC), and juvenile *Dosinia lupinus* (characteristic of SFBC). The remarkable abundance of *T. ovata* may be related to the presence of decantation areas where organic matter, such as dead weed transported offshore by weak currents, tends to pile up. The patchy distribution of sessile epifauna such as *Neopycnodonte* and *Aequipecten* is indicative of a low to moderate sedimentation rate and of a somewhat cohesive bottom. These conditions could locally occur on an uneven seafloor. Gastropods are less abundant and mostly consist of detritus-feeders and grazers (i.e. *Bittium* cf. *reticulatum*, which is related to plant meadows, rissoids, trochiids and *Cerithium vulgatum*, preferential element of the AP biocoenosis and, secondarily, of *Cylichnina umbilicata* (SVMC and SFBC biocoenoses) which feeds on protozoans. It should be noted that small-sized gastropods belong to the same taxa of the allochthonous elements making up the coquinas. Landwards, the sessile gastropod *Tenogodus obtusum* characterizes only the stratigraphically lowest megafossil assemblages. Although its biocoenotic collocation is uncertain, this is a dark-related animal, commonly mentioned from the C and GSO biocoenoses; it seems to live on a hard substratum covered by mud, or within sponge tissue, to achieve greater stability. Therefore, the occurrence of densely packed clusters of their pristine vermetid shells (locally coupled with *T. ovata* -S104) excludes significant transport and points to the existence of a soft substrate inhabited by bivalves where the gastropod shells, derived from nearby hard and shaded substrates, accumulated before being suddenly buried.

Another major component of the fossil concentrations are spicules of calcareous sponges. In the Mediterranean Sea, higher abundance and higher diversity of Calcispongia are reported for populations living on vertical cliffs or caves of the infralittoral zone (Boury-Esnault, 1971), in the bathymetric range corresponding to that of the AP biocoenosis. Their growth on horizontal surfaces or near uncompacted substrates is prevented by the extreme sensitivity of the sponges to sediment accumulation. The common occurrence of oriented spicules in muddy massive shell layers (where they occasionally form spiculitic bands) and in laminated

beds suggests the occurence of a reworking action just enough to remove such light hardparts.

Facies B.

Sedimentology - The repeatedly generated large-scale bedforms are the most spectacular feature of the Upper Pliocene deposits. Their occurrence landwards of the ridge and their landward change in geometry, suggest that a significant role has been played by the presence of the ridge itself. The bedforms were clearly not subjected to any lateral migration: their geometry apparently requires a scour and drape process, i.e. an initial strong scour event which created an erosional wavy topography at the expense of the facies A, followed by vertical accretion which generated the laminated beds. The hummocky surface is therefore not due to generation of a stable bedform, but is inherited from an erosional surface produced during the initial highest-energy stage. A sharp initial erosion of facies A is supported by the fact that a large-scale regular hummocky topography could not have existed as a primary feature. Besides, initial erosion is highlighted by local shell-filled scours. This, coupled with the indication of the flow direction from the high-angle cross-bedding, would suggest that the sediments were mainly deposited by high-energy surges, which at first encroached landwards in relatively protected areas, and then swept back offshore by the retreating surge. Indeed, the composition of the laminated beds suggests contributions from at least two different sources, located in wave-exposed coastal settings and in inner, low-energy areas. In more exposed areas, part of the sediment slid down the submerged slopes, and was entrained by the flows; pellets and tiny skeletal elements, transported from inner coastal areas as a cloud, were selectively redeposited offshore and, together with the finer resuspended sediment, eventually blanketed the seafloor. Low-energy background conditions, probably resulting from the ridge forming a baffle, allowed the good preservation of the wavy bedforms.

The scale of the bedforms seems to imply a genetic relationship with a wave regime far more energetic than the one related to storms or swells, even if surge velocities may have been locally increased by a rebound from the landward cliffs, as a result of the particular topography of the transgressed palaeo depression. Therefore, it can be suggested that the observed bedforms were generated by giant waves of exceptional height and long periods, and by the related surges, such as those generated by the propagation of tsunamis into shallow water areas. A complete hummocky bed is interpreted as representing a single tsunami event.

Tsunami waves are known to be subjected to reflection, refraction and diffraction by islands, seamounts, submarine ridges or shores, and their amplitude to be also greatly enhanced by shoaling, diffraction,

convergence and resonance when they reach the land (Coastal Engineering Research Center - Shore protection manual, 1977). In particular, the interaction with the co-ast gives rise to a very complex pattern of waves, with effects of reflection and refraction caused by the variable bathymetry, and also with effects of propagation along the coast in the form of edge waves. Tsunamites are ra-rely reported in the geologic literature (Moore & Moo-re,1984; Young & Bryant, 1992; Shiki & Yamazaki, 1990). The hummocky boulder pavements described by Eyles (1994) in the intertidal zone of the Gulf of Alaska and interpreted as the product of wave and tidal erosion combined with packing and abrasion by grounding ice-bergs, are suspected to be a tsunamite. Individual boul-der hummocks are up to 1m high and either irregularly spaced or forming elongate mounds about 5 wide and 10 to 15 long. The aerial view of fig. 3 of Eyles's paper gives the clear impression of a field of giant bedforms generated by exceptionally powerful flows.

Coastal areas of southern Italy are known to be exposed to tsunami attacks (Tinti, 1993a) mostly genera-ted by local earthquakes with focal region close to the coast, but in some cases located in the eastern Mediter-ranean, like the tsunamigenic seismic event which took place near Crete on 21 July 365 AD (Tinti, 1993b). Ac-cording to Tinti (1993a) the mean return period for tsu-namigenic earthquakes in southern Italy ranges between 15.1 yr and 60.4 yr.

Tsunamite reports are mostly associated with ex-ceptionally coarse deposits that are obvious candidates for being preserved in the geological record, even if ac-cumulated in a normally high-energy setting. Large-scale sandy bedforms such as those described in this paper are prone to rapid destruction under the action of fair weather and storm waves in an open, inner shelf setting, but may conceivably have a good chance for preserva-tion in a low-energy setting.

Palaeoecology - Most molluscan shells show eviden-ce of displacement from nearby habitats. The life-habits of the animals forming the coquinas confirm that the material was supplied by at least two sources: a high-energy area, presumably a wave-dominated coastal set-ting, and an inner, low-energy area. Near the ridge, the coquina beds as well as, the scour-fill shell concentra-tions, could have originated from episodic mass dischar-ge of benthic organisms, reworked and transported by high-energy currents. The size-sorted shells are mani-festly exotic elements whereas the larger hardparts, as well as the chaotically oriented shells filling scours, could partially represent parautochthonous elements. Burial by clouds of carbonate muds marked the end of the events. Ecological requirements of the assumed exo-tic elements (Table 2, S8) suggest a patchwork of habi-tats (rocks, soft seafloors, meadows) colonized by sessile

or vagile shallow-infaunal and epifaunal suspension-fee-ders (e.g. calcareous sponges, *Salmacina*, bryozoans, rare juvenile *Neopycnodonte*_and the SFBC preferring *Spisula subtruncata*), browsers and detritus-feeders (Rissoids, *Ce-rithium*, *Bittium*, among the others), organisms that feed on deposited and suspended organic matter such as hydrobiids (significant populations of *Hydrobia* are re-ported from muddy intertidal flats - Barnes,1982) and carnivores (*Cylichnina*). Pérès & Picard (1964) report *Salmacina incrustans*, together with melobesians and bryozoans, on overhanging rocks in shallow water. The original palaeocommunities can be compared to the Re-cent AP, HP, SFBC biocoenoses, mixed with few ele-ments from "enclaves" of the Coralligenous biocoenosis. The components of the coquina beds (rissoids, hydro-biids and *Cylichnina*) record SVMC biocoenosis and/or facies with marine phanerogams of SFBC. Considering also the physical and biostratinomic features, a prove-nance of the components from inner protected areas and a transport by weak currents followed by offshore di-scharge into deeper settings, appears likely.

In conclusion, the giant grainstone waves developed between the coast and the sill, probably have been coloni-zed by predominantly infaunal organisms, and sub-sequently stabilized by an epifaunal-dominated communi-ty. Indeed, the fossils occurring in facies A suggest a soft bottom biotope inhabited by a community equivalent to the Adriatic SE (*sensu* Gamulin-Brida, 1974), cyclically shifting towards a community comparable to SFBC-DC ecotone. According to Pérès (1967), the SE biocoenosis, Thorson's (1957) "*Syndosmia* community", as well as Ca-bioch's (1961, 1967) equivalents, are peculiar aspects of the SFBC biocoenosis, resulting from a shallowing of the upper limit of the circalittoral zone due to a higher water turbidity. A depth of the seafloor around 20m can be reasonably inferred. Gradually changing edaphic fea-tures of the seafloor related to a reduced rate of sedi-mentation (type 1 concentration in Kidwell, 1986) possi-bly set off an autogenic feedback reaction that produced the observed shifting of the communities. Many times the-se trends were interrupted by rapid deposition of mud clouds, often spiculitic, probably raised by storms whose effects, however, were significantly attenuated in this pro-tected area. This is suggested by the above outlined organi-zation of the composite beds. Near the ridge, communities equivalent to the AP and HP biocoenoses, as well as the *Spisula* facies of the SFBC biocoenosis, inhabited rocky substrates and softgrounds patchily covered with sea-grass. Furthermore, "enclaves" (*sensu* Pérès & Picard, 1964) of Coralligenous (C) or Semi-Obscure Cave (GSO) biocoeno-ses (presence of *Tenogodus obtusus*), possibly existed on the shaded part of the cliff. The interbedded coquina layers record higher-energy events that produced mass-deposition of exotic skeletal elements and testify the presence of diffe-rent biocoenoses living in nearby shallow-water habitats.

Outer segment.

A community characterized by *Glycymeris insubricus* and *Dosinia lupinus*, equivalent to the present-day SFBC biocoenosis, seems to have been widespread; edaphic conditions favourable to its successful settlement are a high enough water energy to produce a shifting silty sand bottom. The influence of few elements related to circalittoral biocoenoses suggests a depth near the lower bathymetric limit of the SFBC, possibly around 10-15 m. Components of the sessile epifauna occur as exotic elements near the exposed side of the ridge (CM1, SX). This mixing may be attributed to reworking produced by currents, although other mechanisms, such as active transport of gastropod shells by crustaceans and gravity (suggested by organisms related to hardground biocoenosis, e.g. pristine corals, part of bryozoans and some grazing gastropods) may also have been involved. Furthermore, some gastropods (i.e. trochids and *Strombus*) suggest the presence of seaweed and marine plant meadows where AP and HP biocoenoses flourished.

Successively, the SFBC facies spreads out landwards as a result of an uniform open coastal area that originated when the ridge became buried.

Lower Pleistocene deposits

A relative sea-level fall is documented by subaerial debris flow conglomerates (up to 2 m thick) locally intercalated between the Upper Pliocene and Lower Pleistocene marine deposits along the Canale Muscio (Fig. 6). As a result of this relative sea-level drop and the subsequent Early Pleistocene sea-level rise, part of or all older Neogene deposits were eroded and a lag of well-rounded calcareous pebbles and cobbles, mostly reworked from the alluvial substrate, was left on an erosional surface (ravinement surface). The lag is overlain by a succession of sediments showing a transgressive trend. Outcrops, although numerous, are generally discontinuous with sections exposed for not more than a few metres. These deposits, lithologically ranging from coarse-grained calcarenites to fine terrigenous sediments, represent the relatively condensed foreland-setting counterparts of the Bradanic units, i.e. Calcareniti di Gravina and Argille Subappennine (*sensu* Ciaranfi et al., 1992), typically developed in the northern part of the Bradanic foreland basin. The occurrence of Atlantic and/or northern guests ("northern" applies to taxa, which do not live further south of the Gulf of Gascony, Di Geronimo & Li Gioi, 1980) is indicative of lower salinity and/or lower temperature in the Mediterranean Sea. These guests include *Arctica islandica*, *Glycymeris glycymeris*, *Acanthocardia echinata* in the calcarenite; *Diacria trispinosa trispinosa* and *A. echinata* in the transitional interval; *Limacina retroversa* in the terrigenous mud, and *Pseudamussium septemradiatum* the latter occurring throughout the Lower Pleistocene deposits.

On the basis of the fossil content and the lithological features, the succession has been subdivided into three units including different facies having mutual gradational contacts. The stratigraphically lower unit comprises associations of the infralittoral and the shallow-circalittoral zones; the upper unit comprises associations of the lower-circalittoral zone, whereas the association of the middle unit indicates basinal instability (for relations between instability of sedimentary basins and benthic communities structures see Di Geronimo, 1984, and Di Geronimo & Robba, 1987).

Lower unit.

The total thickness of this unit is about 10 m, although no more than 3-4 m of the lower part and about a metre of the uppermost part are exposed in local sections. The pebbles occurring at the top of the basal lag are mostly bioeroded and locally mixed with sparse shells (Aparo dei Valentini - Fig. 2, S69; Canale Muscio - Fig. 6, S56). The matrix is composed of abraded bioclasts and minute rounded lithoclasts. The abundance of bioeroded pebbles, the intensity of bioerosion, as well as the size of the conglomerate components are reduced in the northern sites. The transition to bioclastic, poorly sorted calcarenites (S50[1], S14, S10) occurs through a calciruditic horizon - locally containing flat lenses of well-preserved fossils (S57) in hydraulically stable position - and a coarse-grained calcarenite. The calcirudite consists of heavily encrusted bioclasts mixed with comminuted debris and rhodoliths. The overlying beds show lateral changes in grain size and an overall fining
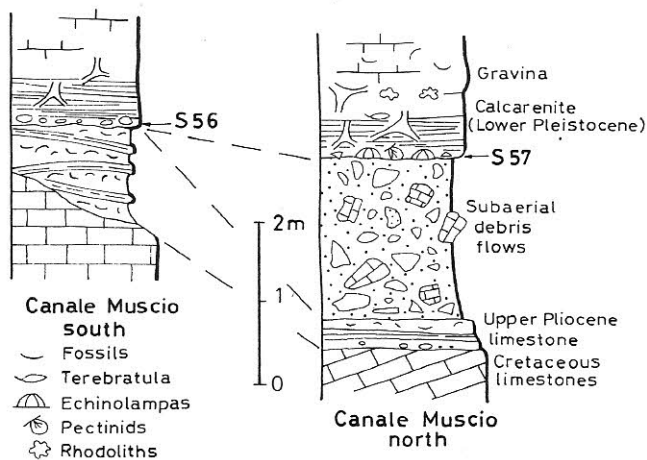

Fig. 6 - Sections along Canale Muscio showing the relationship between the Lower Pleistocene "Calcarenite di Gravina" and the underlying subaerial deposits. In the southern section, pebbles at the base of calcarenite are intensely bioeroded (S56).

upwards trend from coarse to fine calcarenites, including abundant rhodoliths and well preserved shells as ruditic elements. Bioclasts are the dominant component and mainly consist of mollusc debris, benthic foraminifera and red algae; lithoclasts are scarce, small and well rounded. Locally, physical structures occur in the basal 80 cm; they consist of mutually erosive sub-horizontal to low-angle sets of laminae, suggesting a high-energy shoreface environment. Biogenic structures are represented by open *Thalassinoides* systems of low to moderate density. Macrofossils, more concentrated in the basal portion of the calcarenite, progressively disperse upwards.

Interpretation.

Trace and body fossils in the coarser sediments reveal a succession of shallow-marine communities in biotopes that gradually deepened below fair-weather wave base. The bioerosion assemblages (Table 3, S69, S56, S57) are typical of an infralittoral community (see table 1 in Bromley & D'Alessandro, 1990) comparable to the AP biocoenosis. The overlying calciruditic and calcarenitic sediments represented suitable habitats for the SGCF and/or SGVB biocoenoses. The mixing of the unbroken hardparts of animals characteristic of the present-day SGCF and DC biocoenoses (site S57) agree with a rapid burial close to or at the living site of the organisms. The reduced thickness of this facies is explained in terms of a current-swept seafloor where transport prevailed over deposition, or where the locally accumulated material was mostly cannibalized. This setting is typical of the transgressive stage.

Taphonomic features, and the ecological requirements of organisms occurring in the biocalcarenites (S50[1], S14, S10) favour the hypothesis of assemblages primarily composed of indigenous elements. Diagenetic bias of the faunal composition due to selective dissolution can be disregarded, because aragonitic shells are recorded by casts or composite moulds. However, problems in determining such types of fossils at low taxonomic rank, especially those preserved as coarse calcarenite casts, and difficulties in detecting small specimens in cemented beds, cause an underestimation of the species richness and produce problems in evaluating the distortion of the structure of the palaeocommunities.

The dominant ecological groups are those represented by shallow-burrowing bivalves and vagile or pedicle-attached epifaunal forms; these latter are low- and medium-level suspension-feeders. Organisms, which differ in life habits and trophic requirements are subordinate in abundance. As regards the substrate, most fossils belong to species preferring heterogeneous, poorly sorted sediments and/or to species dependent on the presence of small or extensive hard substrates. The abundance of rhodoliths as well as the lack of shell concen-

trations suggest the presence of bottom currents and a moderate rate of sedimentation, although these factors could be locally reduced as in the S10 locality. In fact, the local occurrence of *Terebratula scillae* and of small rounded masses of multilamellar bryozoans (celleporiform A, Scoffin, 1988; nodular, Bone & James, 1993) alternating with algal laminae, are possibly related to both a lower energy and a lower rate of sedimentation.

The elements of the benthic assemblages have an optimal development of their populations on the continental shelf. Consequently, a location of the palaeocommunities in the shallow circalittoral zone fits well with the sedimentologic features characteristic of a neritic setting below the normal wave base. Similar results are achieved by taking into account the biocoenotic preferences of the taxa (Table 3), which emphasize the close relationship with the DC biocoenosis. The suspension-feeder communities in the assemblage of the eastern Canale Fano (S14) can be compared to a shallow, medium-energy DC (with an episode of mud enrichment) and those at Canale Muscio (S10) to a DC/DE ecotone (or DC-E *sensu* Gamulin-Brida, 1974), whereas the exotic elements from the Coralligenous biocoenosis at site S50[1] are in agreement with the presence of a cliff (see discussion for S40, S50[3] samples).

Observations.

The co-occurrence in the Canale Muscio outcrop of the two extinct brachiopods *Terebratula* sp.1 and *T. scillae* requires further discussion. *Terebratula* sp.1 comprises brachiopods resembling *T.scillae*, but showing an average smaller size: although it is easy to discriminate the different populations, isolated specimens are difficult to classify correctly. Up to now *Terebratula* sp.1 has been found in fossil communities mirrored in a relatively high-energy facies of the modern DC biocoenosis (D'Alessandro & Iannone, 1982, under name *T. ampulla*; pers. obs.), therefore it is considered as a characteristic form of the DC fossil counterpart. Populations of the large-sized *T.scillae* are mostly reported from fossil communities that occupied deeper biotopes. This is the case with the examples described from Sicily (presumed depths: 200-250 m after Di Geronimo et al., 1982), and from Salento (90-150 m after Taddei Ruggiero, 1985; 100-120 m according to Taddei Ruggiero, 1994) and shown in communities compared to a facies (*sensu* Pérès & Picard, 1964) of the *Amphiura* Community (D'Alessandro & Palmentola, 1978) or the DE biocoenosis (D'Alessandro et al., 1994), i.e. a bathymetric range equivalent to that assumed by Taddei Ruggiero (1993). So far, its shallower location has been reported from Sicily at a depth of 50-60 m (Di Geronimo et al., 1982) and in the facies under discussion (S10). In agreement with Di Geronimo's (1987) statement and on the basis

of our field observations, this brachiopod is regarded as a species occurring preferentially in the DE Association and in the fossil DC-DE. Under particular condition, it characterizes a facies of the PE Association. *T. scillae* preferred dark or shaded, cohesive sea-bottoms winnowed by currents of low to moderate energy, composed of mud or muddy fine sand, on which the animals lived in small clusters, attached by rootlike extensions of their pedicles.

Transition unit.

Features of this unit can be observed along the eastern side of the Canale Fano. The succession (Fig. 7) is represented, at the base, by a structureless calcarenite containing dispersed fossils - mostly *Pseudamussium septemradiatum* - that grades into a muddy calcarenite characterized by an abrupt increase of *Ditrupa arietina* tubes. The tubes occur scattered and in small clumps associated with a few articulated valves of *T. scillae* (S13), and alternate with two nearly monospecific pavements of *Modiolula phaseolina* shells (S13[1]). The bivalves are prevalently articulated and occur either in life position or lying on the bedding plane. The rapid, but gradual transition to the overlying calcisiltite (S21), is characterized by an increased abundance of large brachiopods and annelids, in separate clusters, coupled with commonly closed valves of *Ps. septemradiatum* and *Hyalopecten similis. M. phaseolina* is present in few, thin lenses of

loosely packed, convex-upwards oriented, disarticulated, but complete shells. Locally, sections can be correlated by means of this assemblage.

This sediment grades into a mottled calcilutite (S22) containing dispersed fossils, where the pectinids occupy the dominant position because of a reduction in the tubeworm and brachiopod populations; the siliciclastic component is clay-sized. Changes in species order and abundance from bulk-sample S13 to bulk-sample S22 are sketched in Fig. 8. Up to S13 planktic and benthic foraminifera are nearly equally abundant, whereas in samples S13[1]-S22 the planktic forms dominate. The section ends with barren terrigenous mudstones.

Interpretation.

The sudden proliferation of *Ditrupa arietina* is indicative of changes occurring in the biotope of the DC Association. The latter was replaced by a Heterogeneous Association (PE) a result of increased turbidity of the bottom water.
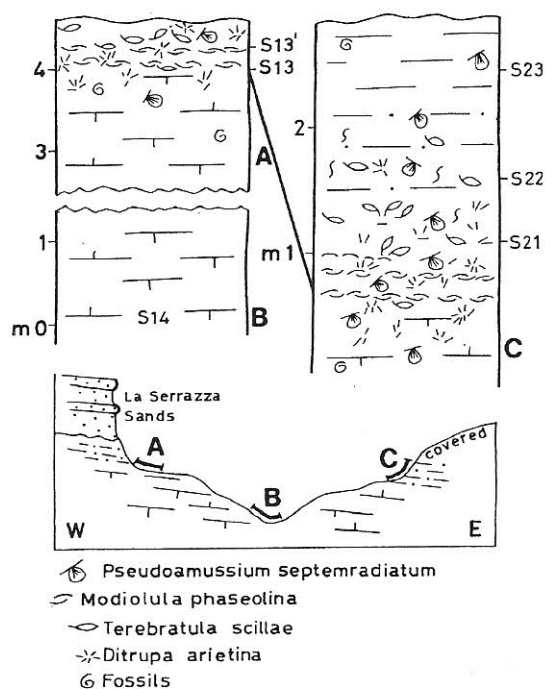
Fig. 7 - Lower Pleistocene deposits outcropping E of Canale Fano. A, B, C: details of the faunal concentrations within the transitional unit between the "Calcarenite di Gravina" and the "Argille Subappennine".
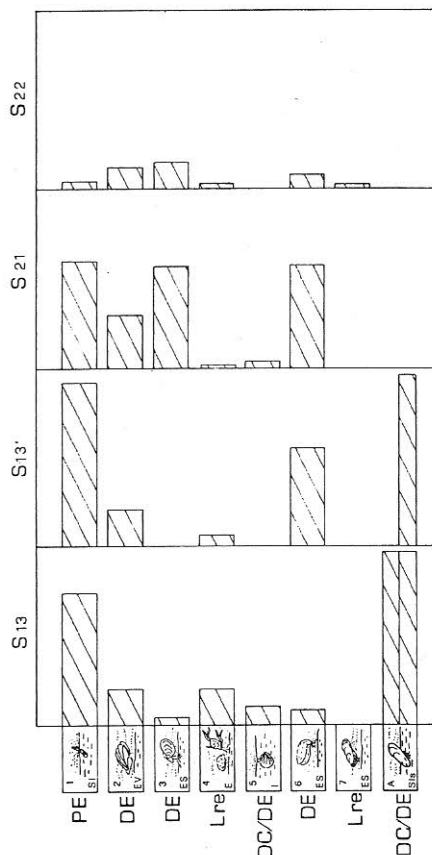
Fig. 8 - Selected taxa (1-7) from 4 bulk-samples showing changes in rank order and abundance of species of succeeding communities. At left ecological meaning of taxa. All organisms are suspension-feeders. 1) *Ditrupa arietina*, 2) *Pseudamussium septemradiatum*, 3) *Hyalopecten similis*, 4) Bryozoa, nodular growth-form, 5) *Parvicardium minimum*, 6) *Terebratula scillae*, 7) *Neopycnodonte cochlear*. A) beds of *Modiolula phaseolina*. Abbreviations as in Table 1.

Terebratula scillae has not the morphology of an opportunistic brachiopod adapted to fluid substrates (Alexander, 1977), and it shows only few of the attributes considered by Levington (1970) as typical of an opportunist. However, the brachiopod does occur together with true opportunists in this interval as well as elsewhere in Apulia, anywhere the transition from the Calcarenite di Gravina Fm. and the Argille subappennine Fm. is exposed. This apparent inconsistency may be resolved by suggesting a high turbidity tolerance of *T. scillae* that gives the brachiopod the chance to form conspicuous populations.

Modiolula phaseolina is a characteristic species of the DC and DE biocoenoses. As a filibranchiate bivalve, it is sensitive to turbidity. Therefore, the fact that *Modiolula* shells form two primary biogenic concentrations (*sensu* Fürsich & Oschmann, 1993) suggests that turbid conditions existed only episodically. According to Picard (1965), settlement and persistence of the Heterogeneous Community is due to a permanent or quickly recurrent edaphic stress, as it could have occurred in the discussed setting. On one hand, stifling by sudden burial is confirmed by the taphonomic signatures. On the other hand, at the horizon S21, the biofabric indicates slight transport. Winnowing is also documented by the occurrence of moulds of both articulated and disarticulated deep-burrowing *Thracia convexa* and *Dosinia lupinus*, the latter judged allochthonous being a sand-related animal. Nevertheless, blanketing events by rapid sedimentation can be taken as the main physical process affecting the seafloor.

The Heterogeneous Community is considered as a good indicator of local instability that could result from climatic changes or tectonic activity (Di Geronimo, 1984, 1987). As the transgressive sequence was produced during a cold climatic interval, a subsidence rate faster than the sea level drop must be assumed. Besides, the appearance of *Limacina retroversa* in the mud (S23) overlying the transitional interval is indicative of a cooling trend during the deepening phase. In this context, the settlement of the PE association is assumed to be linked to a phase of high subsidence rate that deepened the seafloor by at least 30-40 m; the depositional setting would be located well possibly close to the maximum storm wave base (*sensu* Miller et al., 1988).

In conclusion, the replacement of a mixed-bottom association (DC) by a muddy-bottom association (DE) coincided with an abrupt reduction of species diversity and the domination by opportunists (phase 2 of PE; Di Geronimo & Robba, 1989). The loose/dispersed skeletal concentrations would be formed by a predominant production of biogenic hardpart over the rate of sedimentation - a typical feature of transgressive facies. Following the abatement and cessation of the tectonic paroxysm, a new biocoenotic equilibrium (S22) was gradually achie-
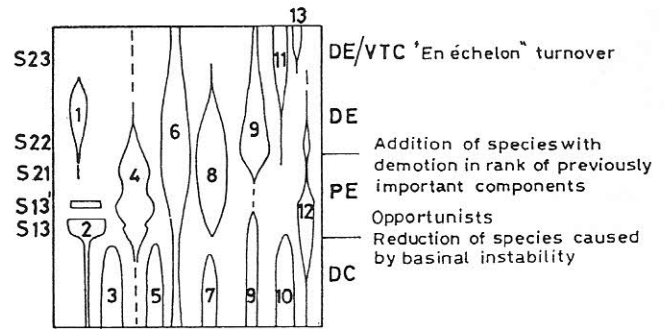

Fig. 9 - Model of community replacements by species turnover caused by recurrent edaphic stress (S13-S21) and gradual environmental change (S22-S23). 1) *Neopycnodonte cochlear*, 2) *Modiolula phaseolina*, 3) *Pecten jacobaeus*, 4) *Ditrupa arietina*, 5) Rodoliths, 6) *Pseudamussium septemradiatum*, 7) *Terebratula* sp. 1, 8) *T.scillae*, 9) *Hyalopecten similis*, 10) *Arctica islandica*, 11) *Pododesmus aculeatus*, 12) Bryozoa, nodular growth-form, 13) *Kellyella abyssicola*.

ved in a deeper setting, around 100 m, by the addition of species with demotion in rank of the previously important components (*sensu* Miller & DuBar, 1988) (Fig. 9). A softer seafloor could be inferred, likely triggered by an increased rate of mud sedimentation.

Upper unit.

This unit is represented by different facies, exposed for limited thickness (up to 7-8 m) at different stratigraphic intervals (Fig. 10).

Facies 1 - This widespread facies is represented by greenish to dark-greenish massive clayey silts. The sediment is barren or poorly fossiliferous (Fig. 7, S23), containing scattered *Ditrupa* tubes, a few *Pseudamussium* valves and rare thin lenses somewhat enriched in small-sized fossils. These are remains of shelled, benthic and planktic molluscs, mostly preserved as moulds (Table 5, S35, S23, S15), few corals, spines and plates of echinoids. Cemented lumps of bioclasts, a few centimetres across, and numerous fragments of thin (around 1 mm), sinuous galleries having a bioclastic wall are also present. Walls and several minute shells are oxidized in the sediments cropping out south of Masseria Serrazza (sample S15).

Facies 2 - West of Masseria Serrazza, a fining-up sequence (from muddy fine sand to clayey mud) has been temporarily exposed in a well about 7m deep (Fig. 10A; samples F 1-5). The megafauna is represented by dispersed shells of mud-pecten, large-sized ostreids, moulds of planktic gastropods, arborescent bryozoans and few tube worms (increasing in abundance in the clayey mud) together with poorly developed, large *Thalassinoides* galleries and several tiny, sinuous burrows. In general, the skeletons exhibit a high degree of articulation, a lack of orientation, a low degree of fragmentation as well as of encrustation, and few scraping structures. A microruditic bed with clasts of Cretaceous limestone and two layers of coarse sand with sharp basal contacts are interbedded and contain the same fossil remnants.

Facies 3 - Along the Canale Fano, marly mud laps onto a fault-bounded wall of Cretaceous limestones trending NNW. The marls, about 8 m thick, extend northwards from the wall over a limited area, merging laterally into the clayey-silt of facies 1. About 500 m south of this outcrop, on the eastern side of the valley, poorly exposed marly sediments are present; the contact with the nearby limestone is obscured. Fossils (Table 5, CF10) were picked up from concentrations produced by rain and colluvial reworking.
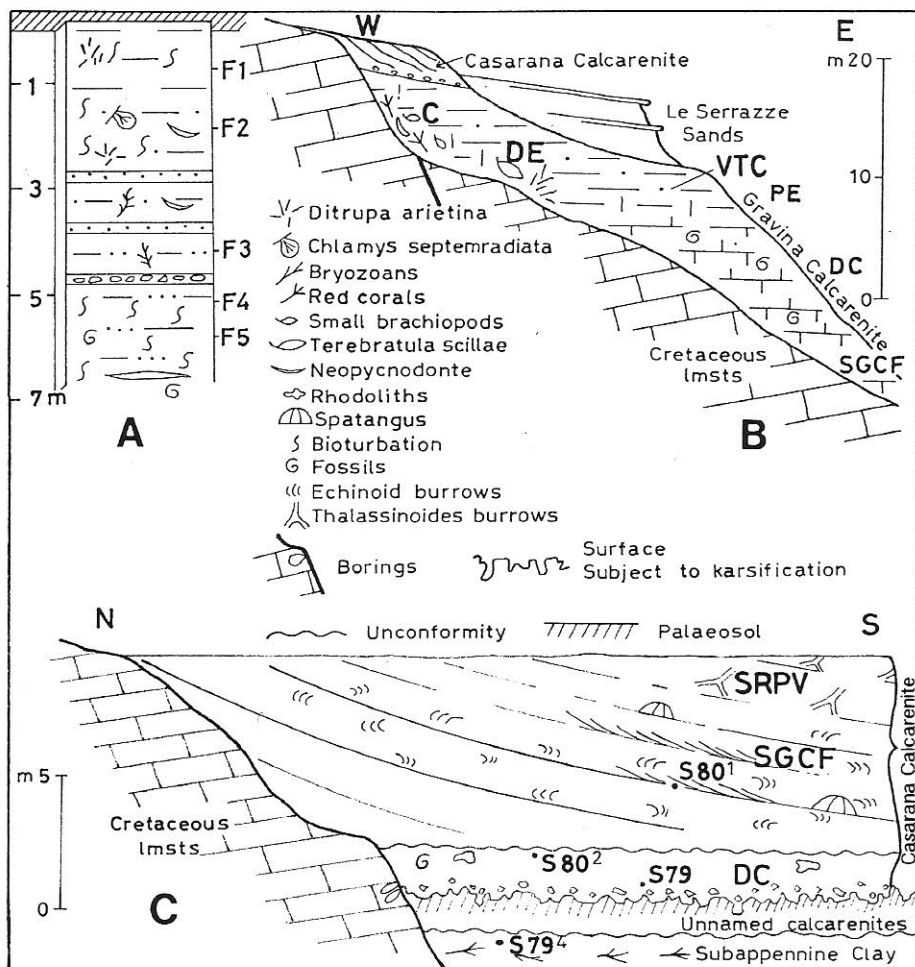
Fig. 10 - A: section of the upper unit of Lower Pleistocene deposits exposed in a well, W of Masseria Serrazza. B: Sketch of Lower Pleistocene deposits and relationships with younger deposits at Canale Fano; abbreviations refer to the biocoenotic interpretation of associations. C: Relathionship between the various Pleistocene deposits at Casarana quarry.

On the western side of the valley, the succession (Fig. 10B) from the bottom to the top is as follows (facies 3 is represented in the upper part of the succession):

1 - Coarse- to fine-grained calcarenites (about 15 m thick) grading into calcisiltites (about a metre thick). Calcisiltite shows dispersed biofabric and few loosely-packed shell layers; common fossils are closed *Terebratula* valves forming small clusters, and *Ditrupa* tubes. Although the quality of the exposure is poor, fossil content and taphofacies are comparable to the previously described lower and transition units, so that similar biocoenotic attributes can be assumed.

2 - Calcisiltite (about 50 cm thick) grading upwards into whitish marl (about 8m thick). In the calcisiltite interval (samples S50[2], S50[3]; Table 5), large brachiopods, pectinids, red coral branches and fragments of bryozoan colonies can be collected. The degree of disarticulation is low for the brachiopods, and high for the remaining epifaunal components. Bryozoans, up to 7-8 cm long, have arborescent, subordinately nodular growth-forms. Several thick fragments of red coral colonies are bored and/or have been encrusted by sedentary polychaetes.

The carbonate muds contain widely dispersed hardparts and few thin lenses of loosely packed skeletal elements (S40). The silt fraction is mainly composed of planktic foraminifera. Macrofossils lack physically-induced breakage, orientation or sorting; articulation frequency is very high for the micromorphic brachiopods, whereas anomiids and oysters are mostly recorded by well preserved upper valves. *Corallium* is represented by long fragments of colonies up to 10 cm in length and up to 3 cm in thickness (average about 1 cm). About 30% of the red coral remnants, as well as the oyster shells, are bioeroded and bear encrusters such as worm tubes, juvenile oysters, membraniporiform bryozoans and brachiopods (*Neocrania*). Bryozoans with arborescent growth-form are numerous.

Facies 4 - In the NW corner of a quarry near Masseria La Casarana a bryozoan-rich, poorly sorted, sandy mud covered by barren sediments laps onto an inclined wall of Cretaceous limestone, and shows an exposed thickness of about 60cm. The dominant components of the fossil concentrations are the same as those of the surrounding dispersed remains. They lack any preferred orientation and are represented by arborescent bryozoans (a few centimetres long), massive nodules made up of crustose bryozoans alternating with melobesian sheets, anomiids, *Pseudamussium* (recorded by less than 2 cm long valves) and some rounded rhodoliths. Few small valves of *Neopycnodonte* are found attached to the rocky surfaces, while some upper valves occur in the fossil concentrations. In addition, among the fossils recovered from the samples (Table 5, S79[4], S3), mud pectens and cardiids are quite abundant, whereas planktic gastropods are subordinate. Epifaunal elements are disarticulated and mostly complete; encrustation and bioerosion are restricted to *Ps. septemradiatum* and to the thicker branches of arborescent bryozoans that occasionally have also been bored by bivalves.

Interpretation.

Facies 1 - The assemblages consist of mainly autochthonous elements; the lenticular concentrations testify episodic higher-energy events. Among the benthos, suspension-feeders are the dominant trophic group, composed of epifaunal and shallow infaunal mollusks, followed by the semi-infaunal polychaete *Ditrupa arietina*. The abundance of walled burrows indicates the presence of sedentary, soft-bodied tiny animals; alternatively they could represent fragments of lined siphonal canals of bivalves no longer preserved. Lumps of bioclasts record

the activity of mobile animals. The scarcity of deposit-feeders could be either due to the high clay content or to their low preservation potential (being largely soft bodied animals).

The depth range of the species (Table 5) covers the circalittoral zone; a few elements are more characteristic of the upper bathyal zone, suggesting that the community lived close to this zone. The biocoenotic relationships of the species confirms this conclusion. Apart from taxa without a precise ecological significance, and those having wide ecological ranges, most species are reported as preferential or accompanying elements of Recent circalittoral biocoenoses. The few taxa related to the bathyal mud biocoenosis (viz. *Keratoisis melitensis* and *Leptaxinus ferruginosus*) are represented by only few specimens. The bulk of the individuals belongs to three taxa: *Ps.septemradiatum, Hyalopecten similis* and *Parvicardium minimum*. This composition reflects a DE biocoenosis substantially impoverished in shelled animals, possibly as a consequence of dysaerobic condition in the interstitial water and of a soft bottom. Therefore, the whole fossil assemblage records a Pleistocene equivalent of the DE-VTC ecotone, at depths around 100 m or slightly more.

In fact, as it may be inferred from the section near the Canale Fano, the compositional change from the DE Association (S22) to the overlying DE-VTC ecotone (S23) is chiefly characterized by (a) a general strong reduction in the abundance of megafossils, and (b) a loss or strong reduction, both in diversity and abundance, of the previously important components of the sessile epifauna (Fig. 9). Quite possibly, such a biological response was controlled by increased soupiness of the substrate that affected the stability of epifaunal organisms. In S15, another limiting factor for organisms having skeletons might have been inadequate oxygen supply. Nevertheless, the rate of the relative sea-level change was low enough to originate long-term environmental changes (regional subsidence continued during a cold climatic phase); consequently the community replacement could occur without any edaphic stresses (*en echelon*, model 2 in Miller & DuBar, 1988). In conclusion, this poorly fossiliferous facies records a low-energy biotope located in the outer shelf.

Facies 2 - Because of sampling difficulties, only small samples were collected (Fig. 10A, samples F 1-5). Therefore, species richness have been certainly underestimated. Fossils belong almost exclusively to attached or vagile epifaunal suspension-feeders, the tube worm *Ditrupa* being the only semi-infaunal element. Infaunal animals are recorded by domichnia/fodinichnia of crustaceans and by tiny galleries of unknown producers, probably sedentary suspension-feeders. Taking also into account the taphonomic features, it is possible to envisage a biotope characterized by stable soft bottom, gently

swept by currents preventing excessive muddiness but unable to cause roll or transport of skeletal elements. The rate of sedimentation consistent with sessile habit of fauna, probably was moderate to relatively high. A higher water energy and an increased consistency of the substrate compared with the facies 1, could explain the different biological response. The fossil assemblage is compared to the DE biocoenosis.

The fossils dispersed in the bioturbated sediments reflect the background conditions of the basin, whereas the coarser-grained beds can be considered as distal storm layers. The biotope was not necessarily shallower than that of facies 1, but possibly closer to a bathymetric high of the basin; all this provided that the relative position of the blocks of Cretaceous limestones was the same as that of today.

Facies 3 - The ecological inconsistency, the biocoenotic relationships, and the biostratinomic features of this facies suggest that the fossil assemblages of the lime-mud (Fig. 8, upper part of interval 2) were derived from two distinct palaeocommunities: (a) Brachiopod-Pectinid palaeocommunity related to loose sediments, and (b) Red Coral-Micromorphic Brachiopod palaeocommunity of rocky substrates. The latter shows the most typical aspect in the upper part of the second interval of the succession, where organisms of uncompacted bottom are missing (sample S40).

Fossil remains picked up from the marls cropping out along the left-hand side of the valley (CF10 assemblage) deserve a particular mention as they seem to suggest a somewhat different habitat.

(a) Brachiopod - Pectinid Community.

Bias by differential preservation should be taken into account, even if the scarcity of fossils can be, at least partly, attributed to primary biological causes. Furthermore, the occurrence in the assemblages of numerous animals that could belong to both inferred palaeocommunities, would significantly distort the dominance relationships. Soft-bottom related epifaunal animals are judged autochthonous together with the few moulds of infaunal bivalves, whereas red coral branches are surely exotic elements. Evidence of physical agents are lacking, whereas biological activity is recorded by bioerosion and encrustation.

Ecological data, supported by taphonomic signatures, help to envisage the main features of the biotope. Arborescent bryozoans are common in shelf settings of low to moderate energy and low rates of sedimentation (Nelson et al., 1988; Bone & James, 1993). Bryozoans with this morphotype encrust flexible substrates such as horny corals or filamentous algae; *T. scillae* needs a stable sandy mud bottom. The micromorphic brachiopods and the mud pecten form large populations on rocky substrates as well as on coarse bioclastic or mixed bottoms whit scattered skeletal elements. Approaching the limestone wall, the significant increase in micromorphic brachiopods, mud pecten and branches of arborescent bryozoans can be related to the supply of hardparts from the cliff community. However, biogenic hardpart production was smaller than the rate of sedimentation. This prevented community replacement. Autogenic succession of palaeocommunities was prevented by sudden deposition of mud which smothered the benthic assemblages and restored a soft, fine-grained bottom.

On the basis of the biocoenotic significance of the species and the textural properties of the sediment, the Brachiopod-Pectinid palaeocommunity would represent a Pleistocene facies of the DE biocoenosis, with a slight tendency to the DL biocoenosis. The subordinate elements of the C and/or the DC biocoenoses and the few elements of the DL biocoenosis, can be explained by a long time of residence on the seafloor of small hard substrates. The depth ranges of species agree well: each range includes the circalittoral zone where, in the deeper horizon, most of the species form large populations. Consequently, the fossil community can be confidently assigned to a position within this bathymetric interval (probably between 100-150 m). This hypothesis is also supported by the composition of the exotic remains, i.e. abundant branches of *Corallium rubrum* mixed with few skeletal elements (*Lophelia pertusa, Chlamys bruei, Pachylasma* sp.) that are more commonly reported from the transition zone between shelf and slope (Di Geronimo, 1987; Zibrowius, 1980). Compared with the DE Association of the Canale Muscio (S22), this facies inhabited a somewhat deeper biotope; the main differences, i.e. a higher abundance and species diversity, can be simply explained by more varied substrates and, possibly, lower turbidity at the bottom.

The biotope inferred for the Brachiopod-Pectinid Community corresponds to that of the modern "*Gryphus vitreus* bottom" of the Mediterranean (Falconetti, 1980). Nevertheless, due to the inadequate knowledge of the Pleistocene community structure a hasty parallelism between the two should be avoided.

Benigni & Robba (1988) analysed a Micromorphic Brachiopod-Pectinid Community that represents a Pliocene "*brachiopod bottom....transitional to and considerably influenced by a palaeobiocoenosis of the Coastal Detritic (DC)*". The community was inferred to live on a relatively high-energy sandy bottom, at an approximate depth of 150 m. In spite of a general resemblance with the Brachiopod-Pectinid community of the Canale Fano as far as the ecological composition (i.e. life-habit, feeding type, depth range) is concerned, the textural properties of the sediments together with the biocoenotic significance of the species, confirm the different biocoenotic assignment.

(b) Red Coral - Micromorphic Brachiopod palaeocommunity.

Micromorphic brachiopods, red corals and celleporiform bryozoans are the dominant taxonomic groups, followed by pectinids, anomiids, crustaceans and barnacles; the presence of other organisms is proved by bioerosion traces (Table 5, S40). Most taxa are reported in the literature as characteristic of both small and extensive hard substrates, with the exception of *C. rubrum*, which is restricted to ceilings and walls of shaded caves and to vertical or overhanging cliffs and is characteristic of GSO and C modern biocoenoses. As calcilutite is hardly a suitable substrate for such organisms, their occurrence in soft marly sediment suggests that all skeletal elements are allochthonous. However, the matching ecological needs of these animals point to a single rock community. As expected in a rocky habitat, the community is composed of suspension-feeders, chiefly consisting of attached and, subordinately, of vagile epifauna and endolithic organisms. Carnivores are mostly represented by crustaceans and *Propeamussium*. Rare shells of *Epitonium*, few ossicles of asteroids and boreholes of muricids complete the list of this trophic group.

The substancial presence of red coral colonies, associated with, or incrusted by, bryozoans and micromorphic brachiopods, does not leave any doubt about the interpretation of the fossil community as a Pleistocene deep Coralligenous facies. In the Recent, the animal-dominated facies of this biocoenosis is indicative of markedly reduced illuminations. In particular, on vertical cliffs the *Corallium rubrum* facies is reported at depths of up to 250 m (e.g. Laubier, 1966), but it is more common, to some extent, in shallower water, i.e. from 80m to 160m (Laborel, 1960; Carpine & Grasshoff, 1975; Di Geronimo & Fredj, 1987). Taking into account also the depth ranges of the brachiopods and bryozoans, it can be inferred that the fossil community flourished on the neighbouring subvertical fault surface at a depth of 100-150 m (possibly closer to the first value).

The lack of any evidence of post-mortem bioerosion in the shells of byssate and pedunculate animals supports the hypothesis that encrustation and bioerosion have been produced exclusively while the animals lived on the cliff. Taphonomic evidence suggests that dead animals, falling by gravity from the cliff, sank into a soupy seafloor or remained on its surface, partly covered by the fine mud resuspended by their impact. Episodic increase in water energy could have produced the loosely packed biofabric of the lenses. Mud clouds, carried basinwards by return flows, probably also contributed to the blanketing that sealed the exotic skeletal material.

Primary causes were possibly responsible for the scarcity of seafloor-dwelling organisms. The observed textural changes, from muddy calcarenites to marls, affected negatively the quality of the seafloor habitats, as suggested by the concomitant decline of the Brachiopod-Pectinid palaeocommunity. The disappearance of *Terebratula scillae*, followed by the whole sessile epifauna group reflects the reduction of substrate consistency. The subsequent loss of more tolerant bottom-dwellers and the lack of a bottom community in the upper part of the succession could be attributed to local morphological features (e.g. a deep, narrow hollow obstructed seawards by the fault wall) and the gradual deepening of the basin. Quiet water conditions would entail an insufficient supply of oxygen and an extreme soupiness of sediments, may be up to thixotropic conditions, that prevented animals with hardparts to live at the sediment/water interface.

From the Salento area, the only report of a community dominated by micromorphic brachiopods is by Taddei Ruggiero (1985, 1993). She described a micromorphic brachiopod coquina from a Lower Pleistocene calcarenite, near Castro, whose dominant taxa are the same as the ones that are found in abundance in the assemblages of the marl. Since the organisms shared by the two communities have a wade ecological distribution, their presence does not necessarily carry the same biocoenotic significance or suggest very similar environmental factors. The palaeocommunity of Castro, in fact, is better compared to the Micromorphic Brachiopod-Pectinid community described by Benigni & Robba (1988).

CF10 assemblage

In spite of the artificial mixing (the sample has been collected from worked soils) of elements belonging to the C biocoenosis with a few elements of the DE biocoenosis, it is worth to point out the significant presence of *Propeamussium fenestratum* and *Delectopecten vitreus*. These species must be added to the other fossils as a major component occurring in the aforementioned communities and supporting the assumed depth of the depositional setting (*D. vitreus* is regarded as "pure bathyal", Di Geronimo et al., 1982). Besides, the absence of red corals and decreased abundance of both arborescent bryozoans and small brachiopods, which show also a lower diversity, could indicate a lack of nearby cliffs and a soft, rather than soupy, bottom where scattered skeletons remained unburied for a certain time. A parallelism with the Recent "fonds à *Gryphus vitreus*", which represent a transition between circalittoral communities of detritic bottoms and those of the bathyal zone (Falconetti, 1980) is suggested.

Facies 4 - The assemblage occurring within the bryozoan-rich sandy mud is a mixture of sessile elements from rocky biotopes and individuals belonging to a shallow infauna and a vagrant epifauna of uncompacted bottoms. From a biocoenotic point of view, the assemblage is characterized by organisms preferentially occurring in either the C, DC or DE biocoenoses. Therefore, taking into account the consistent sandy fraction of the sediments, it is reasonable to infer that a community equivalent to a muddy-DC biocoenosis settled at the toe of the steep slope inhabited by the Coralligenous

biocoenosis. The fossil assemblage is in accordance with a seafloor gently swept by currents and with a low net rate of sedimentation, as confirmed by a certain amount of small rhodoliths. As a result, the organic debris, partly supplied from the calcareous slope, accumulated at a rate high enough to cause a positive taphonomic feedback with a trend from DE towards a DE-DC ecotone.

In conclusion, the gradual increase in the fossil packing, can be interpreted as the expression of a local autogenic change, triggered by the changing textural properties of the sea bottom, related to the physiography of the depositional setting. This hypothesis is supported by the distribution of such concentrations in the proximity of rocky substrates and it is also acceptable for similar concentrations occurring within the marl. The tabular geometry of the fossiliferous bed and the taphonomic attributes of fossils are consistent with an episodic rise of the water energy, such as storm-induced currents that winnowed the bottom and redistributed the organic remains over a wider area. The overlying barren sandy muds may represent blanketing events that restored the soft bottom habitat. The bathymetric ranges of the taxa once more point out the circalittoral zone. Nevertheless, the significant amount of calcareous algae, the high benthic/planktic foraminifera ratio and the lack of any bathyal macrofauna indicate, to a certain extent, a depth shallower than the one inferred for the other facies, supporting the allocation of the habitats below the storm wave base. It is important to underline that the supposed bathymetric difference between facies 1-3 and 4 is in accordance with the existing difference in altitude of the sites.

Lower (?) Pleistocene deposit

A discontinuity surface separates the Argille subappennine Fm. (facies 4) from a light-brown deposit up to 1.5 m thick ("unnamed interval") cropping out in the Casarana quarry (Fig. 10C). A poorly cemented, light-brown, fine-grained biocalcarenite (packstone) grades upwards into an uncemented, mottled bioclastic silty sand, which is overlain by a tobacco-coloured and locally deeply reddened interval of about 40 cm. Bioclasts are composed, in a decreasing order of abundance, of foraminifera, bryozoan debris, spines and plates of echinoids, fragments of mollusc shells and red algae. Intergranular voids, particularly the chambers of the planktic foraminifera, show in some cases a glauconitic infill. Scattered subangular quartz grains are also present. Macrofossils are mainly represented by small bivalves, rare moulds and/or casts of *Acanthocardia* sp. and single valves of *Arctica islandica*, *Aequipecten opercularis*, reteporiform bryozoans, disarticulated plates of *Spatangus*, and a few small nodules composed of algal laminae alternating with encrusting bryozoans. Towards the top, microbio-

turbation is common, glauconite and quartz decrease, while rhodoliths and thin lenses of comminuted shell debris increase, and scattered *Ditrupa* tubes appear. Sparse, small, micritic glaebules with branching calcite-infilled cracks also appear. An irregular surface showing a karstic relief on a decimetric scale terminates the tobacco-coloured interval at the top (Fig. 10C).

Interpretation.

Although the palaeontologic data do not allow to allocate the fossils to a particular biocoenosis, a well aerated biotope characterized by moderate water energy and soft, stable bottom, located in the upper circalittoral zone can be reasonably suggested. The palaeocommunity can be compared to a DC-SE ecotone. If the inference is correct, the glauconite-infilled tests of foraminifera must be reworked from sediments of the Lower Pleistocene Argille subappennine Fm. or from the Lower Pliocene Formazione di Leuca. Palaeosol development is indicated by the mottling, by the presence of carbonate glaebules (calcrete), and by the deep red colour of the upper part of this unit.

Middle(?) Pleistocene deposits

Yellowish, mostly medium- to-coarse-grained calcarenites, informally called Calcarenite della Casarana, are extensively represented in the study area, although major exposures are only available in quarries. In thin-section it can be distinguished from the Lower Pleistocene calcarenite by the presence of numerous corallinacean algae, as well as 5% to 10% rounded quartz grains. The unit crops out in a NW-trending elongate depression bounded by low ridges of Cretaceous limestone. The thickness of the Calcarenite della Casarana reaches its maximum in the central part of the elongate depression where it may exceed 20m (near Masseria Tonda) and progressively decreases towards the marginal areas. Its base is clearly erosional, resting directly on Cretaceous limestone and Lower Pleistocene deposits. The dominant bioclastic components, the ratio between the algae and shell debris, and the depositional textures and fabrics appear to change laterally and vertically. The thin transgressive basal facies is only exposed at the Casarana quarry, above the so-called "unnamed interval", along the western contact between the Cretaceous limestone and the calcarenite. It records low sedimentation rates in infralittoral and shallow-circalittoral environments. Regressive deposits, forming the bulk of the formation, crop out in numerous quarries along the NW-SE elongate depression (Fig. 1). They form a thick shallowing-upwards succession consisting essentially of calcarenites deposited in an environment characterized by

rhythmical variations in sedimentation rate as a result of periodic high-energy events. The presence of northern guests indicates lower salinity and lower temperature values than those of present-day.

Southeastwards, the unit is truncated by an erosion surface with the morphology of an incised valley, which is infilled with coarsening-upward sediments, informally named Sabbie della Serrazza (Fig. 10B).

Transgressive facies.

Facies 1 - Eastward of Aparo dei Valentini, on the eastern side of the Canale Fano, a reddish well-cemented carbonate deposit, about 3 m thick, normal graded (from a microconglomerate to a coarse-grained calcarenite) forms an unconformable transgressive contact with the underlying clayey-silts of the Bradanic cycle. It is a grainstone mainly composed of algal nodules and rounded bioclasts; undeterminable moulds of molluscan shells occur scattered together with rare complete left (free) valves of *Spondylus gaederopus*.

On the western side of the Canale Fano, the Calcarenite della Casarana laps onto a sloping subaerial palaeotopography of Cretaceous limestone and partly on to the Argille subapennine Fm.. Locally, it shows a basal conglomerate up to 20 cm thick. The pebbles are well rounded and heavily bioeroded: *Entobia megastoma* is the best represented ichnotaxon together with *Gastrochaenolites torpedo*; *Caulostrepsis cretacea* is rare. Borings are almost complete due to minimal abrasion of the original substrate. Locally, densely packed valves of *Mytilus* and small-sized oysters (*Ostrea edulis*) are present at the base of the fine-grained calcarenite that laps onto a slope of Cretaceous limestones poorly bioeroded by *Caulostrepsis cretacea*.

Facies 2 - At La Casarana quarry the "unnamed interval" is overlain by a pale-grey, somewhat knobbly caused by *Thalassinoides*, massive, bioclastic muddy-sand, 1-1.4 m thick (Fig. 10C). The two units lap onto a steeply inclined wall of Cretaceous limestone, recognizable as a cataclastic fault plane, poorly bioeroded (mainly by *Caulostrepsis* isp.) at the level of the erosion surface. Scattered, poorly bioeroded pebbles of Cretaceous limestone (up to 7 cm in length, but commonly much smaller), abraded shell fragments and small rhodoliths are found in the basal part of the muddy sand. Complete skeletons are common, even though most are undeterminable, being preserved as moulds, casts or recrystallized shells: trochiids, *Bolma rugosa*, single valves of pectinids and small cardiids (Table 6 - S79, S4), and numerous opercula. Upsection, the sediment is generally muddier, characterized by abundant *Timoclea ovata* casts and by membraniporiform bryozoans (Table 6 - S80²) together with a few meniscate traces. The overall thickness of this interval is no more than two metres.

A sharp discontinuity surface separates this fining upward, muddy bioclastic sand by a well cemented, intensely bioturbated, yellowish calcarenite that represents one of the characteristic regressive facies of the Calcarenite della Casarana.

Interpretation.

Facies 1 - Taphonomic, sedimentologic, and ecological features suggest coastal environments and high-energy conditions. Substrates and energy level favoured the settlement of a palaeocommunity comparable to the SGVB biocoenosis, located in the upper infralittoral, near a rocky coast colonized by the AP biocoenosis the latter supplying the exotic shells (i.e. *Spondylus gaederopus*). Southeastwards of Masseria Brufichi, the AP biocoenosis is recorded by bioerosion of endolithic bivalves

and sponges preserved in rounded pebbles (transgressive lag) accumulating at the toe of a rocky coastal cliff. Furthermore in the same area, the pervasively laminated calcarenites probably reflect a shoreface overlying a ravinement surface marked by the transgressive lag. The good shell preservation and the life habits of the bivalves suggest passive accumulation and short-term reworking, at the toe of cliff, of the shells supplied from an AP-equivalent biocoenosis settled on the nearby rocky surface.

Facies 2 - In the Casarana quarry the karstic surface at the base of the deposits provides evidence of a transgression which encroached on a subaerial topography. The mixed assemblage occurring in the basal part of the transgressive deposits can be considered as a biogenic-sedimentologic concentration consisting of parautochthonous and allochthonous skeletal elements accumulated during a period of low net sedimentation under conditions of low to moderate energy. Parautochthony could be produced by hydraulic and biological reworking of the bottom sediment, whereas allochthony of skeletal elements by biological (such as hermit crabs) and/or physical agents (storm-induced flows). The organisms are vagile epifaunal browsers and detritus-feeders, subordinately shallow infaunal suspension-feeders and scavengers. Most components of the assemblage are related to AP/HP and/or to DC biocoenoses. Consequently, a palaeocommunity corresponding to a shallow (20-30m) DC facies and strongly influenced by the infralittoral AP/HP biocoenoses is suggested.

Upsection, a higher diversity of DC-related organisms, the abundance of *Timoclea ovata*, who commonly settles at depths greater than 30-40 m, and nodular/arborescent bryozoans as well as the reduction of infralittoral forms suggest increased depth and lower water energy, which allowed the finer fraction to settle and to form a mixed sediment suitable for a DC Association.

Regressive facies.

The regressive facies appears as a progradational body showing, in most cases, distinct clinoforms dipping at 8°-10°, with dip azimuth ranging from 180° to 240° and topsets reworked by shoreface processes. A number of facies can be defined with mutual lateral and vertical transitions: (1) Facies characterized by variably preserved physical structures and consisting of predominantly medium-grained bioclasts; (2) algal facies; (3) shelly-bioclastic facies, characterized by shell-gravels, medium to coarse bioclastic sands and coquina beds; (4) *Thalassinoides* facies.

In all facies small, rounded clasts of the Calcarenite di Gravina Fm. and of Cretaceous limestone sparsely occur.

Facies 1 - Three subfacies can be distinguished:

Subfacies 1A is the most widespread of the three and forms the bulk of the progradational body especially between Masseria Tonda and Casina Vecchia dei Cari. The subhorizontal toesets of the body are locally visible in a disused quarry (SW of Masseria Tonda), where muddy sands containing a few large, sphaeroidal rhodoliths and numerous casts of generally undeterminable molluscan shells (Table 6, S7) crop out for about 2 metres. Clinoforms appear as large-scale inclined beds with planar stratification and a maximum dip in the central part of the body. This angle progressively decreases updip and downdip leading to a slightly sigmoidal geometry. Second-order structures are commonly present within clinoforms, and they are represented by medium- to small-scale trough cross-bedding, generally increasing upward in scale, indicating flow directions ranging from 215° - 230° (essentially down the slope of clinoforms), and rarely planar lamination. Traction structures are best developed in the thicker, axial part of the Casarana body.

A characteristic feature of this subfacies is a laminated-to-bioturbated pattern (lam-scram pattern of authors) occurring within the clinoforms (Fig. 11). Each calcarenite bed has a sharp erosional base and can be described as a couplet comprising a lower laminated part and an upper part disturbed by meniscate burrows of upward increasing density. (*Laminites* as emended by Plaziat & Mahmoudi, 1988; according to Uchman, 1995, the ichnotaxon lacks diagnostic value and the author emended the Plaziat & Mahmoudi's *Bichordites* to include *Laminites*).

The top of the beds commonly shows a truncation of the menisci by the erosional base of the subsequent layer. The lower laminated division is a fairly well-sorted, fine- to coarse-grained biocalcarenite, whereas the bioturbated division commonly shows a silty carbonate matrix. All transitions were observed between facies dominated by physical structures and facies pervasively bioturbated (bioturbation index 5-6; Taylor & Goldring, 1993). The latter are typically represented in the Casarana quarry (Fig. 12) and in small quarries nearby and contain rare complete fossils (Table 6, S80[1], S2). A single specimen of *Echinocardium cordatum* was found at the end of a meniscate burrow.

In general, meniscate burrows decrease in density upwards within the progradational body, whereas large, rounded rhodoliths commonly increase in abundance forming, in particular, linear rows and shallow broad lenses (2-3 m wide) in the topsets. Less commonly, rhodoliths are replaced by bivalve remains. The fossil concentrations are composed of loosely packed, mostly convex-up, single valves of mytilids and pectinids in all stages of breakage, together with more complete *Glycymeris insubrica* valves, all of them moderately encrusted and bioeroded. The topset units are locally represented by swaley cross-bedded or trough cross-bedded calcarenites.

Subfacies 1B forms a narrow belt parallel to the contact of the Calcarenite della Casarana with the ridge of Cretaceous limestone, south of Masseria Tonda (Fig. 13) and near Masseria La Casarana. Rarely this subfacies is present at the top of the progradational body in the axial area (e.g. in the Masseria Tonda quarry). It typically consists of large-scale, festoon cross-bedded sets with mutually erosional relationships. Set dimensions range from large-scale festoons up to 3.5m high and up to 15m wide, to medium-scale trough cross-bedding; foreset laminae (Fig. 14) show high dip angles (up to 25°) and an tangential asymptotic basal contact. Both normal and inverse grading were observed within each individual lamina. Bundles of laminae are locally convoluted related to limited slumping or to local liquefaction. Palaeocurrents indicate flow directions subparallel to the margin of the palaeorelief. The sediment is a well sorted algal biocalcarenite to fine biocalcirudite. Large *Laminites* (index 2°-3°) are present within the finer-grained calcarenitic intervals.

Subfacies 1C - Along the south-western margin of the Casarana body, southeastwards of Masseria Brufichi, planar to low-angle laminated calcarenites, rarely including casts of convex-up oriented, large, single valves, lap onto the sloping flank of a ridge of Cretaceous limestone and grade downwards into the basal transgressive deposits. Additional features are planar to broadly curved (both concave-up and convex-up) erosional surfaces bounding groups of laminae at low to high angles, (probable hummocky and swaley cross-lamination), medium-scale trough cross-lamination and convolute lamination. The main stratification dips at 8°-10° towards the axis of the depression, suggesting a clinoform geometry.

Facies 2: *Algal facies* - This facies, in which the algal component dominates over faunal remains, is particularly represented in the central part of the depression. It is a yellowish coarse biocalcarenite to biocalcirudite, mostly composed of oval to rounded grains of fragmented stumpy branches of rhodoliths, bryozoans and small-sized nodules (diameter <5 mm), of algal laminae preferentially encrusting zoaria fragments (pralines). Worn and angular fragments of bivalves, large benthic foraminifera and rounded calcarenite lithoclasts (about 1mm) are subordinate in abundance. Poorly bioturbated intervals (*Laminites*, index 3) alternating with facies (1), consist of biocalcarenite to calcirudite with a silty carbonate matrix including concentrations of large, stumpy-branched rhodoliths in loosely packed beds or lenses (i.e. quarry near Casina Vecchia dei Cari). Complete specimens of macrofauna are rare and mainly represented by *Echinocyamus pusillus*, *Pododesmus aculeatus*, rare *Glycymeris bimaculata*, few pectinids, mytilids,
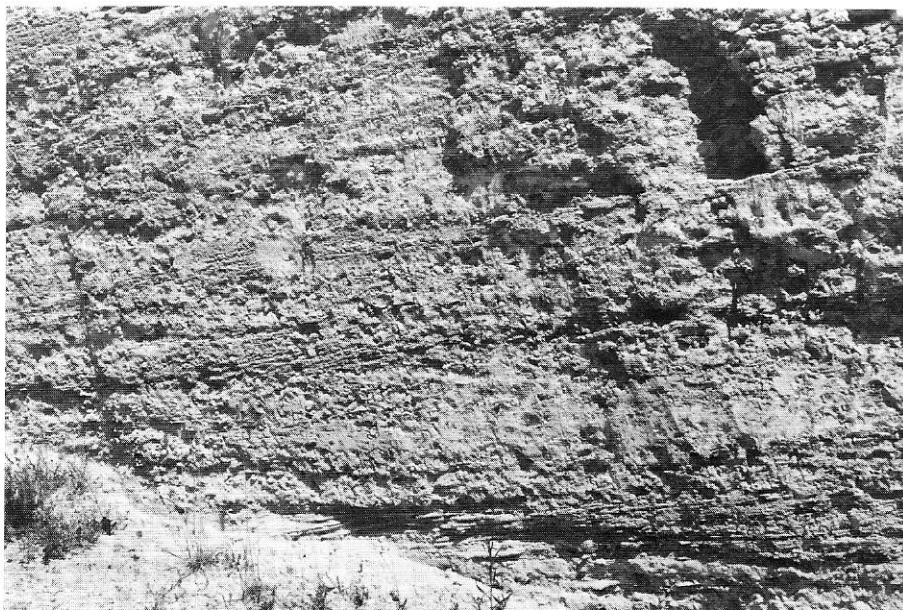
Fig. 11 - "Calcarenite della Casarana", facies 1 (subfacies 1A); laminated-to-bioturbated pattern at Masseria Tonda.

Fig. 12 - "Calcarenite della Casarana", facies 1 (subfacies 1A); pervasive bioturbation (*Laminites*) at Casarana quarry.

undeterminable moulds of gastropods, *Turritella* cf. *turbona*, naticids, and rare *Ditrupa* tubes.

Trough cross-bedding is common within the clinoforms, but the lam-scram facies typical of facies (1), is generally lacking.

Topset beds are made up of poorly bioturbated algal calcarenite, rich in rhodoliths commonly forming linear or broadly lenticular stripes. In general, where meniscate traces dominate, large rhodoliths as well as praline grains decrease in abundance whereas shell debris increases.

Facies 3: *Shelly bioclastic facies* - This facies is particularly represented in a NW-trending belt extending eastwards of the axis of the sediment body. The shelly bioclastic fraction becomes dominant and the prograding body is mostly made up of coarse-grained skeletal debris. Coquina layers (up to 40-50 cm thick) are interbedded with medium-grained calcarenite and poorly fossiliferous horizons moderately bioturbated (*Laminites*, index 2-3). The coquina beds are made up of moulds of complete, mostly articulated thin-shelled bivalves and gastropods, with random plan-view orientation. The shells do not show signs of bioerosion or encrustation. They are represented by common tellinids and trochiids (*Thracia pubescens, Acanthocardia aculeata* are su-

bordinate; *Astarte fusca* valves and *Haliotis lamellosa* moulds are rare). Locally, coquina beds contain levels or lenses of articulated larger molluscs (i.e. *Arctica islandica, Glycymeris bimaculatus*). The less fossiliferous beds are commonly laminated in the lower part. There, fossil remains, both scattered and packed in thin lenses, are mainly represented by rhodoliths and/or thick-shelled bivalves commonly in current-stable orientation or imbricated. Beds of well-sorted, coarse shell-gravel made up of abraded and encrusted elements are patchily distributed.

Facies 4: *Thalassinoides facies*. This facies is present in the uppermost part of the prograding body on the south-western side of the Casarana quarry. It is represented by an extensively bioturbated fine calcarenitic unit (up 2 m thick) showing irregularly branched *Thalassinoides* boxwork that obscure stratification. The packing of the burrows is so high that the basic pattern of single systems is beyond recognition. This facies overlies the intensely bioturbated variety of *subfacies 1A*; at the contact, few oblique *Thalassinoides* shafts extend into the underlying calcarenite cross-cutting the meniscate traces. The unit wedges out and disappears toward the eastern ridge of the Cretaceous limestone.

Fig. 13 - Longitudinal section of a calcarenitic sand wave with high-angle foresets, S of Masseria Tonda.

Fig. 14 - "Calcarenite della Casarana", facies 1 (subfacies 1B); detail of high-angle foresets in the sand-wave facies; small disused quarry, SW of Masseria Tonda.

Interpretation.

Facies 1 - *Subfacies 1A* - The different degrees of bioturbation and the different styles (evenly distributed - pervasive or scattered -, concentrated in layers or in lam-scram sequences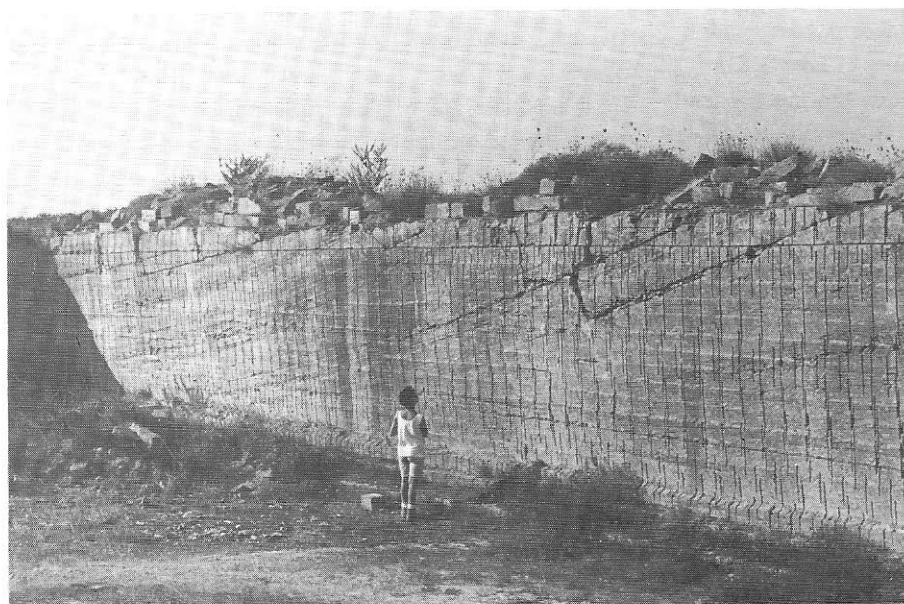) depend on the interplay between the net rate of sedimentation and the rate of biogenic sorting. In the lam-scram sequences, thought to result from episodic major storms, the preservation of the primary lamination is due to fact that the thickness of each event-bed is greater than the maximum burrowing depth of the trace maker (Ekdale et. al., 1984). The thicker bioturbated beds represent the accumulation of several erosive and depositional events (viz. multiple-event beds, each thinner than the producer tier). The end member of subfacies 1A is represented by thoroughly bioturbated facies, in which biogenic sorting exceeded the sedimentation rate. The meniscate burrows occurring in the Calcarenite della Casarana have been most probably produced by *Echinocardium cordatum*, which preferentially inhabits shifting medium to coarse sandy bottoms of the shallow sublittoral zone. Among the few preserved skeletal remains, *Spatangus purpureus* and *Glycymeris glycymeris*, known to thrive in high-energy settings swept by strong currents, are common. From a biocoenotic point of view, the fossil assemblages may belong to SGCF Association that inhabited a seafloor at depth probably shallower than 30 m.

The accretion of the progradational body by the addition of clinoforms was episodic, due to discrete most probably storm-related high-energy events. These were separated by pauses, during which the sediment, already settled, was colonized by populations of burrowing opportunistic echinoids. Storm-induced currents allowed development and migration of trains of small dunes down the frontal slope of the prograding body.

We infer that the material, periodically swept by storm currents, was essentially supplied from the platform developed at the top of the prograding body.

The rarely outcropping toe set beds, characterized by widely dispersed, large rhodoliths in a matrix of sandy mud, probably represent the distal downcurrents deposits of the storm-dominated flows. The preservation quality of the shallow-infaunal mollusc hardparts point to short-term reworking without extensive transport. The biostratinomic features of the fossils in the topset units formed through long-term exposure to current/wave action.

Subfacies 1B - Subfacies 1B probably resulted from the migration of sinuous-crested sand waves. Palaeocurrents suggest that the flows which generated the bedforms were confined to a narrow strip between the already existing progradational body and the palaeorelief of the Cretaceous limestone that probably was at least partly emergent at this stage. The strait enhanced flow strength, entailing the formation of large-scale bedforms.

Subfacies 1C - This subfacies represents a high-energy lower to upper shoreface facies developed in a marginal, nearshore area. Its relationship with the regressive rather than transgressive stage is indicated by its clinoform geometry.

Facies 2 - *Algal facies* - This facies may be compared to the present-day SGCF or to the algal facies of DC. The distribution of rhodolithic concentrations and the presence, among the molluscs, of *Turritella* cf. *turbona* (maërl-loving), *Pecten jacobaeus* (exclusive in DC), *Glycymeris bimaculata* (SGCF), *Echinocyamus pusillus* (SGCF) indicate a SGCF/DC ecotone alternating with a more typical maërl facies of DC. Maërl-type deposits are preferentially found in wave-protected sites (with minimal terrigenous supply) swept by constant though re-

latively weak currents, such as sounds and channels where waves are suppressed and linear currents are enhanced (Scoffin, 1988). In the Mediterranean Sea such kind of currents typically form in sounds between islands, shoals or between coasts and islands ("passe" and "vent" currents of French authors), whereas in the Atlantic they are tidal and estuarine in origin. In present-day settings this facies is commonly reported at depths of 25-30 m, exceptionally up to 90 m in the Mediterranean Sea (Jacquotte, 1962). More recent data report this facies at about 40 m in the western basin, about 60 m in the eastern basin (Basso, 1995). Furthermore, free coralline associations are recorded from 30-90 m in the western Mediterranean, down to over 120 m in the eastern Mediterranean (Di Geronimo & Giaccone, 1994). For the facies discussed above, associated fauna and sedimentary features suggest depths closer to the shallower limit. Biotopes with currents still unidirectional, constant and, to a certain extend, stronger than those reported for maërl (Bourcier, 1981) are here inferred from the pralines-rich facies.

The preferential localization of this facies in the central part of the depression suggests that the axis of the seaway was more or less constantly swept by unidirectional currents which created conditions favourable to the successful development of coralline algae. The presence of rhodolithic concentrations within the progradational body reflects the periodic transport and the mechanical sorting by storm-induced flows. Therefore, we envisage the interaction of two different processes: the more or less constant activity of an unidirectional current flowing along the seaway, and episodic storm-induced flows.

Facies 3 - *Shelly-bioclastic facies* - Some of these beds are simple, others are clearly composite due to amalgamation of a number of event-beds. Fossil concentrations, especially towards the north-western area, can be considered as sedimentologic concentrations (Kidwell et al,. 1986). For some coquinas, the percentage of articulated specimens, the lack of sorting as well as the good preservation, suggest short-term reworking without extensive lateral transport. Fossil concentrations with dispersed, convex-up oriented shells, mostly single, moderately encrusted and bioeroded, formed a long-term winnowing by currents/waves. Local origin of most skeletal elements is suggested by the congruity between most of the species in the fossil concentrations and those recovered from the poorly fossiliferous intervals. Particularly significant is the presence, among the indigenous components, of reophilic forms (i.e. *Astarte fusca, Glycymeris bimaculata, Spatangus purpureus*) and of taxa commonly inhabiting infralittoral and/or upper circalittoral zones (i.e. tellinids, *Arctica islandica, Acanthocardia aculeata*). Exotic elements derived from HP/AP biocoenoses are *Haliotis lamellosa* and at least part of

the trochids. A SGCF biocoenosis or a SGCF-SFBC ecotone is suggested that lived on coarse-sand substrate approximately around 15-20 m depth, to where shells of HP/AP biocoenoses were episodically transported from nearby rocky areas. This seabottom was affected by storm waves and storm-induced currents that disturbed and concentrated the shells, producing both storm wave concentrations (type 2 of Fürsich & Oschmann, 1993) and, basinwards, proximal tempestites (type 3 of Fürsich & Oschmann, 1993). A subsequent return to normal conditions produced a texturally mixed sediment, recolonized by the previous palaeocommunities, and recorded by the beds locally with current-oriented shells of the shallow infauna and meniscate traces.

The taphonomic features of the shell-gravels (i.e at Casina dei Cari 2) indicate long-term, high energy reworking of debris in a wave-dominated setting, where the shelly material was eventually dispersed and accumulated below the fair-weather wave base by storm-induced flows. The inferred environmental conditions were suitable for a palaeocommunity comparable to the SGBV biocoenosis, or for a SGBV-SGCF ecotone. In the English Channel, Recent shell-gravels are reported from sites affected by strong storm-generated currents (Carthew & Bosence, 1986) and characterized by a low terrigenous supply and/or by a winnowing of the finer-grained sediment.

Facies 4 - *Thalassinoides facies* - Edaphic conditions suitable to crustacean-dominated communities are inferred from the widespread *Thalassinoides* ichnofacies. Although *Thalassinoides* is preserved as an élite trace fossil (Bromley, 1996), the ichnospecies diversity was originally very low. It is well known that *Thalassinoides* is not a reliable indicator of water depth, its distribution being mainly controlled by the substrate. It is commonly present in fine-grained sediments that are stable and not prone to collapse, in calm depositional environments (Ekdale, 1992). We suggest that this facies was generated by a crustacean-dominated community, which is preliminarily compared to the SRPV regarded by Le Gall (1969) as an higher-energy extreme facies of the SVMC biocoenosis. Habitats favourable to a successful settlement of such a biocoenosis could have existed in sheltered areas located beyond offshore bars or shoals, or within a bay formed by the emergence of the calcareous ridges during the regression.

Middle Pleistocene deposits

The last pre-Tyrrhenian unit of the investigated area has been informally named Sabbie della Serrazza (Fig. 1); its stratigraphic position suggests a Middle Pleistocene age. It forms a coarsening-upward succession

evolving from micaceous sandy muds to coarse-grained calcarenites. It appears as the marine fill of erosional depressions cut into Lower Pleistocene deposits, as well as into the Calcarenite della Casarana deposits. In marginal areas it transgressed the Cretaceous limestones, whereby the deposits onlap on the flanks of the topographic depressions. The most complete succession (about 15 m) includes four facies which grade vertically and laterally into each another; the finest basal deposits are found seawards and in the axial part of the deeper topographic depression. The overall thickness decreases northwards (i.e. landwards). Throughout the whole succession, species indicative of climatic conditions cooler than present-day (*Pseudamussium septemradiatum*, *Arctica islandica*, and *Acanthocardia echinata*) are present.

Facies 1 - This facies is present only in the depocenter along the Canale Ariano. Unfortunately the lower contact is not exposed. This facies consists of about 4m of greenish massive micaceous sandy muds. The fossils (Table 7, S41), uniformly dispersed, are mainly represented by well preserved, usually articulated bivalve shells. *Parvicardium minimum* and *Limatula sulcata* are typically abundant.

Facies 2 - This facies consists of micaceous, sandy muds grading upwards into bioturbated silty sands. It is characterized by abundant, though dispersed, mostly articulated valves of *Pseudamussium septemradiatum*. The facies is laterally highly variabile, both in thickness and faunal composition. Locally, widely spaced thin beds of bioclastic fine sandstones, as well as lenses of comminuted bioclastic debris or, rarely, pavements of *Ps. septemradiatum* are intercalated. In a few sections located on the flanks of a palaeodepression, westwards and south-westwards of Masseria Serrazza, facies 2 makes up the basal deposits of the Sabbie della Serrazza, sharply overlying the Argille subappennine Fm.. In one of these sections, it is represented by clayey-muds (about 50 cm thick) characterized by rare, dispersed fossils (Table 7, S16[1]) and by *Thalassinoides* networks (index 2) of which the few thick galleries piped into the underlying Argille subappennine, exhibit *Spongeliomorpha* features. The uppermost term is represented by barren mud with tiny ferruginous galleries. Where the muddy interval is missing, the micaceous sandy mud directly overlies the substrate.

Locally, the fine-grained deposits of facies (2) are interbedded with small lenses of comminuted bioclastic debris or with a few thin sandstone layers showing planar lamination to low-angle cross-lamination and occasionally ripples at the top. Fossils are mostly dispersed; few discontinuous shelly layers are dominated by complete, disarticulated, rarely imbricated, pectinid valves (S16[3], S16[4]). In the depocenter (central segment of Canale Ariano), facies (1) grades into moderately bioturbated fossiliferous silty sands, about 3 m thick (S 42), lacking *Arctica islandica*.

In the upper part, facies (2) is represented by better sorted, silty sand with regularly distributed fossils and usually with closed valves or valves that are against each other slightly shifted. As a rule, valves of *Ps. septemradiatum* and *Arctica islandica* are abundant, the latter increasing in abundance upwards (Table 7, S6, S7), and occurring either randomly oriented, in loosely packed lenticular concentrations, or in thin beds. Depending on relative abundance of these two taxa, clumps of *Ditrupa* tubes may be common.

The transitional interval to facies (3), well exposed eastwards of Canale Fano and westwards of Masseria Serrazza, is characterized, as a rule, by the presence of scattered *Thalassinoides* galleries (3-4 cm in diameter) grading upwards into complex networks (index 1 to 3), and truncated at different levels by thin calcarenitic planar-laminated beds. The fossil assemblages (S7, S26) are characterized by an abundance of *Ditrupa* and a high species diversity. In contrast, at Canale Ariano, the transition to facies (3) is indicated only by an increase in the density of *Thalassinoides* burrows and by the interbedding of proximal tempestites and bioclastic sands.

Facies 3 - This facies is characterized by silty fine-sand and bioclastic sand, up to 6-7m thick, locally intensely bioturbated by *Thalassinoides* boxworks, with dispersed, complete fossils (Table 7, S27, S28) interbedded with coarsening- and thickening-upward bioclastic calcarenite layers, 10-60 cm thick. A thick, bioturbated (*Thalassinoides*, index 5-6) calcarenitic bed is usually present at the base; abundant galleries, infilled with whitish bioclastic sand, are piped into the underlying yellowish muddy sediment, obscuring the basal contact.

Throughout the whole facies, the burrows systems of the sandy intervals are truncated at the top by the calcarenitic layers but, in turn, extend into the underlying calcarenitic beds. The latter contain a variable fraction of quartz sand and may show small flutes at the base; internal structures locally include: well developed normal grading, planar to low-angle lamination and pavements of nearly monospecific, convex-up oriented, sometimes regularly imbricated valves (mostly of *Arctica* or pectinids), the shells are rarely broken, abraded or encrusted. In contrast, in a few 2-3 cm thick shell beds with packstone matrix, skeletal elements show random orientation, high fragmentation, abrasion and encrustation by algal laminae. Rarely, the carbonate beds are rich in large rhodoliths.

Southwestward of Mass. Serrazza, a progressive wedging out of the biocalcarenite layers can be observed, with locally a transition to a fine-grained, intensely bioturbated bioclastic sand (up to 6 m thick). Furthermore, few calcarenite layers appear deformed within overturned folds and partially disarticulated in blocks as a result of slumping events which involved, although with minor intensity, also the associated sands, as is clearly shown by partial deformation of the *Thalassinoides* networks. The macrofauna in the sands is either dispersed or concentrated in thin lenses (S28).

Towards the shoreline, the thickness of facies 3 decreases at the expense of the sandy intervals. At the transition to the facies (4) (thickness about 150 cm), the calcarenites show a well developed, amalgamated hummocky cross-stratification; they are characterized by a bimodal texture due to the presence of complete shells in a packstone matrix; articulated and disarticulated convex-up oriented valves of *Arctica islandica* form discontinuous pavements or lenticular bodies; meniscate traces are locally preserved.

Facies 4 - The fourth facies is characterized by coarse-grained, well-sorted biocalcarenites with abundant coarse shell debris and skeletal fragments in lenses and layers. Identifiable fossils (*Arctica*, *Aequipecten opercularis*, *Chlamys multistriata*, *Ch. pesfelis*, *Patella*, mytilids, tubeworms, spatangoids and rhodoliths) are mostly broken, abraded and encrusted by algae and/or laminar bryozoans. Northwards and northeastwards, the thick calcarenitic beds grade upwards into coarser sediments showing medium-scale trough cross-bedding; the fossil content is reduced to a few meniscate traces and rare convex-up oriented bivalve moulds. Near the head of Canale Fano, facies (4) is typically represented by thick, bioturbated (small-sized systems of *Thalassinoides*, index 5-6) calcarenite beds which progressively become thinner lapping, to the west, onto a palaeorelief of Cretaceous limestones.

Interpretation.

The fossil assemblage present within facies (1) records a palaeocommunity rich in shallow infaunal and epifaunal suspension-feeders commonly reported from VTC and DE biocoenoses; the presence of a VTC-characteristic detritus-feeder such as *Abra nitida*, tolerant of euxinic conditions, could be related to the fine grain size of the sediments and to the redox level close to the depositional interface. The palaeocommunity may be

compared to a VTC-DE ecotone living on a soft seafloor at an approximate depth of 50-60m.

The palaeocommunity recorded in the basal part of facies (2) is compared to a facies of the Recent VTC biocoenosis, living during background conditions of low energy and, locally, impoverished due to a reduced oxygen content. The thin fossiliferous intercalations, interpreted as distal storm layers, contain parautochthonous elements of a VTC Association mixed with small exotic shells from a DC Association. Skeletal elements of organisms commonly reported from the VTC biocoenosis tend to decrease upwards and laterally northwards, while DC elements tend to increase, suggesting a change from low energy to higher energy settings and an evolution from a VTC-DE ecotone (S41) towards a VTC-DC ecotone (S6) and to a facies of the DC Association rich in burrowing crustaceans (S42). It is reasonable to assume that lateral changes in the associations have been induced by an irregular bottom, which controlled particularly the pattern of bottom currents and the sedimentation rate. Taphonomic features, increase in thickness and abundance of storm layers, and changes of palaeocommunities in accord with changes in sedimentological features suggest a shallowing trend.

The fossil assemblages occurring in the transitional interval to facies (3) (S7, S26) may be interpreted as an incipient Heterogeneous Community (first phase of PE; Di Geronimo & Robba, 1989). As above noted, in the Canale Ariano area, the transition is only marked by an increased density of *Thalassinoides* and by proximal tempestites; therefore, development of the PE was probably related to local factors.

In the sandy intervals of facies (3), the fossil assemblages record palaeocommunities equivalent to DC/SE or VTC/SFBC ecotones, living on bottoms located at the infralittoral/circalittoral transition. The intercalated calcarenitic beds represent increasingly proximal storm layers, as shown by the thickening- upward and coarsening trend, with eventual amalgamation commonly highlighted by the repetition of fossil concentrations; fossils mostly belong to the already identified palaeocommunities of the transitional zone. A complex origin can be inferred for the thin shell beds: the taphonomic signatures of the skeletal components indicate long-time exposure to high energy settings, but the biofabric suggests that final deposition was due to short-time events. The biocoenotic meaning of the observed organisms (DC, AP/HP, SGCF, or SFBC) suggests the influence of currents rather than waves (as is the case, for instance, in the "intermattes" channels of the HP biocoenosis, or on current-swept bottoms colonized by the SGCF biocoenosis) and deposition on nearby, deeper bottoms.

Reworking and subsequent faunal burial due to storm waves and storm-induced flows better explains the fossil concentrations of the layers in transition to facies (4); the fossil association, comparable to a deep SFBC biocoenosis, inhabited a bottom located at an estimated depth of 10-15 m. The fossil concentrations within the thick beds of facies (4) are better interpreted as storm concentrations. Physical features suggest a bottom located near the fair-weather base, where coarse debris and fragmented skeletons, possibly from palaeocommunities comparable to the SGCF and/or SGBV biocoenoses, were deposited. The presence of cold-water faunas suggests that the drop of sea-level was essentially glacio-eustatic. Near the head of Canale Fano, the fine-grained bioturbated calcarenites suggest more protected areas colonized by a crustacean community, tentatively compared to the high-energy facies of the SVMC biocoenosis.

In summary, both physical structures and fossil assemblages of the Sabbie della Serrazza are indicative of shelf to shoreface settings (maximum depth in the order of 50/60 m). Facies (1) is thought to represent the maximum flooding stage, whereas the bulk of the succession records a progradational-regressive trend. Interbedded layers, within the second and third facies, are interpreted as distal and proximal tempestites respectively, while facies (4) more probably represents the record of a storm-dominated lower to upper shoreface.

The position of the maximum flooding shoreline, at present time located at about 70 m above present-day sea level (Fig. 16), and distribution of the facies indicate that the Calcarenite della Casarana and the Cretaceous limestones were partly emergent during deposition of the Sabbie della Serrazza, limiting a wide bay with minor embayments located on drowned palaeo-valleys. The largest embayment was in the northwest where a more protected setting was established. The levelling-off of seafloor depressions was still in action during deposition of facies (3), as suggested by still persisting lateral facies variations and the emplacement of slump-related sediment slices, and it was presumably completed at the end of deposition of facies (3).The uniformity of facies (4) indicates that, at that stage, deposition was taking place on a level sea floor, differently exposed to wave action.

Conclusions

Lower Pliocene deposits show evidence of a quiet outer-shelf setting, apparently not affected by the physiography of the transgressed palaeotopography. In contrast, the onlapping of Upper Pliocene infralittoral deposits onto topographic highs and small-scale lateral and vertical changes of biofacies, testify that sedimentation was preceded by a block faulting event and that it took place in erosional depressions flanked by ridges of Cre-

taceous limestone and was truncated during a subaerial stage. The Late Pliocene transgression flooded a landscape characterized by a complex karst relief. The first deposits, accumulated in a small karst depression, records a coastal sabkha setting, episodically flooded by marine water and subject to intense evaporation under warm, dry climatic conditions. A low energy, marginal-marine, probably lagoonal environment was then established in more landward areas; in southern areas, the early phase of transgression occurred in more marine conditions, ranging from protected intertidal to upper infralittoral environments. A ridge of Cretaceous limestone created a protected environment in which wavy bedforms of exceptional scale, interpreted as the result of the action of tsunami surges, were generated and preserved. Various palaeocommunities lived in such heterogeneous biotopes characterized by differences in water energy, turbidity, rate of sedimentation and substrate consistency. The overall trend suggests an upward increase in the average background energy of the environment, as a result of burial of the ridge with consequent cessation of the restricting effects. This produced a uniform silty sand bottom allowing the landward spread of the SFBC Association.

After a continental phase, the Early Pleistocene rise of sea level is documented by a transgressive coarse calcarenite grading upwards into terrigenous mud. The former includes fossil remains of infralittoral associations that were gradually replaced by the DC Association and, locally, by DC/DE ecotones. A relative rise of sea level during cool climatic conditions implies a rate of subsidence exceeding that of sea level drop. However, the former only slightly exceeded the latter, since depth of the seafloor did not significantly increase, as suggeste-

sted by the persistence of the DC Association. Increased rates of basin subsidence caused environmental instability, documented by the episodic development of the Heterogeneous Association (PE). The fossil assemblages of the following muddy unit are assigned to the DE Association evolving, through the DE/VTC ecotone, to the VTC Association. Local edaphic conditions favoured the development of the Coralligenous Association (C) or of an ecotone between DE and DL Associations, that inhabited deep circalittoral bottoms. A shallower location for the northern site (La Casarana quarry) is suggested by both biostratinomic and ecological data.

Deposition of the Calcarenite della Casarana was preceded by a subaerial phase, documented by palaeosols, local karst morphology, and pronounced erosion of previous deposits. Deposition took place within an elongated depression limited by fault-bounded low reliefs of Cretaceous limestones, mostly trending NW-SE. Such depression formed a kind of seaway similar to the present-day submerged valleys along the Adriatic coast of former Yugoslavia.

During transgression, different associations of the infralittoral zone were gradually replaced by facies of the Coastal Detritic Association, recording a decrease in the energy level of the gradually deepening seafloor (up to 40-50 m). Bioerosion traces on the fault scarp exclusively at the level of the transgressive layer underlying the Calcarenite della Casarana suggest that the scarp was generated before the transgression, or perhaps during the transgressive event, as a result of exhumation of an old fault wall. Progradation apparently started from the fault scarps bounding the depressions. The downward shift of facies tracts at the base of the regressive facies of
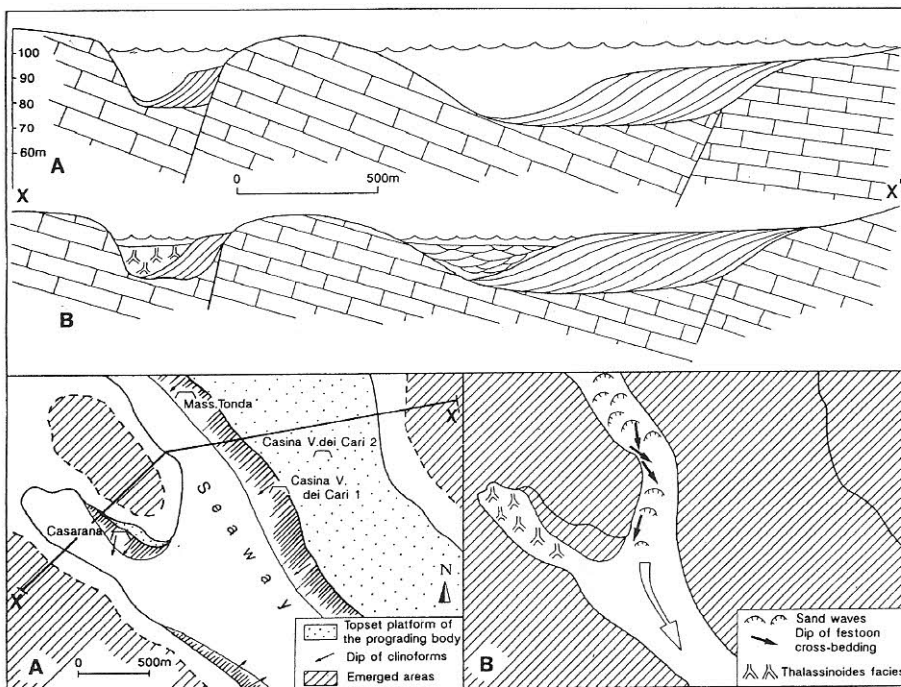

Fig. 15 - Interpretative sketch showing on cross-sections and idealized palaeogeographic maps the successive stages which generated the "Calcarenite della Casarana" (thin basal transgressive deposits are not taken into account). A: progradational stage; B: final stage, showing confinement of flow in the main axis of the seaway and formation of a protected embayment in the western branch.

the Calcarenite della Casarana points to a definite drop of the relative sea-level. The presence of cold-water faunas suggests that the sea-level drop was essentially glacio-eustatic in origin. The bulk of the Calcarenite della Casarana was laid down during forced regression which generated an offlapping body with distinct clinoforms (Fig. 15A). This body prograded into a current-swept seaway starting from an eastern ridge of Cretaceous limestone. Accretion at the front during progradation was essentially episodic, due to dispersal of bioclastic debris by storm-induced flows.

Towards the axial part of the seaway, the SGCF/DC algal facies prevailed, whereas the SGCF Association developed where wave action dominated or at sites periodically swept by storm processes with the highest energy. In the shallower areas towards the NW, or in settings more exposed to strong and constant wave action, the SGCF Association was patchily replaced by the SGBV Association. Inferred depth of the sea-floor possibly ranged between 10 and 30m.

Characteristic features of the later-stage facies (subfacies 1B) (trains of sand waves generated by flows evidently diverted and forced to flow parallel to the ridge of Cretaceous limestone) suggest that during the late stage of the Calcarenite della Casarana deposition the original seaway was reduced to a very narrow reach, as result of a relative fall of sea level (Fig. 15B). This may have produced a flow diversion and enhanced flow strength due to strait conditions. During this stage of forced regression, a protected embayment may have formed in the Casarana quarry area, which was a suitable habitat for the SRPV Association recorded by the *Thalassinoides facies*.

Two aspects are worth to be commented upon: (1) a large sediment body, which may be classified as foramol calcarenite *sensu lato* was laid down during a cold climatic phase; (2) this phase was characterized by marked and frequent meteo-marine events.

The Middle Pleistocene Sabbie della Serrazza, the last pre-Tyrrhenian unit of the investigated area, is a shallowing-upward succession. Taphonomic features, succession of palaeocommunities and concurrent changes of physical features suggest a trend from low energy circalittoral ecotones (VTC/DE, VTC/DC) indicating maximum depth in the order of 50-60m, towards increasingly shallower, up to less than 10m deep, storm-dominated infralittoral (shoreface) associations (first DC/SE or VTC/SFBC, then SGCF, SGBV or, locally, SRPV and SVMC). Facies distribution indicates that the Calcarenite della Casarana and the Cretaceous limestones were partly emergent during the deposition of this unit, limiting a wide bay. Minor embayments were located in drowned palaeovalleys, incised during a previous stage of relative lowstand, probably of glacio-eustatic nature, after deposition of the Calcareniti della Casarana.
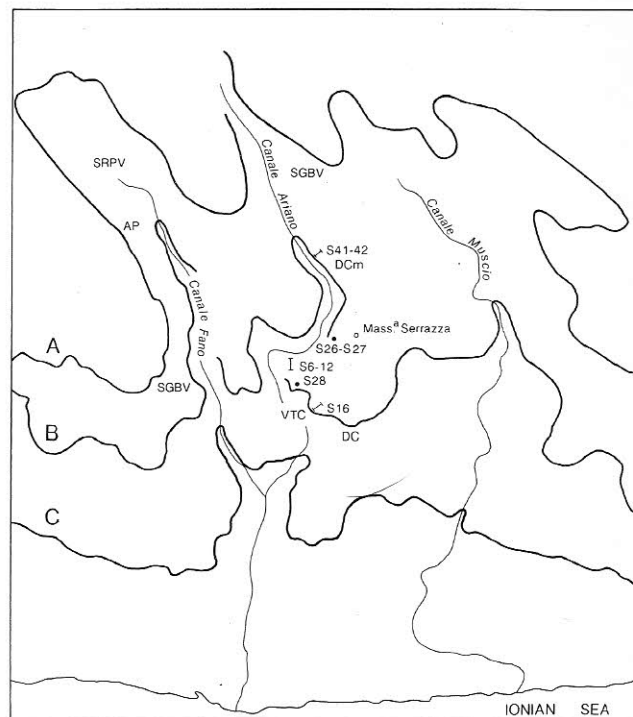
Fig. 16 - Pattern of the coastlines at maximum flooding stage, during Middle Pleistocene (A, Sabbia della Serrazza) and Late Pleistocene (B, C); areas of the bay inhabited by middle Pleistocene associations are indicated by the letter code of the equivalent Recent biocoenosis. AP: biocoenosis of Photophilic Algae; SRPV: biocoenosis of Sands Protected against Breaking Waves; SGBV: biocoenosis of Coarse Sand and Gravel Stirred by Waves; VTC: biocoenosis of Terrigenous Mud; DC: biocoenosis of Coastal Detritic Bottoms; DCm: muddy facies of DC.

Although the faunal content suggests a depositional depth during maximum flooding of the same order as that attained during the deposition of the Calcarenite della Casarana, position of the shoreline was largely displaced seawards (Fig. 16), indicating that a regional uplift was ongoing from before the transgression. The regressive stage was, however, mainly caused by a glacio-eustatic fall, as indicated by the presence of Atlantic guests. The rate of the regional uplift was significantly slower than that of the glacio-eustatic fluctuations.

Table 1

Letter code of the Mediterranean biocoenoses mentioned in the text:

LEE = biocoenosis of Eurhyhaline and Eurytherm Lagoons; SVMC = biocoenosis of Superficial Muddy Sand in Sheltered Areas; AP = biocoenosis of Photophilous Algae; HP = biocoenosis of *Posidonia* Meadows; SGCF = biocoenosis of Coarse Sand and Fine Gravel under Bottom Currents; SFBC = biocoenosis of Fine Well Sorted Sand; SE = Muddy Sand biocoenosis; pC = biocoenosis of Pre-Coralligenous; C = biocoenosis of Coralligenous; GSO = biocoenosis of Semi-Obscure Caves; DC = biocoenosis of Coastal Detritic Bottoms; DE = biocoenosis of Muddy Detritic Bottoms; DCE = DC-DE ecotone; VTC = biocoenosis of Terrigenous Mud; DL = biocoenosis of Shelf-Edge Detritic Bottoms; RL = biocoenosis of Offshore Rocky Bottoms; CB = biocoenosis of White Corals; VP = biocoenosis of Bathyal Mud; PE = Heterogeneous Community.

Table 2 - Late Pliocene assemblages

TAXA / SITES	S9	CM1 SX	CM7 S8	S104	S71 S56	CM6 S103	CM5	S76	TG	H	Sp	D	Notes
			southward				northward						
Bryozoans			—						S	E			crustose and/or in lumps
Calcispongia	▬					- - -			S	Es	h	il(cl)	
Madracis pharensis		- - -							S	Es	h	cl	
Acanthochitona communis				- - -					B	Es	h	il	
Dentalium inequicostatum						- - -			D	Sl	mxd	cl	ciliar deposit-feeder
Dentalium sp.	—			- - -					D	Sl			ciliar deposit-feeder
Cadulus politus								—	D	Sl			ciliar deposit-feeder
⊕ *Calliostoma* cf. *cingulatum*							- - -		B	Ev			
Gibbula magus							- - -		B	Ev	ms,mxd	il,cl	
Gibbula guttadauri								- - -	B	Ev		il	
⊕ *Diloma patulum*	▬		—						B	Ev	tol.s.rel	il	
Jujubinus exasperatus					- - -				B	Ev	h	il,cl	
Jujubinus striatus			- - -						B	Ev	*	il,cl	*preferential of *Zostera* meadow
Trochidae		—	—			- - -		- - -	B,D	Ev			
Hydrobiidae			▬						B	Ev			
Alvania sp.			—						D	Ev			
Apicularia sp.		- - -					- - -	- - -	D	Ev			
Rissoa variabilis		- - -							D	Ev			
Rissoidae			—						D,B	Ev			small size; in lags
⊕ *Turritella spirata*	- - -	- - -							S	sh.lv	m	il,cl	ciliar suspension-feeder
⊕ *Turritella vermicularis*					- - -				S	sh.lv	tol.m-rel.	il,cl	ciliar suspension-feeder
Tenagodus obtusus				▬					S (C?)	Es	f,st, h*	cl	*hard bottom covered by mud or in sponge tissue
Bittium cf. *reticulatum*		▬	▬		—	—			D	Ev	h,s	r.eur	
Triphora sp.					- - -	—			aD	Ev			
Cerithium vulgatum		- - -	- - -	—		- - -	- - -	- - -	B	Ev	tol.m.-rel. *	il	* pref. meadows of *Zostera* and *Cymodocea*.
⊕ *Cerithium varicosum*					- - -	—			B	Ev	mxd	cl	
⊕ *Strombus coronatus*	—								B	Ev	s, soft	il	The extant *S. bubonius* lives on algal weedy soft bottom; rarely half-buried in sand.
Naticarius sp.				—					C	Iv			
Mitrella sp.			- - -						C	Ev			
⊕ *Hinia prysmatica*			- - -						C	Ev	mxd	eur	
Hinia sp.					- - -	- - -	- - -		C	Ev			
Retusa truncatula					- - -				C	Iv	ms	cl	
Cylichna sp.	—												
Cylichnina umbilicata		- - -	—		—			▬ *	C	Iv	s	il	feeds on protozoans; * lags
Chrysallida interstincta					—				P			il,cl	
Gastropoda ind.	▬	▬	▬	- - -	—			—					
Nucula nucleus					- - -				D	sh.l	mxd	il,cl	
Arca tetragona								- - -	S	Es	shs,pb	eur	
Barbatia barbata				—					S	Es	h *	il	* nestler
Anadara diluvii					- - -				S	Sls	tol.m.rel	r.eur	commonly at depth > 30-40m
Striarca lactea					- - -	- - -	- - -		S	Es	shs,db	cl, il	
Glycymeris insubricus	▬				- - -	—			S	sh.l	s.rel.	il	

Table 2 - continue

TAXA / SITES	southward				northward				TG	H	Sp	D	Notes
	S9	CM1 SX	CM7 S8	S104	S71 S56	CM6 S103	CM5	S76					
Aequipecten opercularis		- - -			—				S	Ev	mxd,pb	w.eur	
⊕ *Aequipecten seniensis*				—	—				S	Ev	mxd	cl	
Pecten jacobaeus					- - -				S	Ev	mxd	cl	
Ostreola forskalii				—			—		S	Es	h,shs	il	
Neopycnodonte cochlear		—	—			—			S	Es	shs,cob	r.eur	
Divaricella divaricata							- - -		S	I	ms		
Lucinoma borealis		- - -							S	d.I	s,ms	il, cl	
Diplodonta rotundata					- - -		- - -		S	I	m.rel	cl(il)	juv. in CM5
Pseudochama gryphina				—					S	Es	h,shs,f	il,cl	
Cardita calyculata					- - -				S	Es	h,m	il	
Acanthocardia paucicostata		▬			—		---		S	I	tol.m.rel.	il	
Acanthocardia mucronata	---				—	—	—		S	I	mxd	cl	small specimens (<2cm)
Cardiidae			---			—		---	S	I			small
Plagiocardium papillosum					---				S	SI	mxd	il,cl	shallower than 80m
Spisula subtruncata			—	—					S	I	s.rel.	il	juv.
Venus cf. *multilamella*	- - -				- - -	—			S	I	m.rel.	r.eur	
Gouldia minima		- - -							S	I	mxd,pb		related to bottom currents
Pitar rudis	—				- - -		—		S	I	mxd,ms	cl(il)	
Dosinia lupinus	—				—		---		S	I	s.rel.	il	juv. in S71
Chamelea gallina					—		- - -		S	I	s.rel.	il	juv.
Timoclea ovata	---	---		—	▬	▬	—	---	S	I	mxd	eur	positively related to organic material
Corbula gibba					---		---		S	I	m,sm	cl(il)	
Thracia sp.					- - -				S	I			
Bivalvia ind.		---		—	---		- - -						
Irregular echinoids (spines)					—	---	---		D	Iv			
Crustaceans (chelae)					—								
Salmacina cf. *incrustans*			▬						S?	Es	shs,pb	r.eur	
Rhodoliths			---									cl,il	

ICHNOTAXA									Inferred makers	Substrates
Caulostrepsis cretacea	—	—							Polychaetes	*G. insubricus*
Entobia paradoxa			—						*Cliona* sp.	Gastropods
Entobia parva			—						Unidentified boring sponge	Rhodoliths
Entobia isp.	- - -								Unidentified boring sponge	*G. insubricus*
Iramena isp.					—		- - -		Bryozoans	*O. forskalii*
Terebripora isp.					- - -				Bryozoans	*N. cochlear*
Trypanites isp.	—				- - -				Polychaetes	*G. insubricus*

Legend for Tables 2 to 7:

TROPHIC GROUP (TG): S = suspension-feeder, D = deposit/detritus-feeders, aD = animal detritus, C = carnivore, P = parasite, B = browser, O = omnivorous.

HABIT (H): I = infauna, sh.I = shallow infauna, dI = deep infauna, SI = semi-infauna, E = epifauna, v = vagrant, s = sedentary, sessile (byssate or cemented).

SUBSTRATE PREFERENCE (Sp): h = hard, st = soft, cob = cohesive bottom, f = firm, shs = small hard substrates, fix = flexible substrates, pb = pebbly bottom, gravel of coarse detritic, db = detritic bottom, mxd = mixed granulometry, s = sand, cs = coarse sand, s.rel = sand-related, m.rel = mud-related, tol = tolerant, applying to species able to endure a small fraction of sediment other than the one that they are commonly related to.

DEPTH RANGE (D): il = infralittoral, cl = circalittoral, b = bathyal, eur = eurybathic species, w.eur = widely eurybathic (continental shelf and slopes down to about 2000m), r.eur = restricted eurybathic (continental shelf and upper part of slopes down to about 600).

⊕ = extinct taxa.

j = juveniles.

- - - = 1-2 specimens, **- - -** = uncommon; widths of bar indicate relative abundance of fossils.

Table 3 - Bradanic cycle, lower unit assemblages

TAXA / SITES	S69	S56	S57	S50¹	S14	S10	TG	H	Sp	D	Notes
Caryophyllia cf. *smithii*				---		---	S	Es	mxd	cl	
Neocrania anomala						—	S	Es	h,cd	eur	ubiquitous
⊹ *Terebratula* sp.1				■		■	S	Es	mxd	cl	
⊹ *Terebratula scillæ*						---	S	Es	sm	cl	
Terebratulina retusa				---			S	Es	h,shs	r.eur	depth related
Megathiris detruncata				—			S	Es	h,mxd	cl	Mediterranean Sea:-40-80m
Arborescent bryozoan						—	S	Es	h,flx	r.eur	low energy, below swell wave base
Fenestrate bryozoan						—	S	Es	h	r.eur	commonly attached to undersurface of rocks in nearshore environments; moderate -low energy, low-moderate sedimentation rate.
Flat robust branching bryozoan						- - -	S	Es	h	cl	greatest density is where the seafloor is swept by deep sweels and/or on sites of incipient hardgrounds.
Dentalium sp				- - -			D	Sl			ciliar deposit-feeder
Gastropoda			- - -	---	- - -	---					
⊹ *Yoldia nitida*						- - -	D	sh.l	tol.m.rel.		
Barbatia sp.				- - -			S	Es			
Glycymeris glycymeris				—	—		S	sh.l	s,cs	il	
Propeamussium fenestratum				- - -			C	Ev		cl, b	
Hyalopecten similis				---			S	Es	mxd,shs	r.eur	
Pseudamussium septemradiatum				- - -			S	Ev	tol.m.rel.	r.eur	
Chlamys multistriata				- - -		- - -	S	E	h,db,mxd	cl,il	
Aequipecten opercularis				■		■	S	Ev	mxd,pb	w.eur	
Pecten jacobaeus		- - -	—	---	—	---	S	Ev	mxd	cl	
Neopycnodonte cochlear				---		---	S	Es	shs,h,cob	r.eur	small-sized valves
Ostrea gr. *edulis*		---					S	Es	h,f	il(cl)	
Acanthocardia echinata				—	—		S	I	mxd	cl	
Laevicardium oblongum				- - -			S	I	mxd	cl	
Arctica islandica					—	---	S	I	s.rel.	il,cl	salinity<35.5‰; commonly < -80m
Timoclea ovata				—		---	S	I	mxd	r.eur	positively related to organic material
Veneridae				—		—	S	I			
⊹ *Echinolampas hoffmanni*			■				D	Sl	cs,mxd	il	
Cidaris sp.						- - -	B*	Ev		r.eur	spines; *sponge browser
Rhodoliths		- - -	---	---	■					il,cl	mostly *Lithotamnium*; up to 6 cm in S57

ICHNOTAXA	S69	S56	S57			S10	Inferred makers	Notes
Caulostrepsis cretacea	■	---					polychaetes	eurybathic isp; may be found in brackish water
Caulostrepsis taeniola		---					polychaetes	eurybathic isp.
Conchotrema canna	—	---					Phoronids	eurybathic isp.
Entobia ispp.	■	■	■				*Clione* spp.	
Entobia ovula	—						*Clione* spp.	ichnospecies mainly reported from shallow water settings
Entobia geometrica		■					*Clione celata* Grant	ichnospecies mainly reported from shallow water settings
Entobia megastoma			---				*Clione celata* Grant	
Gastrochaenolites isp. ind.	---	- - -					bivalves	
Gastrochaenolites torpedo	- - -	■					*Lithophaga lithophaga* (Linnæus)	moulds of shells preserved; low intertidal and upper infralittoral
Gastrochaenolites dijugus		—					*Gastrochaena dubia* (Pennant)	moulds of shells preserved
Gastrochaenolites lapidicus	- - -						bivalves	
Gnathichnus pentax	- - -	- - -					regular echinoids	
Maeandropolydora sulcans		—					polychaetes	eurybathic isp.
Maeandropolydora isp.		—					polychaetes	
Trypanites solitarius		—					polychaetes	eurybathic isp.
Thalassinoides isp.			—			---	burrowing crustaceans	coherent softgrounds, firmground

Table 4 - Bradanic cycle, transition facies assemblages

TAXA	S13	S13¹	S21	S22	TG	H	Sp	D	Notes
Caryophyllia smithii form clavus	——	- - -	——	- - -	S	Es	mxd	cl	common in the *V. ovata* sub-community
Neocrania anomala				- - -	S	Es	h,shs,pb	eur	ubiquitous
⬦ *Terebratula scillae*	- - -	——	▬	——	S	Es	tol.m,.rel.	cl	needs of cohesive bottoms
Terebratulina retusa				- - -	S	Es	h,shs,pb	r.eur	depth related
Megathiris detruncata			- - -	- - -	S	Es	h,shs	cl	Mediterranean Sea: -40m -80m;
Megerlia truncata	- - -	- - -	- - -	- - -	S	Es	h,shs	cl	populations between 100-150m
Megerlia monstruosa				- - -	S	Es	h,shs	cl	deep circalittoral
Nodular bryozoan	——	——	- - -	——	S	E	h,mxd	r.eur	commonly circalittoral, in low energy environment
Arborescent bryozoan	——			- - -	S	Es	flx,h	r.eur	low energy, below swell wave base.
Delicate branching bryozoan				- - -	S	Es	h,mxd	r.eur	low water energy; l ow (moder.) sedimentation rate; more frequent at shelf-edge. top of slope. see Table 3
Fenestrate bryozoan			- - -	——	S	Es	h	cl	
⬦ *Dentalium rectum*	- - -		- - -		D	Sl	tol.m.rel.	cl	ciliar deposit-feeder
Clelandella miliaris			- - -		B	Ev	shs	r.eur	
⬦ *Turritella tricarinata pliorecens*			- - -		S	sh.lv	tol.m.rel.	cl	ciliar suspension feeder
⬦ *Turritella vermicularis*		- - -	- - -	- - -	S	sh.lv	tol.m.rel.	cl, il	ciliar suspension feeder
Xenophora crispa			- - -		D	Ev	f,mxd,m	r.eur	
Euspira cf. *fusca*	- - -				C	lv			
⬦ *Hinia* cf. *prismatica*			——		Sc	lv	mxd	eur	
Diacria trispinosa form *trispinosa*			——		plankton				Temperature range=14°-27°, salinity=36‰-36.8‰. Indicative of Atlantic-influenced water (it is restricted to western Mediterranean)
⬦ *Nucula placentina*				- - -	D	sh.l	tol.m.rel.	cl,il	
Nucula sp.	- - -			- - -	D	sh.l			
Nuculana commutata		- - -			D	sh.l	mxd,sm	eur	
Striarca lactea	- - -				S	Es	shs,pb	eur	
Modiolula phaseolina	▬	▬	——		S	Sls	mxd	r.eur	disarticulated in S21
Camponectes striatus			- - -	- - -	S	E	mxd,h,shs	cl,b	
Palliolum incomparabile			- - -	- - -	S	Es	shs,h	cl	
Hyalopecten similis	——	- - -	▬	——	S	Es	mxd,shs	cl	
Pseudamussium septemradiatum	▬	——	▬	——	S	Ev	tol.m.rel.	r.eur	
Pseudamussium clavatum				- - -	S	Ev		cl	
Chlamys multistriata			- - -		S	E	h,db,mxd	eur	
⬦ *Chlamys angelonii*				- - -	S	E	mxd,s	il,cl	
Chlamys varia	- - -				S	Ev	mxd,db	il,cl	commonly shallower than 100m
Aequipecten opercularis		- - -			S	Ev	mxd,pb	w.eur	
Pododesmus squamulus			——	- - -	S	Es	shs		
Pododesmus aculeatus				- - -	S	Es	shs	w.eur	
Pododesmus glaucus			- - -		S	Es	shs	cl,b	depth-related
Limatula subauriculata			- - -	- - -	S	Ev	m.rel.	w.eur	
Limatula sulcata	- - -		- - -	- - -	S	Ev	mxd	r.eur	
Neopycnodonte cochlear			- - -	- - -	S	Es	shs,h,cob	r.eur	in small clusters; juv. in S22
Lucinoma boreale	- - -	- - -	——		S	d.l	s,ms	eur	
Thyasira flexuosa	——	- - -	——		S	d.l	m.rel.	cl	positively related to amount of organic material; degradation indicator
Diplodonta rotundata	——				S	d.l	m.rel.	eur	
Acanthocardia echinata		- - -			S	sh.l	mxd	cl	
Parvicardium minimum	——		- - -	——	S	Sl	mxd,m	cl	populations deeper than 40m
Parvicardium spp.	——	——	——		S	l			
Mactra stultorum	- - -				S	l	s.rel.	il	
Gari fervensis	- - -	- - -			S	l	s,mxd	il,cl	
Abra prysmatica	- - -				D	d.l	mxd	cl	
Venus multilamella	- - -				S	l	tol.m.rel.	r.eur	
Pitar rudis			- - -	- - -	S	l	mxd	cl(il)	
Dosinia lupinus			——		S	l	s.rel.	il	
Timoclea ovata	- - -			- - -	S	l	mxd,ms	eur	positively related to organic material
Veneridae	——				S	l.			
Corbula gibba	- - -	- - -	- - -		S	l	m	cl	opportunist
Pandora sp. ind.		- - -			S	l			

Table 4 - continue

TAXA / SITES	S13	S13¹	S21	S22	TG	H	Sp	D	Notes
Thracia convexa	- - -	- - -	▬		S	l	m,ms	cl	articulated and disarticulated in S21
Mollusca ind.	- - -	▬	▬	▬					
Ditrupa arietina	▬	▬	▬	▬	S	Sl	sm,ms	cl	opportunist
Cidaris sp.		- - -	- - -	- - -	B*	Ev		r.eur	* sponge browser
Echinus acutus			- - -		O	Ev		cl(b)	
Irregularia	- - -	- - -	- - -	- - -	D	lv			spines
Decapoda				- - -					
Lepas sp.				- - -	S	Es			
Teleostoma		▬							vertebrae and teeth

ICHNOTAXA					Inferred makers			Substrates	
Iramena isp.		- - -	▬		endolithic bryozoans			*Terebratula scillae*	
Conchotrema canna			▬		endolithic phoronids			*Neopycnodonte cochlear*	

Table 5 - Bradanic cycle, upper unit assemblages

TAXA / SITES	S23	S15 S35	F 1-5	S79⁴ S3	CF 10	S50² S50³	S40	TG	H	SP	D	Notes
FACIES	1	2	4	3	*	3						* assemblage of 2 paleaocommunities
Corallium rubrum						▬	▬	S	Es	h	cl	dark-related
⬦ *Keratoisis melitensis*	- - -							S	Es	*	b	*muddy cohesive bottom with coarse debris
Caryophyllia smithii		- - -		- - -				S	Es	mxd	cl	
Lophelia pertusa					- - -		- - -	S	Es	h,shs	b*	also deep circalittoral in cold water
Neocrania anomala				- - -		▬	▬	S	Es	h,shs,pb	eur	ubiquitous
⬦ *Terebratula scillae*				▬		▬		S	Es	tol..m.rel.	cl	cohesive bottoms
Gryphus sp.						- - -		S	Es			
Terebratulina retusa			- - -	▬	▬	▬	▬	S	Es	h,shs,pb	r.eur	populations 100-400 in Mediterranean Sea
Megathiris detruncata			▬	▬		▬	▬	S	Es	h,pb	cl(b)	40-80m in Mediterranean Sea
Platydia anomioides				▬		▬		S	Es		cl,b	common at 100-150m
Megerlia truncata				▬		▬	▬	S	Es	shs	eur	Mediterranean populations: 100-150m
Megerlia monstruosa		- - -					▬	S	Es	shs	cl	frequently 100-150m
Nodular bryozoans		- - -	▬					S	E	shs	r.eur	see Table 4
Arborescent bryozoans		- - -	▬	▬	▬	▬	▬	S	Es	h,flx	r.eur	see Table 3
Encrusting bryozoans			- - -	▬		- - -	▬	S	Es	h	l,cl	High/moder.energy, low sedim.rate; <-100m
Rigide delicate branching bryozoans	▬		- - -			- - -	- - -	S	Es	h	r.eur	see Table 4
Endolithic bryozoans			▬	- - -		▬	▬	S	ls	h.shs	eur	low sedimentation rate
⬦ *Dentalium rectum*					- - -			D	Sl	tol.m.rel	cl	ciliar deposit feeder
Coccolinoidea				- - -				B	E			
⬦ *Turritella vermicularis*				- - -				S	Slv	tol.m.rel.	cl	ciliar deposit feeder
Epitonium sp. ind.						- - -	- - -	C,P				
Euspira fusca						- - -		C	lv	m,sm	eur	
Roxania utriculus	- - -							C	lv	tol.s.rel.	eur	
Odostomia conoidea	- - -	- - -						P				

Table 5 - continue

TAXA (SITES)	S23	S15 S35	F 1-5	S79⁴ S3	CF 10	S50² S50³	S40	TG	H	SP	D	Notes
FACIES	1	2	4	3	*	3						* assemblage of 2 paleaocommunities
Limacina inflata			---	---								plankton, circumtropical. Temperature range = 14°-28°C, Salinity = 35.5‰-36.7‰
Limacina retroversa	---	---										plankton; climatic indicator. Temperature range = 2°-16°C, Salinity = 31.06‰-36‰
Nuculana commutata				━				D	sh.l	mxd.rel.	eur	
Portlandia tenuis	---	---						D	sh.l	m	r.eur	from the deep circalittoral
Arca tetragona				━				S	Es	shs,pb	eur	dark-related
Bathyarca grenophia		---						S	Es		r.eur	from the deep circalittoral
Propeamussium fenestratum	---	---		---	━	---	---	Sc	Ev	shs	r.eur	from the deep circalittoral
Cyclopecten hoskynsii			---					S	Es	shs	b	optimum: 300-600m
Camponectes striatus	---	━		━	━	━		S	Ev	mxd,h, shs	cl,b	
Palliolum incomparabile			---	---	---	━	━	S	Es	shs,h	cl	
Delectopecten vitreus					━			S	Es	cob,shs	b	
Hyalopecten similis	---	━	━			━	━	S	Es	mxd,shs	cl	
Pseudamussium septemradiatum	---		━			━	━	S	Ev	tol.m.rel.	r.eur	
Peplum clavatum					---	---		S	Ev		cl	
Chlamys bruei					---	---		S	Es	shs	r.eur	70-500m
Chlamys multistriata					---	---		S	E	mxd,pb,h	cl,il	
Chlamys varia	---		---*	---*				S	Ev	mxd,db	il,cl	commonly shallower than 100m; * juv.
Aequipecten opercularis				---				S	Ev	mxd,pb	eur	
Pododesmus squamulus	━			━				S	Es	shs		
Pododesmus aculeatus	━	━	━	━	━		━	S	Es	shs	w.eur	encrusted and bioeroded shells
Pododesmus glaucus			---			---	---	S	Es	shs	cl,b	
Pododesmus patelliformis				━				S	Es	shs,pb	cl	
⊹ Pododesmus brocchii				---		---		S	Es	shs		
Lima lima			---					S	E		il,cl	usually attached
Limaria exilis			---	---		---		S	E	s	il,cl	usually attached; shallower than 50m
Limaria loscombi	---							S	E	mxd,pb	cl	
Limatula subauriculata			---	---				S	Ev	m.rel.	w.eur	
Limatula sulcata	---	---	---	---		---		S	Ev	mxd	r.eur	
Limea sarsii			---			━	━	S	Ev	m	r.eur	max.abundance: 150-300
Neopycnodonte cochlear			━	━		---	━	S	Es	cob,shs,h	r.eur	
Thyasira flexuosa	---	---						S	l	m.rel.	cl	see Table 4
Leptaxinus ferruginosus		---						S	l	m.rel.	b	
Kellia suborbicularis			---					S	l	mxd	cl	
Mysella bidentata	---							S	l	m,mxd	cl	
Parvicardium minimum	━	━		━				S	Sl	mxd,m	r.eur	populations deeper than 40m
Parvicardium roseum	━							S	l	db,ms	il	
Parvicardium spp.	---	━						S	l			
Kellyella abyssicola	━	━						S	l	tol.m.rel.	w.eur	
Timoclea ovata				━				S	l	mxd	eur	positively related to organic material
Thracia convexa						---		S	d.l	m,ms	cl	
Hiatella arctica				━				S	l	h,f,shs		into multilamellar bryozoans
Ditrupa arietina	━	━	━	---	---	---		S	Sl	m,ms	cl	opportunist, abundant in CF 1
Spirorbis sp.				---		---	━	S	Es	s,shs		on C.rubrum and multilamellar bryozoans
Sedentaria				━		━	━		Es			on C.rubrum and bryozoans
Asteroids		---				━	━	C	E, Sl			sclerites
Cidaris sp.				---		---	---	B*	Ev		eur	*sponge browser; spines
Echinus acutus	---	---						O	Ev	db	cl(b)	
Regularia	---								Ev			spines
Irregularia	---	---	---	━	---	---		D	lv			spines
Decapoda	---	---	━			━	━					
Lepas sp.		---	---					S	Es			
Scalpellum sp.		---	---		---	---	---	S	Es			
Verruca strömia (Müller)	━	━		---				S	Es	h,shs		northern guest
Pachylasma sp.	---	---				---	━	S	Es	h,shs	cl	
Teleostoma		---				---	---					teeth, vertebrae
Calcareous algae				---								encrusting celleporiform bryozoans; rodoliths < 2cm

Table 5 - continue

ICHNOTAXA				Inferred makers	Substrates	Notes
Caulostrepsis isp.		- - -	- - -	polychaetes	*N. cochlear, P. aculeatus*	
Conchotrema canna		—	—	endolithic phoronids	*N. cochlear*	
Entobia paradoxa		---	—	*Cliona* sp.	*C. rubrum*	
Entobia isp.		---	—	*Cliona* sp.	*C. rubrum, N. cochlear*	
Gastrochænolithes dijugus	—			endolithic bivalves	rhodoliths	
Maeandropolydora isp.		- - -	- - -	polychaetes	*N. cochlear*	
Oichnus paraboloides		—		Naticidae	*Pododesmus* spp.	
Oichnus simplex	- - -	- - -	- - -	Muricacea	*Pododesmus* spp.	
Podichnus isp.			- - -	brachiopods	*C. rubrum*	
Radulichnus inopinatus	—	- - -		grazing gastropods	*Ps. septemradiatum*	
Rogerella isp.			- - -	acrothoracic cirripedes	*C, rubrum*	
Thalassinoides isp.	—			infaunal crustacean	soft-, firm-grounds	
Walled, sinuous burrows	—	—	▬	unknown	softgrounds	diameter about 1mm

Table 6 - Assemblages of Calcarenite della Casarana

		M.Tonda		Casarana quarry							
TAXA	**SITES**	**S7**	**S8**	**S79 S4**	**S80²**	**S80¹ S2**	**TG**	**H**	**Sp**	**D**	**Notes**
Terebratulina retusa					---		S	Es	h,shs,pb	r.eur	depth-related
Megathyris detruncata				---		—	S	Es	h,shs	cl	see Table 4
Argirotheca cordata				- - -		- - -	S	Es	h,shs	il,cl	commonly < 100 m
Megerlia sp.					- - -		S	Es	h,shs		
Myriapora truncata				---	- - -		S	Es	h	cl	fragments
Encrusting bryozoans				—			S	Es	h,flx	il,cl	high-moderate energy; low sedim. rate; multilayered, commonly alternate with algal laminae; the most opportunistic of the bryozoans.
Nodular/arborescent				—	—		S	Es	h,flx	r.eur	see Tables 3, 4.
⊕ *Dentalium rectum*					- - -		D	Sl	tol.m.rel.	cl	ciliar deposit feeder; bioeroded
Dentalium sp. ind.				- - -			D	Sl			
⊕ *Calliostoma* cf.*cingulatum*				- - -			B	Ev			microphagous
Calliostoma granulatum				- - -			B	Ev			
Clelandella miliare					- - -		B	Ev	*	il,cl	*muddy gravel or hardground covered by mud
Jujubinus exasperatus					- - -		B	Ev	*	il,cl	*related to algae or plants
Jujubinus striatus				- - -			B	Ev	*	il(cl)	*preferential of *Zostera* meadow
Clanculus corallinus				- - -			B	Ev	*	il(cl)	*seem to indicate hard bottom
Trochidae				—			B,D	Ev			both shells and opercula
Homalopoma sanguineum				- - -	- - -		B	Ev	algae	il(cl)	
Bolma rugosa					- - -		D	Ev	mxd,db	il,cl	feeds on benthic diatoms
Turritella turbona		—	—				S	Slv	mxd	cl	
Bivonia triquetra				—			S*	Es	h,shs	il	*collector
Cerithium cf. *vulgatum*	- - -			— / *	- - -		H	Ev	st,h,m	il	pref. shallow,muddy bottoms and *Zostera, Cymodocea* meadows; * bioeroded
Cerithiopsidae				---			D*	Ev			* also sponge - eating
Calyptraea chinensis					—		D	Es	db-rel.	il,cl	
⊕ *Hiinia* cf. *clathrata*				- - -			C*	Ev	m,mxd	cl	*scavenger, subordinately detritus-feeder
Hinia limata				- - -		---	C*	Ev	m,mxd	cl	*scavenger, subordinately detritus-feeder
Nucula nucleus				- - -	- - -		D	sh.l	mxd-rel.	il,cl	
Nucula nitidosa				- - -			D	sh.l			
Nuculana pella					- - -		D	sh.l	ms		
Nuculana commutata					—		D	sh.l	mxd	eur	
Portlandia sp.					—		D	l			

Table 6 - continue

TAXA	SITES	M.Tonda S7	S8	Casarana quarry S79 S4	S80²	S80¹ S2	TG	H	Sp	D	Notes
Arca tetragona				- - -			S	Es	shs,pb	r.eur	possibly nestler
Striarca lactea					- - -		S	Es	shs,db	eur	
Glycymeris glycymeris			—				S	sh.l	s, cs	il,cl	
Glycymeris bimaculata		—					S	sh.l	s,cs	il	
Modiolula phaseolina					—		S	Sls	mxd	cl	
Hyalopecten similis					- - -		S	Es	mxd,shs	cl(b)	
Pseudamussium septemradiatum					- - -		S	Ev	tol.m.rel.	r.eur	
Aequipecten opercularis				—			S	Ev	mxd,pb	w.eur	
Chlamys varia				- - -	- - -	- - -	S	Ev	mxd,db	il,cl	usually shallower than 100m
Pecten jacobaeus				—	—		S	Ev	mxd	cl	
Pododesmus patelliformis						- - -	S	Es	shs,db	cl	coarse sediment-related
Anomiidae		—			—		S	Es			juv in S79
Thyasira flexuosa					—		S	I	m.rel.	cl	
Astarte sulcata					---		S	I	mxd	cl	
Acanthocardia paucicostata				—	---		S	I	tol.m.rel.	il,cl	
Parvicardium minimum				—	—		S	Sl	mxd,m	cl	populations deeper than 40m
Plagiocardium papillosum				- - -			S	Sl	mxd	il,cl	populations shallower than 80m
Cardiidae				—			S	I			
Arctica islandica		▬*			---		S	I	s.rel.	il,cl	salinity <35.5‰; commonly< 80m; *closed or slightly open valves
Clausinella fasciata				- - -			S	I	*	il,cl	* sand- and gravel-related
Timoclea ovata			—		▬		S	I	mxd	eur	positively related to organic material
Mollusca ind.		▬	*	▬	▬	*					*fragments
Ditrupa arietina							S	Sl	sm,ms	cl	opportunist
Regularia			---			- - -		Ev			spines
Echinocyamus pusillus						—	C	Iv	pb.rel.	cl	
Spatangus purpureus						---	D	I	sm,db	il,cl	bottom-current indicator; more abundant at 20 - 50m in sandy-mud
Lepas sp.						- - -	S	Es			
Rhodoliths		—	▬	—	—					il,cl	In S7, S79, S80² small rhodoliths, few encrusted by bryozoans; in S8 up to 5cm; in S2, S80¹, films coating skeletal grains;

ICHNOTAXA					Inferred makers	Substrates	Notes
Caulostrepsis taeniola			- - -		polychaetes	pebbles	restrictedly eurybathic isp.
Entobia ovula			—		*Clione* spp.	pebbles	eurybathic isp.
Gastrochaenolites dijugus			—		bivalves	rhodolits	infralittoral, u. circalittoral isp
Maeandropolydora isp.			- - -		polychaetes	pebbles	
Trypanites solitarius			- - -	- - -	polychaetes	pebbles, *D. rectum*, *Ps. septemradiatum*	
Ophiomorpha nodosa				- - -	burrowing crustaceans	coarse bioclasts	isp. pref. of loose, shifting sediments
Laminites isp.	---	▬	---	— ▬	*Echinocardium cordatum*	mxd,db	

Table 7 - Assemblages of Sabbie della Serrazza

TAXA	S16¹	S16³	S16⁴	S41	S42	S6	S7	S11/S11*	S12	S26	S27	S28	TG	H	Sp	D	Notes
Facies	2	2	2	1	2	2	2-3	3	3	2-3	3	3					
Megathiris detruncata		┄	┄	┄									S	Es	h,shs	cl	high-moderate energy; opportunistic bryozoans
Megerlia truncata		┄											S	Es	h,shs	r.eur	
Fenestrate bryozoans					⁞	⁞							S	Es	h	r.eur	
Encrusting bryozoans		┄		⁞	⁞	■	■		■	■	■	■	S	Es	h,flx	il,cl	low (moderate) sedim. rate, moderate (low, high) energy, middle (inner) shelf
Robust branching bryozoans	┄	■	┃	■	■	■	■			■	■	■	S	Es	h (shs)		
Clelandella miliaris							┄						B	Ev	*	il, cl	*muddy gravel or hard covered by mud
Gibbula magus							┄					┄	B	Ev	ms,mxd	il,cl	
Jujubinus striatus													B	Ev	*	il (cl)	* pref. of Zostera meadow
Turritella tricarinata pliorecens										┄			S	sh.lv	tol.m.rel.	cl	high sedimentation rate
T. cf. turbona									┄	■	┄		S	sh.lv	mxd	cl	
Vermetus semisurrectus													S	Es	h		
Euspira fusca									⁞				C	lv	m,sm	eur.	collector suspension-feeder
Naticidae				⁞									C	lv			
Trophon muricatus									┄				C	Ev	m, s, db	r.eur	
Hinia limata										┄		⁞	C	lv	mxd	eur.	
Scaphander lignarius							⁞						C	Ev	m. tol.	eur.	
Nucula nucleus								■					D	sh.l	mxd rel.	il, cl	
N. nitidosa											⁞		D	Sl		il	
Nuculana commutata							┄						D	sh.l	mxd rel.	eur.	
Anadara diluvii												■	S	Sls	tol.m.rel.	r.eur.	commonly deeper than 30-40m
Glycymeris glycymeris				┄								■	S	sh.l	s, cs	il,cl	
Modiolula phaseolina							┄	┄	┄				S	Sls	mxd	cl	high dominance in relatively low sediment. rate compatible with settlement on db or shs
Camponectes striatus						■	■			■			S	E	mxd,h,sh	cl,b	
Palliolum incomparabile				⁞			⁞					⁞	S	Es	shs,h	cl	
Hyalopecten similis	┃	■		⁞			■	■		■	■		S	Es	mxd, shs	cl, b	
Pseudamussium septemradiatum		■	■	⁞	⁞	■	■		┄	┄	■	■	S	Ev	tol.m.rel.	r.eur.	
Chlamys multistriata		┄	┄										S	E	h,db,mxd	eur.	
Ch. varia	┄				┃								S	Ev	mxd, db	il, cl	
Aequipecten opercularis										┄			S	Ev	mxd, pb	w.eur.	commonly shallower than 100m
Flexopecten flexuosa													S	Ev	s, db, pb	eur.	bottom-current indicator
Flexopecten glaber													S	Ev	s, db	eur.	
Pecten jacobaeus											⁞		S	Ev	mxd	cl	
Anomia ephippium						┄					┄		S	Es	shs,bd	r.eur.	

SITES: S - E Can. Fano (S16¹, S16³, S16⁴) | C. Ariano (S41, S42) | E. Can. Fano (S6, S7, S11/S11*, S12) | W. Mass. Serrazza (S26, S27, S28)

Table 7 - continue

TAXA	TG	H	Sp	D	Notes
Pododesmus squamulus					
P. aculeatus	S	Es	shs	il, cl	
	S	Es	shs, mxd	w. eur.	
P. glaucus	S	Es	shs, mxd	cl, b	
P. patelliformis	S	Es	shs, pb	cl	
+P. brocchii		E			
Limaria exilis	S	E	s, cd	il (cl)	usually shallower than 50m
Limea loscombii	S	E	mxd, pb	cl	
Limatula sulcata	S	Ev	mxd	w.eur.	
+Limatula gravinae	S	Ev	tol.m.rel?	cl	
Lucinoma borealis	S	d.l	s, ms	eur.	
Thyasira flexuosa	S	l	m	cl	see Table 4
Th. granulosa	S	l	tol.m.rel.	eur.	
Kellia suborbicularis	S	lv	mxd	cl	
Glans aculeata	S	lv	mxd	cl	
Astarte fusca	S	lv	mxd, db	cl, il	
Goodallia triangularis	S	lv	s, db	il cl	bottom-current indicator
Acanthocardia aculeata	S	sh.l	mxd, s	il, cl	
Parvicardium minimum	S	sh.l	mxd, m	eur.	population deeper than 40m
Parvicardium roseum	S	sh.l	db, s	il, cl	
Plagiocardium papillosum	S	sh.l	mxd	il, cl	populations shallower than 80m
Laevicardium oblongum	S	sh.l	mxd	cl	
Cardiidae	S	sh.l			
Tellina pulchella	S	d.lv	s.rel.	il (cl)	
Abra nitida	D	d.l	tol.m.rel.	r.eur.	tolerant of euxinic conditions
A. prismatica	D	d.l	mxd, ms	cl	
Arctica islandica	S	lv	s, ms	il, cl	climatic indicator
Kelliella abyssicola	S	sh.l	tol.m.rel.	w.eur.	
Glossus humanus	S	sh.l	m, ms	cl	
Pitar rudis	S	l	mxd	cl, il	pref. soft bottoms
Dosinia lupinus	S	l	mxd	cl, il	
Clausinella fasciata	S	l	tol.s.rel.	il (cl)	
Timoclea ovata	S	lv	s.db,pb	il, cl	current-related
Hiatella arctica	S	l	mxd	eur	related to organic material
Saxicavella plicata	S	•	shs, f		*Nestler, weak borer of firm bottoms
Thracia sp.	S	l		il	
	S	d.l		r.eur.	
Ditrupa arietina	S	Sl	m	r.eur.	opportunist; related to water torbidity

SITES

	S - E Can. F a n o			C.Ariano		E. Can. F a n o				W. Mass.Serrazza		
samples*	(S16¹	S16³	S16⁴)	(S41	S42)	(S 6	S 7	S11 S11*	S12)	(S26	S27	S28)
Facies	2	2	2	1	2	2	2-3	3	3	2-3	3	3

Table 7 - continue

TAXA	TG	H	Sp	D	Notes
Asteroids	C	Ev			arm ossicles
Cidaris sp. (radioles)	B*	Ev	h, mxd		*sponge browser
Psammechinus microtuberculatus	D	Ev	mxd	cl	
Paracentrotus lividus	B	E	h, cb	il	
Diatematoidea	B	Ev			
Echinocyamus pusillus	C	lv	cs,db,pb	cl	
Spatangus purpureus	D	sh,lv	db,pb,ms	il, cl	bottom-current indicator
Echinocardium cordatum	D	lv	s.rel.	eur.	
Spatangoida	D	lv			
Decapoda					
Lepas sp.	S	Es			
Scalpellum sp.	S	Es			
Verruca strömia	S	Es	h, shs	cl	Northern guest
calcareous algae					

SITES: S - E Can. Fano (S16¹, S16³, S16⁴); C.Ariano (S41, S42); E. Can. Fano (S6, S7, S11/S11*, S12); W. Mass. Serrazza (S26, S27, S28)

ICHNOTAXA	Inferred makers	Notes
Caulostrepsis cretacea	polichaetes	
Entobia paradoxa	Clione sp.	reported from sublittoral settings
Stenomorphic entobians	boring sponges	
Gnathichnus pentax	regular echinoids	
Iramena isp.	boring bryozoans	
Maeandropolydora isp.	polichaetes	
Terebripora falunica	boring bryozoans	
Thalassinoides isp.	burrowing crustaceans	
Sinuous tiny galleries	unknown	
Walled, branched tiny galleries	unknown	wall made of minute grains

*In each site the samples have been collected in stratigraphic order.

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