MARINE AND NORMARINE TRACE FOSSILS AND PLANT ROOTS IN A REGRESSIONAL SETTING (PLEISTOCENE, ITALY)

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Riassunto. In un terrazzo marino pleistocenico esposto lungo la costa ionica, sono presenti strutture sedimentarie indicative di una successione di paleoambienti marini via via meno profondi fino a continentale. Sulla base delle strutture sedimentarie, sia organiche che inorganiche, sono state riconosciute quattro facies. La facies A, costituita da sabbie con stratificazione incrociata (hummocky), rappresenta un ambiente marino costiero dominato da onde. La brusca riduzione dell'idrodinamismo dedotta dalla facies B, è stata posta in rapporto con il costituirsi di un ambiente protetto, più che con un aumento di profondità. Le caratteristiche della facies C suggeriscono un ambiente di shoreface superiore, fortemente influenzato da apporti continentali che, verso l'alto, gradua verso condizioni più continentali. L'ultima facies (D), infine, indica l'instaurarsi di zone umide o acquatiche di ambienti terrestri.

L'intensità della bioturbazione è generalmente bassa nelle facies A-C, alta nella facies D, caratterizzata da una ichnofabbrica dominata da *Taenidium* isp. Sparse radici verticali di piante vascolari si estendono in molti casi, fino a 3 metri al di sotto dei sedimenti della facies D. Del tutto insolita è la loro associazione con *Taenidium* di grandi dimensioni: le tracce si affollano intorno alle radici e le seguono in profondità fino ad oltre 1 metro dalla base della facies D.

Abstract. The sedimentary structures occurring in one of the Pleistocene marine terraces at the Ionian coast, indicate a shoaling upward trend from the shoreface of a sandy beach to nonmarine conditions. Four main facies have been recognized. Facies A consists of hummocky cross-bedded sands representing a wave-dominated nearshore environment. Physical and biological structures of facies B are suggestive of an abrupt reduction in energy level, possibly related to the establishment of shallow protected environments. Features of facies C suggest a stable environment of upper shoreface but strongly influenced by continental supplies. Upward, this facies passes into sediments deposited in continental conditions. The last facies (D) is related to moist or wet terrestrial environments.

Bioturbation levels of facies A to C are in general low. Facies D, however, is well bioturbated, having an ichnofabric dominated by *Taenidium* isp. Sparse, vertical roots of vascular plants extended in many cases to at least 3 m below the base of facies D. Particularly unusual is the close association of large *Taenidium* isp. and vertical roots, where the trace fossil is clustered tightly around the plant, in some cases to more than 1 m below the water-sediment interface.

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Introduction.

The Pleistocene marine terraces along the Ionian coast of southern Italy were studied by Brückner (1980), who established a stratigraphy comprising eleven terraces, T1-T11 (Fig. 1). While working on terrace T3, our attention was drawn to some unusual biogenic structures. The best exposures are at the Mercure (now destroyed), Mercure Sud and San Salvatore Quarries (Fig. 1). The most spectacular trace fossils are
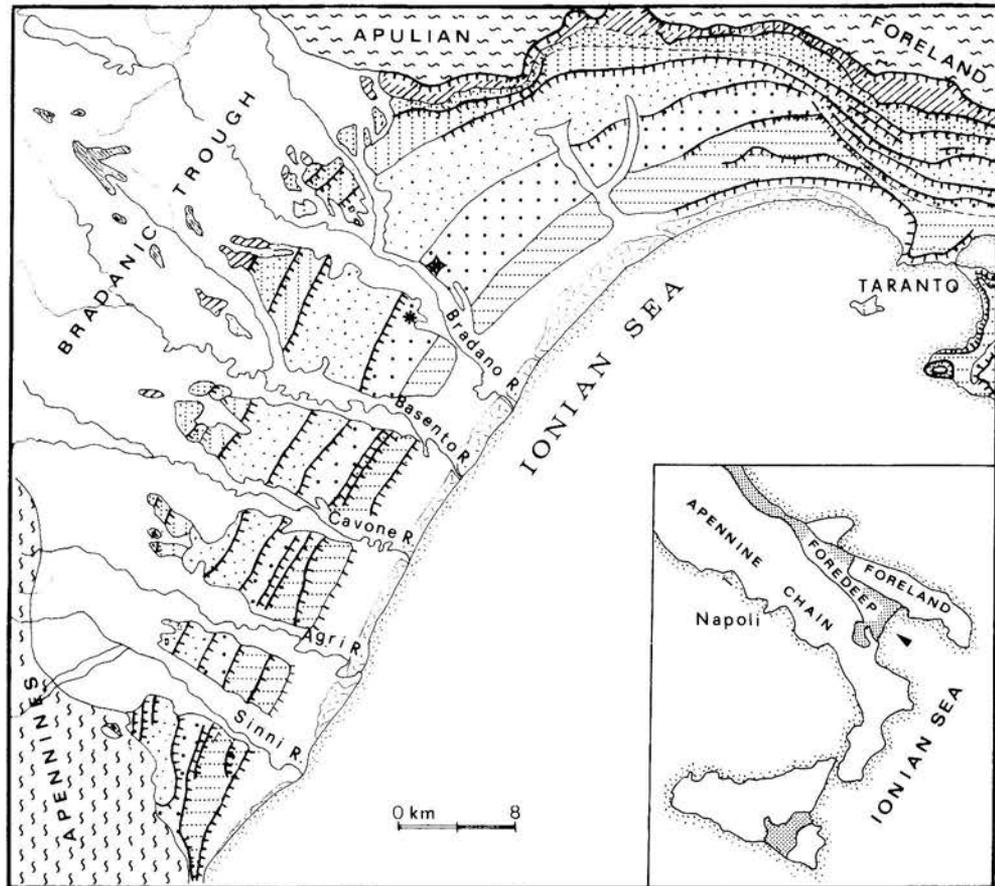
After Brückner.1980, slightly modified.
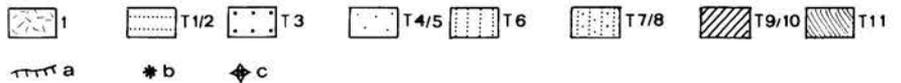
Fig. 1 - Map of Pleistocene marine terraces in the southeast part of the Bradanic Trough. T1-T11) Marine terraces. 1) Recent beach ridges and coastal dunes; a) front slope of terraces; b) San Salvatore Quarry; c) Mercure and Mercure Sud Quarries.

large meniscate burrow-fills clustered around vertical, non-marine plant roots (Fig. 2); the two component structures, however, also occur separately. This composite fossil occurs within sands partly characterized by hummocky cross stratification and its two separate components are related to erosive contacts that have been largely obliterated by bioturbation.

Fig. 2 - *Taenidium*/root-cast composite structures, vertical length 1.5 m, superimposed on the *Thalas sinoides* suite. San Salvatore Quarry.

Closer investigation of both biogenic and physical aspects of the sequence revealed a more complex pattern of environmental evolution than the simple offshore/shoreface transition of a progradational gravel beach sequence suggested by Massari & Parea (1988 a, b). The presence of plant roots requires a re-examination of the offshore/shoreface interpretation.

Geological setting.

During the Quaternary, the Ionian coast underwent several transgressive-regressive events, caused by interactions between tectonic uplift and glacioeustatic fluctuations of the sea level. According to Brückner (1980), between 775,000 and 80,000 BP at least eleven of such events are recorded by marine terraced deposist. The age of terrace T3 (*sensu* Brückner, 1980) is about 200,000 BP.

The Ionian Sea is a gulf of the Mediterranean Sea characterized by a microtidal and high-energy wave regime. The dominant winds blow from southeast and southwest and entail periodic storms, especially in the winter. The pattern of the resulting coastline was produced by a convergence of the strong longshore drift and the periodic heavy discharge of fluvial sediments brought from the rivers crossing the Bradanic area and southeastern Apennine. Consequently, fluvial regimes and sea-level fluctuations have a strong influence on the progradational stage of the Ionian beaches.

Massari & Parea (1988b) pointed out that the main controlling factor has been the interplay of fair-weather and storm periods, the latter more effective in the processes of coastal sedimentation. The same authors proposed for these Pleistocene sequences a general model of progradational gravel beaches. However, in the case of the T3 terrace this model cannot be applied, at least in the area examined.

Trace fossils and plant roots.

The sands of the T3 terrace contain diverse and abundant trace fossils: 15 kinds of biogenic structures have been distinguished. Two ichnogenera, *Thalassinoides* and *Taenidium*, are dominant elements throughout the sequence; plant roots, mainly preserved as casts or rhizoliths, are another important feature. ? *Polykladichnus*, *Scolicia*, slender *Skolithos*, "branched U-tubes" and "vertical bundled structure" are locally abundant. Rare forms include in approximate order of decreasing abundance, *Terebellina*, "polygonal-patterned burrows", *Arenicolites carbonarius*, *Cylindrichnus concentricus*, "J-shaped burrow", *Conostichus* and *Ophiomorpha*. In the following section only the unusual forms are described.

The trace fossils are rendered temporarily visible in three dimensions by gentle wind erosion of unlithified sand. With the exception of *Scolicia* isp., cementation of the trace fossils is generally extremely poor, almost negligible for the *Taenidium* isp., "vertical bundled structure", polygonal-patterned burrows" and root-casts. The burrows are not distorted by compaction, which suggests a generally coherent substrate.

Rhizoliths and root-casts (Fig. 3, 4).

Roots are almost perfectly vertical, simple structures preserved as casts or rhizoliths. The maximum recorded length was 3.5 m and diameters were 2-4 cm. Branching is uncommon, and always in a downward direction. Remnants of preserved vascular tissue occur within many examples, but commonly a central space has been filled with sand, around which a thin, empty tube represents the lost plant material. Outside this tube, there is normally a feebly cemented zone. In some cases, there is a filamentous extension of this cement into the surrounding sediment that resembles minute rootlets (Fig. 4A). However a similar texture is seen in several thin beds and around some *Taenidium*, and thus a purely diagenetic origin for the filaments cannot be excluded. Another possibility is that these structures are hyphae of fungi, which are commonly calcitized in palaeosols (Wright, 1986; Jones & Pemberton, 1987).

In Mercure, Mercure Sud and San Salvatore Quarries, under favourable weathering conditions, remarkable rounded structures were seen attached to roots (Fig. 4B). These are irregularly flattened ovoidal bodies up to 10 cm wide, rarely more, which occur singly at variable intervals along the root, lying more or less concentrically around its axis. The swellings (Fig. 4C) consist of white porous powdery material and
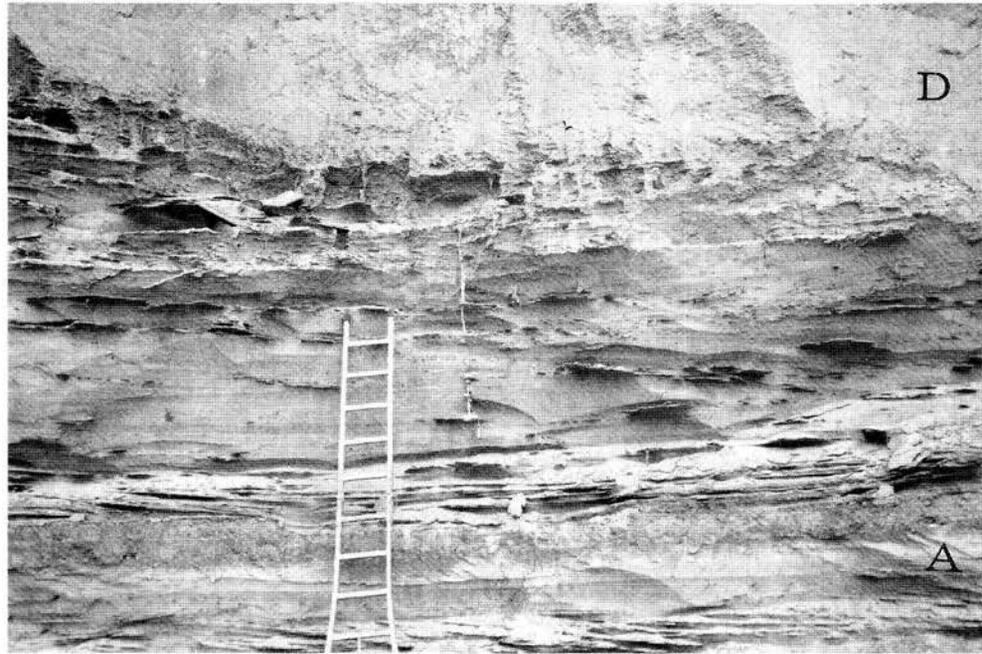
Fig. 3 - Facies D filling a channel cut in facies A. Rhizoliths and *Taenidium* penetrate down from facies D into facies A. The true boundary between the two facies is about 40 cm higher than is visible in the picture, owing to intense bioturbation. The longest rhizolith (centre of picture) exceeded 3.5 m, its base incomplete. Note the hummocky cross stratification in facies A.

are extremely friable; close observation reveals that they are composed of tangled tubules. One root bore at least three of such bodies, the lowest more than 3 m below a trough erosional surface. In addition, some roots carry small lateral inflations that could be interpreted as abortive lateral roots (Fig. 4B, arrowed). The simple, vertical morphology of these roots does not resemble that of marine grass (e.g. *Posidonia* or *Zostera),* and it would seem that they represent terrestrial or fresh-water vascular plants.
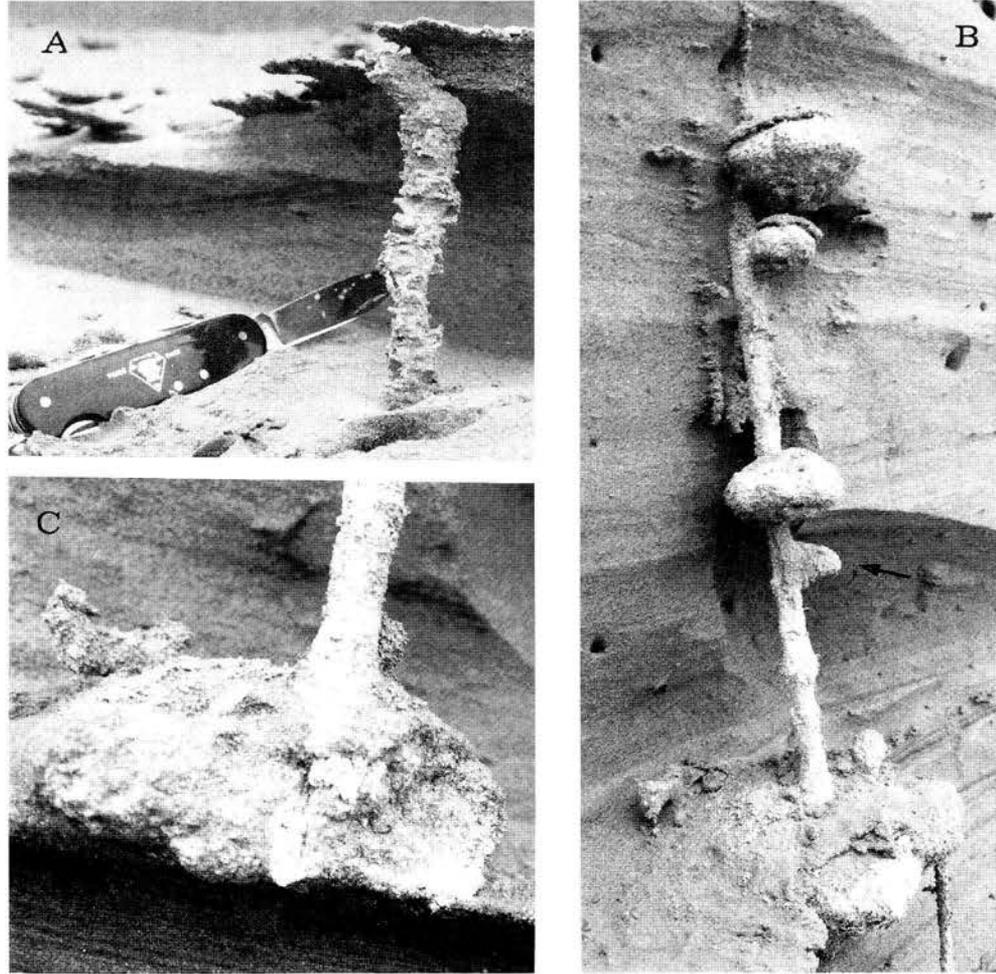
Fig. 4 - Rhizoliths. A) Filamentous extensions of cement resembling "rootlets" in facies A. B) Ovoidal structures attached to a rhizolith. The lowest structure (18 cm wide) bears an upward-orientated swelling. On the left side a poorly preserved *Taenidium* runs parallel to the root. There is a short side branch on the rhizolith (arrow). Mercure Quarry, facies A. C) Section of the middle rounded structure shown in Fig.4B (10 cm wide) displaying the central root.

The original nature of the ovoidal bodies is uncertain. Two possibilities invite consideration. The immediate impression given is that they are a part of the plant, representing a natural root nodule, or a reaction by the plant to a parasite. Unfortunately, preservation of the original plant material was not adequate to resolve this problem. Another possibility is suggested by the minute tabular structure of the interior and comparison might be made with the termite nests described by Bown (1982). However, the tubules and organisation of termites' nests are quite different from our material.

Because the roots associated with *Taenidium* are initiated not only at the discontinuity surfaces between two facies, but also from levels up to 50 cm within the continental sediments of facies C and D (see section of facies analysis), it would seem that the plant growth and its utilization by the burrowers occurred more or less simultaneously and thus in the same terrestrial environments.

Systematic ichnology.

Branched U-tubes (Fig. 5A,B). In addition to *Arenicolites carbonarius* (Fig. 5C) there are also small, U-shaped burrows, 1 mm in diameter, the two apertures several centimetres apart. The structure deviates from the ichnogenus *Arenicolites* in having ramification. Partly this represents growth in the form of a W, a larger U being constructed by replacing one limb of the original U. This is a common mode of growth of U-burrows (Bromley, 1990). Partly, however, additional branches are present, departing from the U laterally and downward.

J-shaped burrow. A J-shaped shaft, thicky walled (3 mm) and gently tapering downward, maximum outer diameter 3 cm, visible length about 60 cm. The infilling is composed of structureless loose coarse sand, that differs from the surrounding silty-sand. The trace represents a domichnion.

Vertical bundled structure (Fig. 6A). Bundled, vertically orientated burrow system, composed of variable numbers of slender (2-3 mm) thinly-walled galleries that radiate as ribs in a semi-conical, rarely fully conical, array. Most of these vertical galleries have shifted laterally in various directions for short distances, and curve to leave behind them an upward spreading, crude spreite.

The "vertical bundled structure" deviates from traces of *Phycodes* mainly in the different orientation of the structures, which is due to a lateral shifting of vertical galleries. Very similar but more crowded structures were reported from nearshore sediments (Bourgeois, 1980, fig. 5A-C; fig. 11B-C). However, we do not find any resemblance (Bourgeois, 1980, p. 685) with the modern polychaete burrow system figured by Hill & Hunter (1976, fig. 16). In a certain way, these are reminiscent of the *Arenicola* burrow sketched by Schäfer (1962, fig. 218).

? Polykladichnus isp. System of slender (1.5 mm in diameter), sinuous, sparsely branched galleries having the main components vertically arranged. Maximum length

observed is 7-8 cm. This system can be compared to some recent polychaete feeding-dwelling structures (see Frey & Pemberton, 1985, fig. 19C). The traces are similar to ? *Skolithos* isp. reported by Curran (1985, pl. 4A) in nearshore palaeoenvironments, but
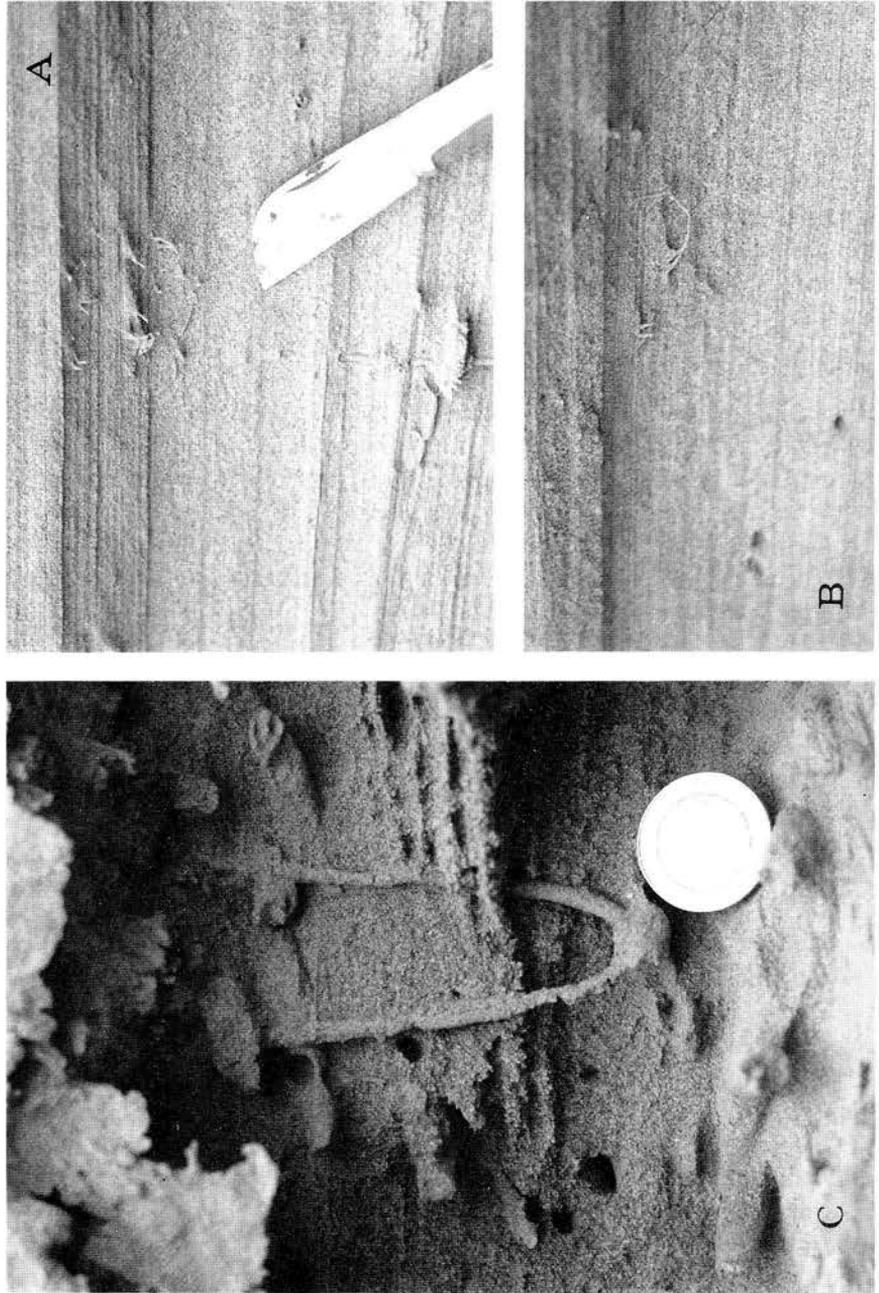
Fig. 5 - "Branched U-tubes". A) and B) Mercure Quarry, facies A. The slender root in Fig. 5A originated from the overlying facies D). C) *Arenicolites carbonarius*, San Salvatore Quarry, facies B. 5 cm high.

are more branched. Branching without a regular pattern differs the sistem from *Poly-kladichnus*.

Skolithos isp. Straight, unwalled, unbranched shafts, about 10 mm in diameter, 70-80 cm in length, composed of structureless sand. They occur in beds well bioturbated with *Thalassinoides* systems (Fig. 7A) that cross-cut them, but no connection with them was discovered. The tops are truncated by erosional surfaces.

Thalassinoides isp. (Fig. 7). Structures referred here to *Thalassinoides* isp. are not typical of the known ichnospecies, although the structural plan is that of the ichno-
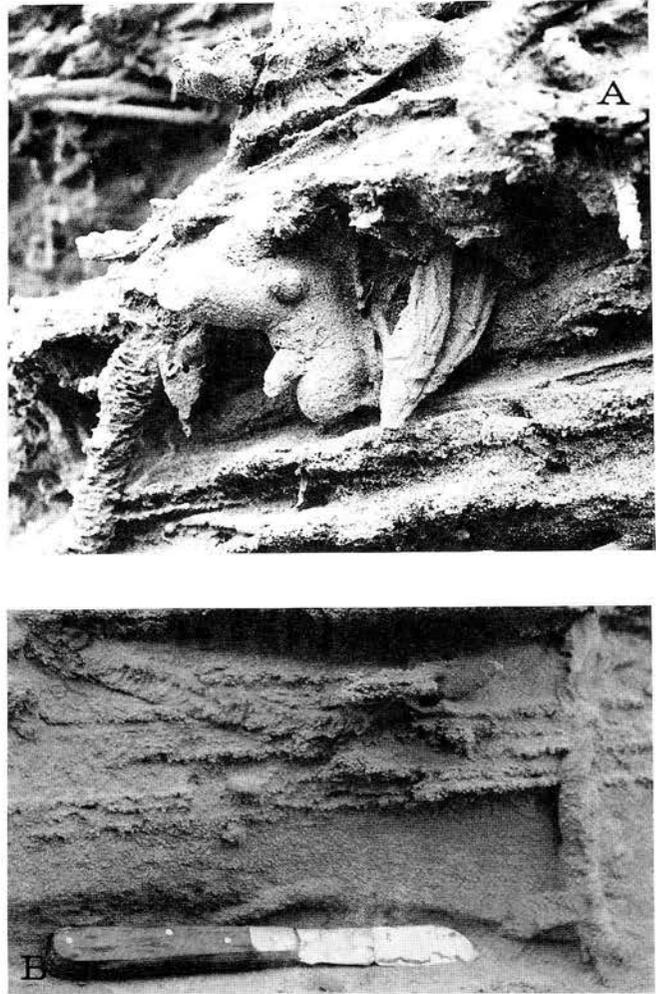
Fig. 6 - Trace fossils from the lower part of facies B at San Salvatore Quarry. A) "Vertical bundled structure". The smaller structure on the left predates a vertically orientated *Taenidium* that avoids crossing *Thalassinoides*. B) *Taenidium* isp. Each individual meniscus wraps around the next one. A false branching is visible at bottom right.

genus. Nodal points are far apart, generally T-shaped and unswollen (Fig. 7D). The internodal sections are winding, locally helicoidal (Fig. 7B, C) but dominantly sub-horizontal. Geometrical mazes are not present, but in dense occurrences, a loose, ir-regular boxwork is developed. Shafts to the seafloor have not been recognized, pre-sumably having been truncated by erosion.

Terebellina isp. (Fig. 8A). Straight subcylindrical tubes of 10-15 mm in diameter slightly tapering downward and up to 7-8 cm in length, arranged obliquely to the
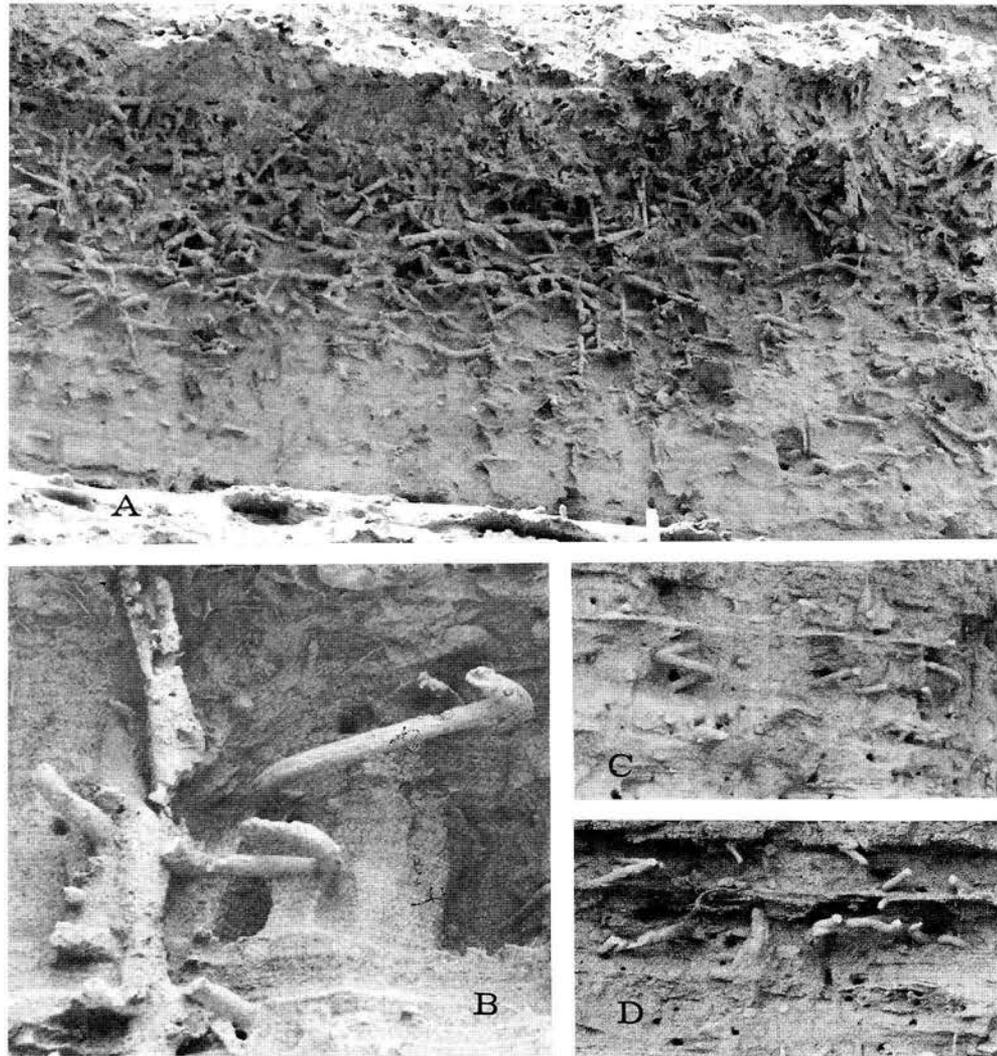
Fig. 7 - *Thalassinoides* isp. A) *Thalassinoides* isp. and *Skolithos* isp. in a laminated-to-scrambled unit of facies B. San Salvatore Quarry. B-D) Details of *Thalassinoides*. Note spiral elements. Diameter of bur-rows 1 cm.
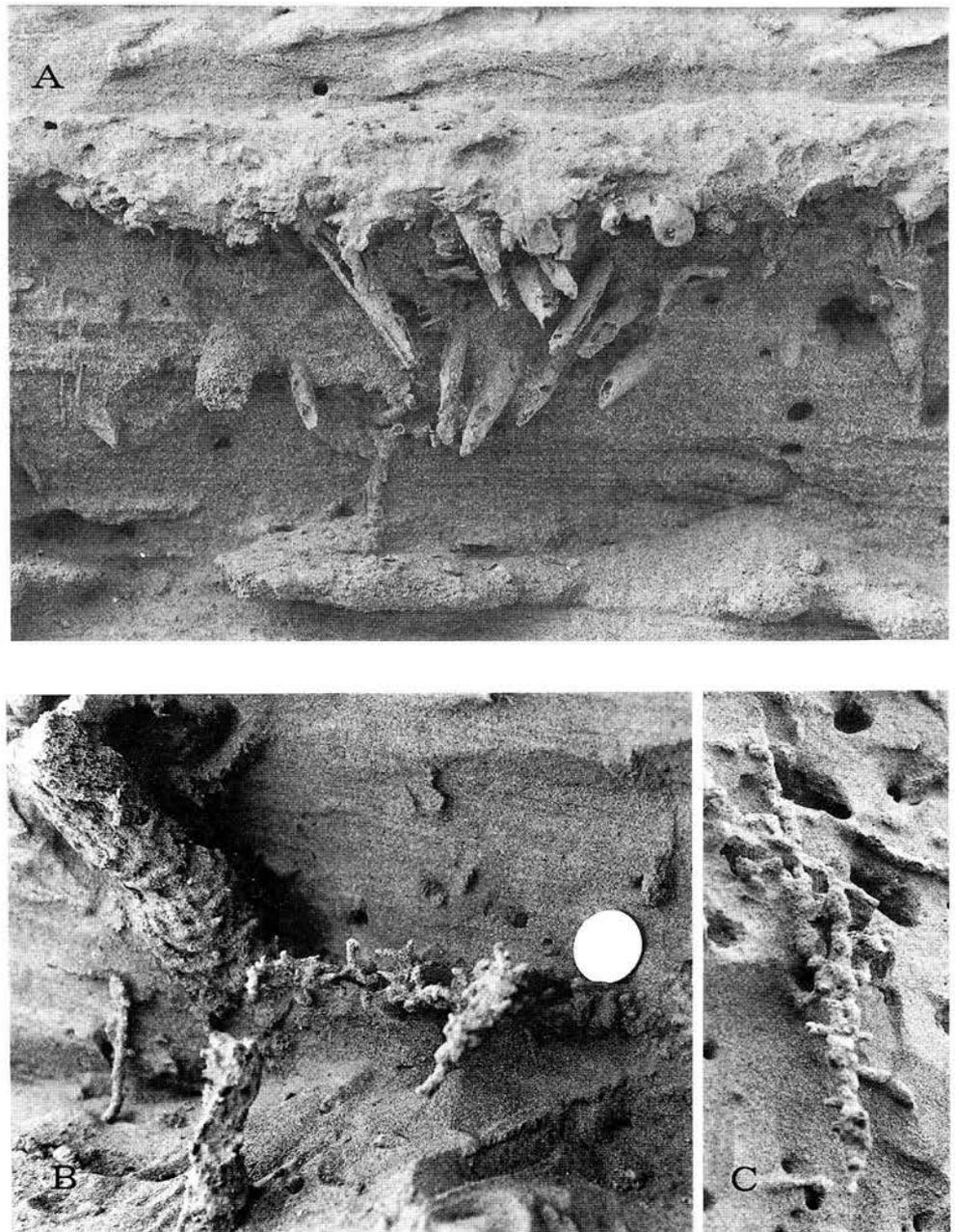
Fig. 8 - Facies B trace fossils at San Salvatore Quarry. A) *Terebellina* isp. associated with "vertical bundled structure" (far right) and *Skolithos linearis* (far left). Lower part of facies B. B) Polygonal-patterned burrows wrapping around a large *Cylindrichnus* shaft and connected with a horizontally expanded net. C) A vertically developed system of polygonal-patterned burrows, about 20 cm long.

sedimentary surface. The wall is thick and the filling structureless. Commonly they occur singly or in radiating groups.

Terebellina isp. exhibits a more radiate pattern than *Schaubcylindrichnus*, the tubes of which run essentially parallel, and *Terebellina* has thinner walls. The maker seems to have been a facultative rather than an obligate gregarious suspension-feeder.

Polygonal-patterned burrows (Fig. 8B, C). Delicate system of unwalled burrows (1.5-2 mm in diameter) regularly branched in an ordered manner forming polygonal networks in horizontal or oblique planes. More frequently the system has a vertical development (up to 40 cm of preserved length) and in such cases the general pattern is somewhat less regular, although the branching points tend to be regularly spaced. The shape of these burrows is somewhat reminiscent of a hanging piece of lace. In such vertical arrangement the lower end of the network can be tapered (Fig. 8C) or, on the contrary, wraps around itself as a small ball composed of a tangle of branched galleries. Commonly the burrows that wrap around large *Cylindrichnus* shafts may be connected with extensive polygonal nets. Facultative commensalism between two tracemakers is suggested.

The burrow-system closely corresponds to the "polygonal-patterned and wraparound burrows" described and illustrated by Curran (1985, p. 273; pl. 3C; pl. 6A, C, D) from a Cretaceous nearshore sequence and interpreted as a fodinichnion of an unknown polychaete. The numerous systems have been found only at the top part of facies B, where abundant ? *Arenicolites* also are preserved, and postdate all the other traces.

Taenidium isp. (Fig. 2, 6, 9, 10).
Because of its special significance, we treat this ichnotaxon separately.

Description. Cylindrical meniscate backfill structures having a constant diameter from 12 to 25 mm. The menisci are hemispherical in shape and 3 to 5 mm apart. Individual menisci wrap around the next one forward as they die out against the burrow boundary, and in this way produce a perfectly smooth external surface to the trace. A discrete wall structure has not been detected (Fig. 6).

Where the structure occurs freely and in uncrowded situations, it is straight, mainly oblique to horizontal but also vertical down to a depth of about 50 cm, occasionally more, making sudden changes in direction. Morphology becomes contorted in crowded situations. Horizontal orientation dominates most ichnofabrics, but in some, structures are tangled in all directions (Fig. 9). Sharp bends and intersections are abundant.

A characteristic mode of occurrence of this ichnotaxon is in connection with vertical roots (Fig. 2, 10). It is remarkable that the sediment immediately in contact with roots appears to have been more attractive for the *Taenidium* animal than the root itself. A few examples show this clearly (Fig. 10). In crowded situations, more commonly the roots have been largely destroyed by the *Taenidium* maker as it
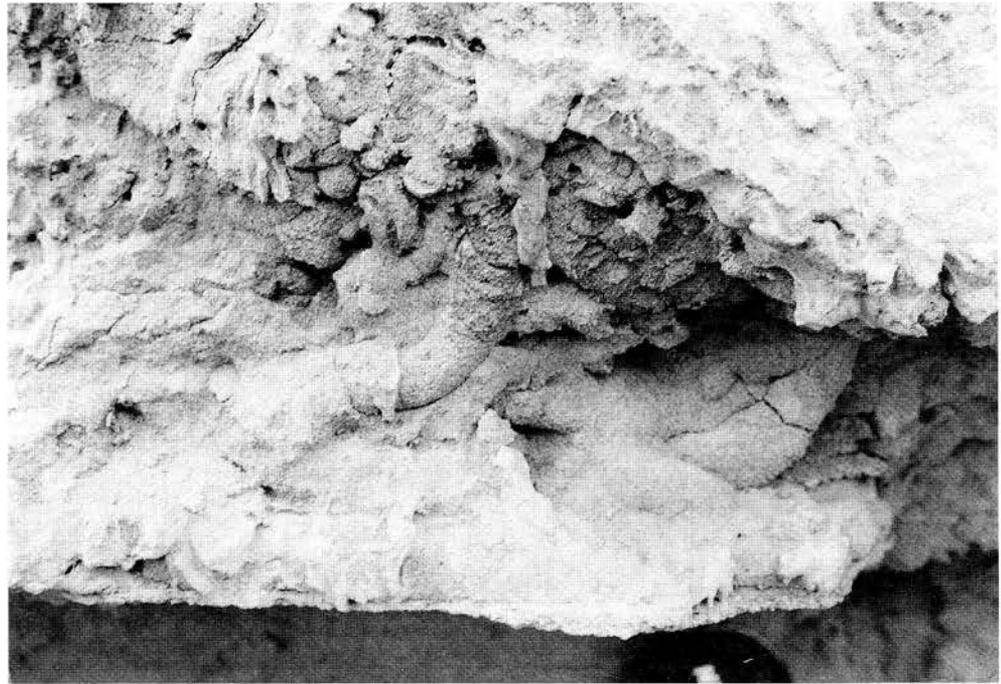
Fig. 9 - Tangled mass of *Taenidium* isp. at the boundary between facies C and D. Mercure Quarry. Diameter of the largest structures about 3 cm.

worked down along them and bioturbated the sands. In such cases, the contortion of the *Taenidium* is most extreme. Crowding around the root causes vertical elements to dominate the fabric locally, the menisci indicating both upward and downward movement. The backfilled structures continue downward along the roots to a maximum observed distance of 250 cm. More commonly, however, the backfill structures reach 100-150 cm. Unexploited remnants of the longer roots extend further down beyond this (Fig. 2). Blindly ending burrow fills showing various orientations are also abundant (Fig. 10A).

Taxonomic observation. The trace fossil somewhat resembles *Taenidium serpentinum* Heer but is considerably larger than the type material. Moreover, the degree of contortion in crowded situations and abundance of blind ends are unusual. The size approaches that of *Beaconites*, but the menisci in that form are more crowded and flattened (Bradshaw, 1981).

The Ionian trace fossil resembles the structure named *Ancorichnus coronus* by Frey et al. (1984). General form, orientation, meniscus shape and distance are similar in the two forms. The diameters of our specimens (12-25 mm) are larger on average but overlap with measurements of Frey et al. (1984) for larger examples of *A. coronus*.
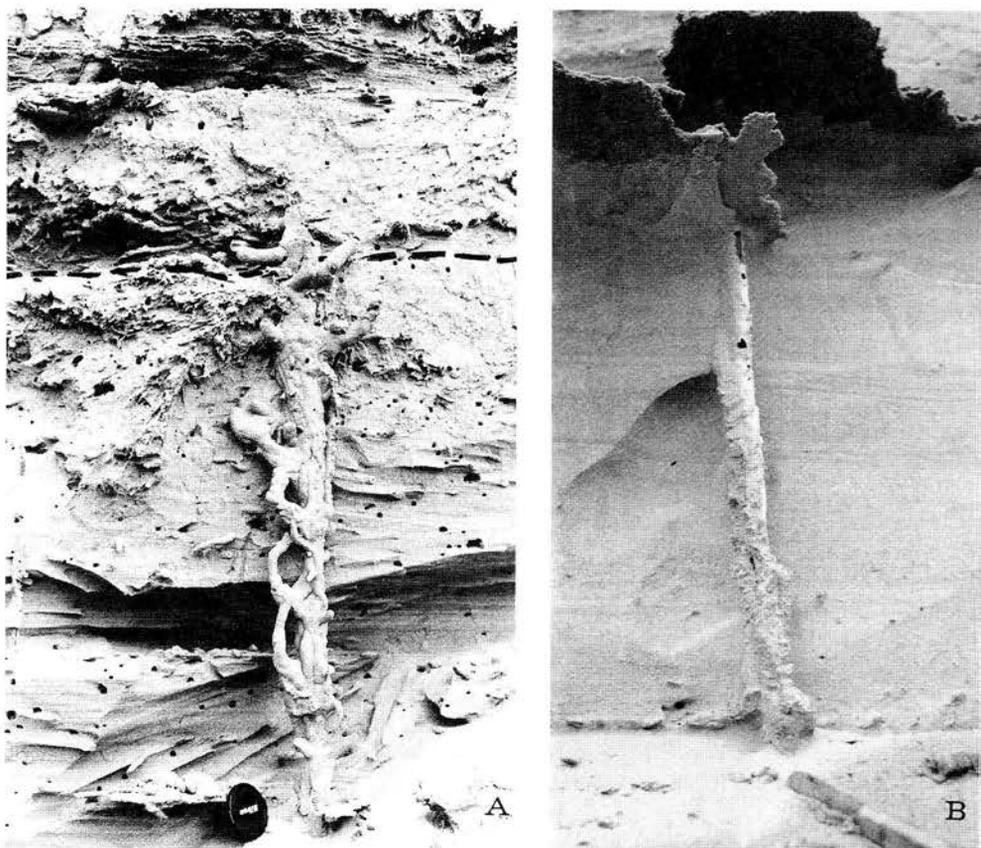
Fig. 10 - *Taenidium* isp. connected with vertical roots. A) The boundary between facies A and B is indi-
cated by a broken line. The base of facies D, from which the *Taenidium*/rhizolith structure pre-
sumably originated, is just above the top of the picture, about 1.5 m above facies A. Note the
blind ends in the *Taenidium*; the concave-up menisci are just visible in places. The top of facies A
contains white mottles representing *Thalassinoides*. San Salvatore Quarry. B) *Taenidium* wrapping
around a root-cast. Facies A, Mercure Quarry.

On the basis of both description and pictures of *A. coronus* we deduce that in
this form too the wall could result by partial overlappings of contiguous menisci
rather than represent a discrete structure. Therefore we suggest removing *A. coronus*
from *Ancorichnus*, which is an ichnogenus having a distinctively structured wall
(Heinberg, 1974), suggestive of a different constructional behaviour. Trace fossils
walled by overlapping menisci could be better placed within *Taenidium* as emended by
D'Alessandro & Bromley (1987).

Discussion. Taenidium isp. has two distinct modes of distribution. a) As a hori-
zontal to oblique, locally vertical trace fossil tending to follow bed units, the structure
either occurs sparsely or in total bioturbation as a tangled mass. b) In dominantly
vertical orientation passing down, up and around thin vertical roots. The morphology

of the two occurrences is identical to the smallest detail, except for orientation, and therefore we judge the trace-making animal to have been the same in both cases. The association with roots is so pronounced that it begs an explanation. Three interpretations are given below, of which we consider the first to be most likely. In order to discuss these interpretations, several facts need to be noted.

1) The variations in diameter indicate that more than one individual was active in reworking the sediment along the root. 2) The animals moved both up and down the root as is seen by meniscus orientation. 3) Lateral excursions away from the root normally are abandoned, having a blind end. In roots unaccompanied by *Taenidium*, no corresponding lateral branches are to be seen. Therefore the blind ends do not seem to correspond to root morphology. 4) In fact, the animal normally did not consume the tissue of the plant. A well preserved root at least locally is normally present at the heart of the vertical tangle of backfills (Fig. 10B).

Interpretation 1. The animal lived more or less contemporaneously with the plants, and thus in a terrestrial/fresh-water environment. Either the animal was associated with the living plant, or exploited the bacteria decomposing the dead plant. In the latter case, it is difficult to envisage how a fairly large animal could penetrate the substrate to over 2 m, packing sediments behind it and having no possibility of a shaft to the surface. Possibly the animal could use the partially air-filled porosity of the damp substrate in the meteoric phreatic environment for respiration.

Alternatively, the plants' life processes led to a deepening of the redox boundary by diffusion of oxygen throughout the root system, thereby indirectly enabling the organisms to exploit otherwise unused resources at a remarkable depht. This hypothesis implies an animal/plant commensalism.

Interpretation 2. The plants' flourished during brief emersion periods on a flat coastal plain. Inundation by the sea would permit a marine animal to harvest the microbial cultures produced by plant decay. The animal would have to penetrate very far within the anoxic zone of the substrate, and anoxia would be encouraged by the bacterial activity in the proximity of the root. The trace fossil does not suggest a strategy suitable for exploiting deep-tier anoxic environments.

Interpretation 3. The two modes of occurrence of *Taenidium* may be the work of two completely different animals. The "horizontal" habitus would represent normal deposit feeding in a marine environment by an echinoid, holothurian or large annelid. The "vertical" habitus could correspond to activity of a terrestrial herbivore of unknown nature; the structure may be too finely laminated to suggest a mammal, land crab, crayfish or a giant insect. This interpretation would permit a more "marine" evolution of the sequence as a whole, but the *in situ* plant roots do not allow dismissal of periods of emergence.

Trace fossil suites (Fig. 11).

In the sequence studied, uncritical use of ichnofossil assemblages as a key to environmental information would be misleading. This is because the assemblages are

Polykladichnus
Terebellina Suite

Scolicia Suite

Thalassinoides
Suite

Thalassinoides
Skolithos Suite
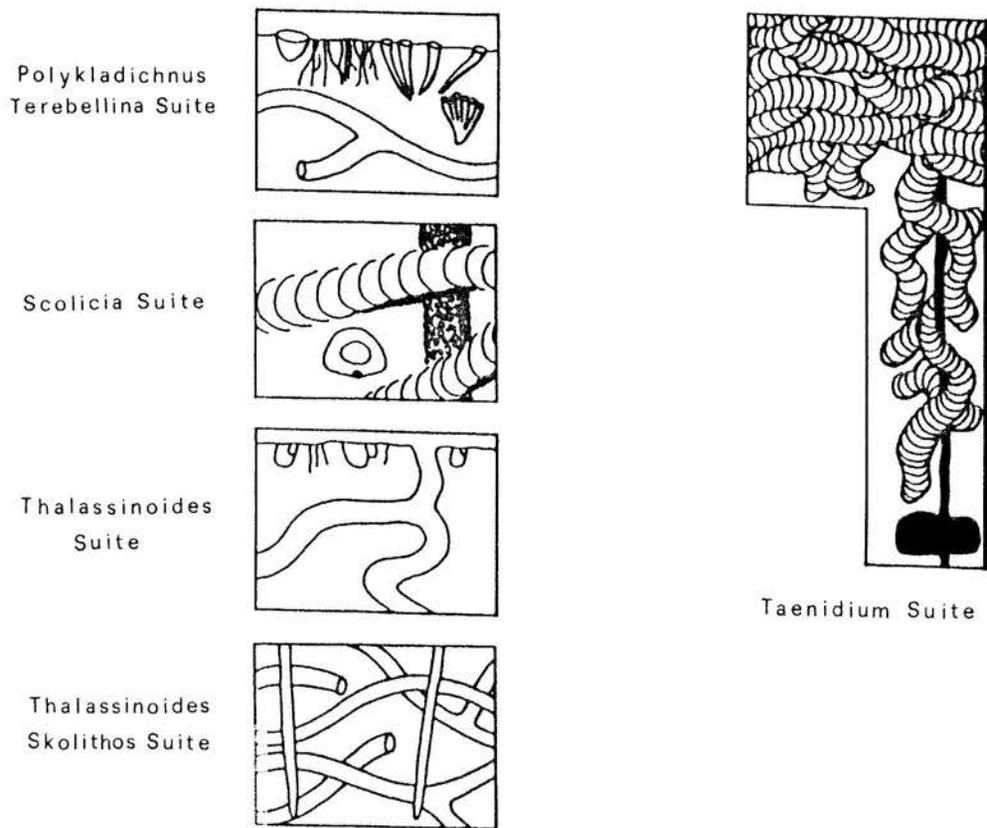
Taenidium Suite

Fig. 11 - Diagrammatic representation of the five trace fossil suites.

composite and do not represent single bioturbational events or units. The heterogeneity is produced by deep-tier activity such as *Taenidium*, cutting deeply across facies boundaries to become mixed with earlier assemblages. Even middle-tier *Thalassinoides* is superimposed beneath erosion surfaces in this way among earlier trace fossils. Disentangling this information on the basis of cross-cutting relationships and the location of ichnotaxa within beds allows the reconstruction of five suites of trace fossils (Tab. 1).

Thalassinoides suite. The suite is dominated by feeding/dwelling burrows in low or moderate density. Erosion has locally reduced their occurrence to patches or thin horizons. Domichnia, represented by "branched U-tubes", occur locally, while a single shaft of *Cylindrichnus concentricus* has been found in the top part of the facies. The kind of preservation suggests colonization events of the sea bottom during brief periods of moderate energy in a wave-dominated shoreface.

? Polykladichnus-Terebellina suite (Fig. 12). This distinctive, high diversity suite is characterized by the dominance of chiefly vertical, dwelling and dwelling-feeding

TRACE FOSSILS	ICHNOFOSSIL SUITES	?Polykladichnus Terebellina	Scolicia	Thalassinoides	Thalassinoides Skolithos	Taenidium
Rhizoliths						C
Arenicolites carbonarius	Domichnia	O				
Branched U-tubes	Domichnia	O		R		
?Polykladichnus isp.	Domichnia/ Fodinichnia	C			O	
Conostichus isp.	Domichnia	R				
Cylindrichnus concentricus	Domichnia/ Fodinichnia			RR	O	
J-shaped burrow	Domichnia				RR	
Ophiomorpha nodosa	Domichnia		RR			
Vertical bundled structure	Fodinichnia	O				
Scolicia isp.	Pascichnia/ Repichnia		C			
Skolithos linearis	Domichnia	C				
Skolithos isp.	Domichnia				C	
Taenidium isp.	Pascichnia					A
Thalassinoides isp.	Fodinichnia/ Domichnia	C		C	A	
Terebellina isp.	Domichnia	C			O	
Polygonal-patterned burrow	Domichnia/ Fodinichnia					

Tab. 1 - Distribution of the ichnotaxa in the five suites. A = very abundant, C = common, O = occasional, R = rare, RR = 1 specimen.

structures, reflecting a mainly suspension-feeder infaunal community. Only *Thalassinoides* exhibits a more horizontal development; its preferential location below the other traces of the suite indicates emplacement in a deeper tier. The preservation of such frozen tiers could be indicative of a relatively short interval between two successive erosional events. The presence of suspension-feeder structures would seem to reflect relatively high energy levels, although less high than these of the *Thalassinoides* suite.

Scolicia suite. This suite is composed of low-medium density *Scolicia* isp. and a single *Ophiomorpha* shaft has been recognized. *Scolicia* is interpreted as the work of

Fig. 12 - ? *Polykladichnus-Terebellina* suite in the lower part of facies B. The confused ichnofabric was pro-
duced by the local superimposion of numerous *Taenidium* and *Taenidium*/rhizolith structures
from facies D. San Salvatore Quarry.

spatangoid echinoids (see Bromley & Asgaard, 1975) and occurs in coarse, well-sorted,
cross-bedded sand. Having a circular cross-section and a single drain placed along the
base of the backfill, the trace fossil may be ascribed to *Echinocardium mediterraneum*
(cf. Bromley, 1990, fig. 5.13). The suite is thus considered indicative of a shallow
marine environment and shifting sea-bottom.

Thalassinoides-Skolithos suite. This suite includes *Thalassinoides* isp., *Skolithos*
isp. (Fig. 7A), few *Cylindrichnus concentricus*, "polygonal-patterned burrows" and lo-
cally "branched U-tubes". The uncommon survival of otherwise obliterated small
traces at the top of beds is likely to be a preservational effect and suggests a relatively
intense scouring of sea-bottom. The observation that *Skolithos* isp., "branched U-
tubes", and the "polygonal-patterned burrows" postdate the *Thalassinoides* systems sug-
gests a tiering development in a late successional stage (Bromley, 1990, fig. 11.2C) so
that the suite may represent the activity of two successive communities. Sediments
highly bioturbated to locally mottled by *Thalassinoides*, for a thickness of 60-70 cm,
indicate long periods of slow, continuous deposition interrupted by rare storm events.
Mainly unwalled feeding and dwelling structures suggest a well-developed infaunal
community in an oxygenated biotope having moderate turbulence and coherent sub-
strate (Bromley, 1990).

Taenidium suite (Fig. 2, 3, 9, 11). This comprises a monotypic suite made by animals and rooted plants. The presence of vascular plants and the close relationship between them and *Taenidium* indicates that the tracemaker most probably was a non-marine animal (interpretation 1 above).

Facies analysis.

In the sediments of terrace T3, four major facies have been distinguished (Fig. 13, 14) whose characteristics are briefly described below. Recognition of the facies is based on the ichnofossil suites (Tab. 2) and inorganic sedimentary structures.

Facies A. This facies is no more than 5 m thick in the sections studied and is composed of medium- and fine-grained sand. A few thin clayey to silty layers and lenses are interbedded in the lower part. The clay fraction is rich in small clusters of ferruginous grains and foraminifera, probably reworked from the "Subapennine Clays" Formation cropping out inland. The sands of this facies are well bedded; hummocky stratification is common and erosional surfaces locally cut deeply into the clayey layers (Fig. 15A).

In the upper part of facies A small pebbles, mud armoured balls (Fig. 15 B) and clay chips occur. Rarely, in small channel fills, there are moulds of small molluscs representing both fresh water (*Theodoxus fluviatilis*) and shallow marine species: *Lentidium mediterraneum, Cerastoderma edule, Ostrea edulis* (juv.), *Epitonium celesti, E. commune* and *Jujubinus* sp. Axes of erosive scours show NW-SE direction and foresets dip seaward (SW).

Biogenic structures are generally lacking but *Thalassinoides* isp. occurs as sparse patches. A mottled or heavily bioturbated interval, 15-20 cm thick, representing the first preserved record of a change in the depositional regime, has been taken as the boundary between facies A and B. The ichnofossil assemblage at this boundary is heterogeneous, comprising traces of pre-omission *Thalassinoides* suite together with ? *Polykladichnus-Terebellina* and *Taenidium* post-omission suites. Locally, the boundary surface dips landward (N), causing a slight angular discontinuity with the overlying beds of facies B (Fig. 13).

Facies B. This facies, about 4 m thick at the San Salvatore section, is characterized by thickening upward, laminated-to-scrambled units (Fig. 7A). In the basal part of facies B, sand units are 20 to 30 cm thick, variable in grain-size and display different structures. These include small scours having concordant fill of laminated coarse sands, sets of large-scale oblique laminae and thin layers of fine-grained sand with symmetrical ripples (Fig. 8A), some topped by planar surfaces. The *Polykladichnus-Terebellina* suite occurs in each unit of the lower interval, except in one composed of coarse laminated sand, where it is replaced by the *Scolicia* suite. The small size of the trace fossils of the first-mentioned suite is significant because their survival demonstrates
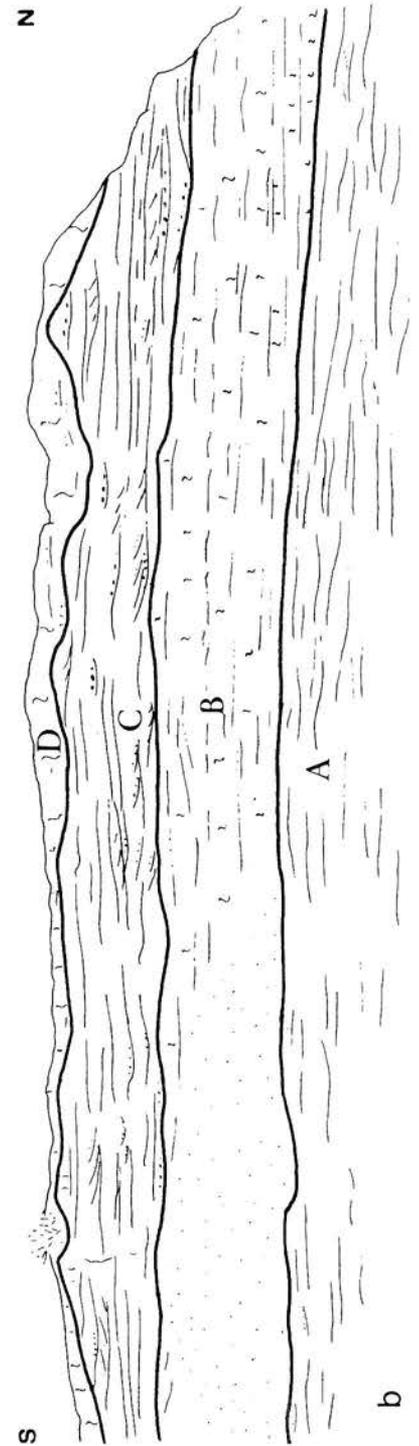
that scouring by sheet flow and local trough formation has been very minor (Fig. 16).

In the main body of facies B is a rhythmic sequence of units, up to a metre thick, characterized by the *Thalassinoides-Skolithos* suite. Each of these units is unbioturbated at the base, and thoroughly bioturbated at its truncated top. The units have erosive, planar or irregularly undulating bottom surfaces characterized by a plane-parallel lamination, small pebbles and clay intraclasts. Despite intense bioturbation, trough cross-bedding (sets of 50-70 cm) is still recognisable within the units. The cross-bedding is associated with thin lenses of ripple-laminated muddy sand, no more than 25 cm thick and laterally extensive to tens of metres. Where facies C is locally reduced or lacking, composite ichnofabrics are produced by the emplacement of numerous *Taenidium* suite traces from facies D into the highly bioturbated sediment of facies B (Fig. 12, 14, 16). Curiously, vertical *Taenidium* isp. is apparently more abundant in the lower thin beds of this facies.

The upper contact of facies B is a wavy erosive surface emphasized by a conglomerate of variable thickness (25 cm at maximum) composed of rounded pebbles (average diameter 1 cm) and clay chips.

Facies C. Overlying an erosion surface, facies C reaches a thickness of 3 m but locally shows a deeply eroded upper surface and has a residual thickness of less than 1 m. The facies is composed of heterolithic units up to 20-30 cm thick bounded by erosive contacts. The units consist of 1) gravels, both disorganized and well sorted, 2) high-angle cross-bedded coarse sands, 3) very thin-bedded cross-laminated fine sands, and 4) locally deformed and/or eroded clays, 10 cm thick. In the Mercure Sud Quarry, the gravel units are thicker and coarser and the clayey ones are less continuous than in San Salvatore Quarry. In both sections, the coarse sands of the lower horizons contain *Scolicia* isp. The traces cross the oblique sets of laminae horizontally, suggesting that the bioturbation occurred after a scouring event.

In the lower part (2 m) the foresets of the sandy units suggest landward accretion. Sandy sets inclined southward together with symmetrical wave rippled horizons are visible in the upper part (1 m) of the facies. At the top of this facies, in the San Salvatore section, a fine-sand layer, up to 50 cm thick, overlies the heterolithic beds of facies C with a sharp contact. Laminae in this light-coloured sandy layer are inclined landward. In the same direction it thins rapidly, passing into a clayey layer and reddish sands with cross-bedding and scattered pebbles, about 2.5 cm thick. The *Taenidium* suite is present in this interval, originating within the sandy bed near or at the top of facies C.

Fig. 13 - Geometry and facies relationships in San Salvatore Quarry. a) The boundary between facies A and facies B is marked by a surface inclined landward (toward right). The erosional surface between facies B and C and their characters suggest the approach of an alluvial plain towards a protected beach. Facies D overlies facies C with an erosional contact. b) The main features of the facies are sketched.
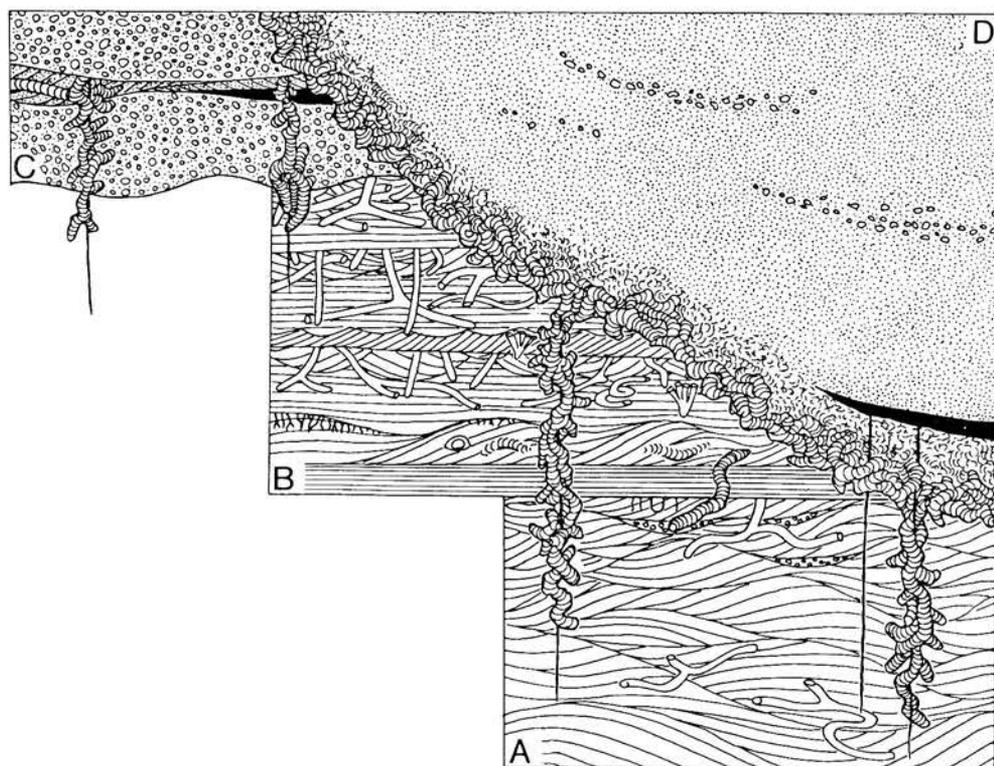
Fig. 14 - Cartoons representing the features of the four facies (A-D) and their interrelationships.

ICHNOFOSSIL - SUITES	FACIES			
	A	B	C	D
?Polykladichnus-Terebellina		*		
Scolicia		*	*	
Thalassinoides	*			
Thalassinoides/Skolithos		*		
Taenidium			*	*

Tab. 2 - Relationship between suites and facies. In facies B ? Polykladichnus-Terebellina and Scolicia suites occur in the basal part (marks on left), whereas Thalassinoides-Skolithos suite characterizes the thicker beds of the upper part.
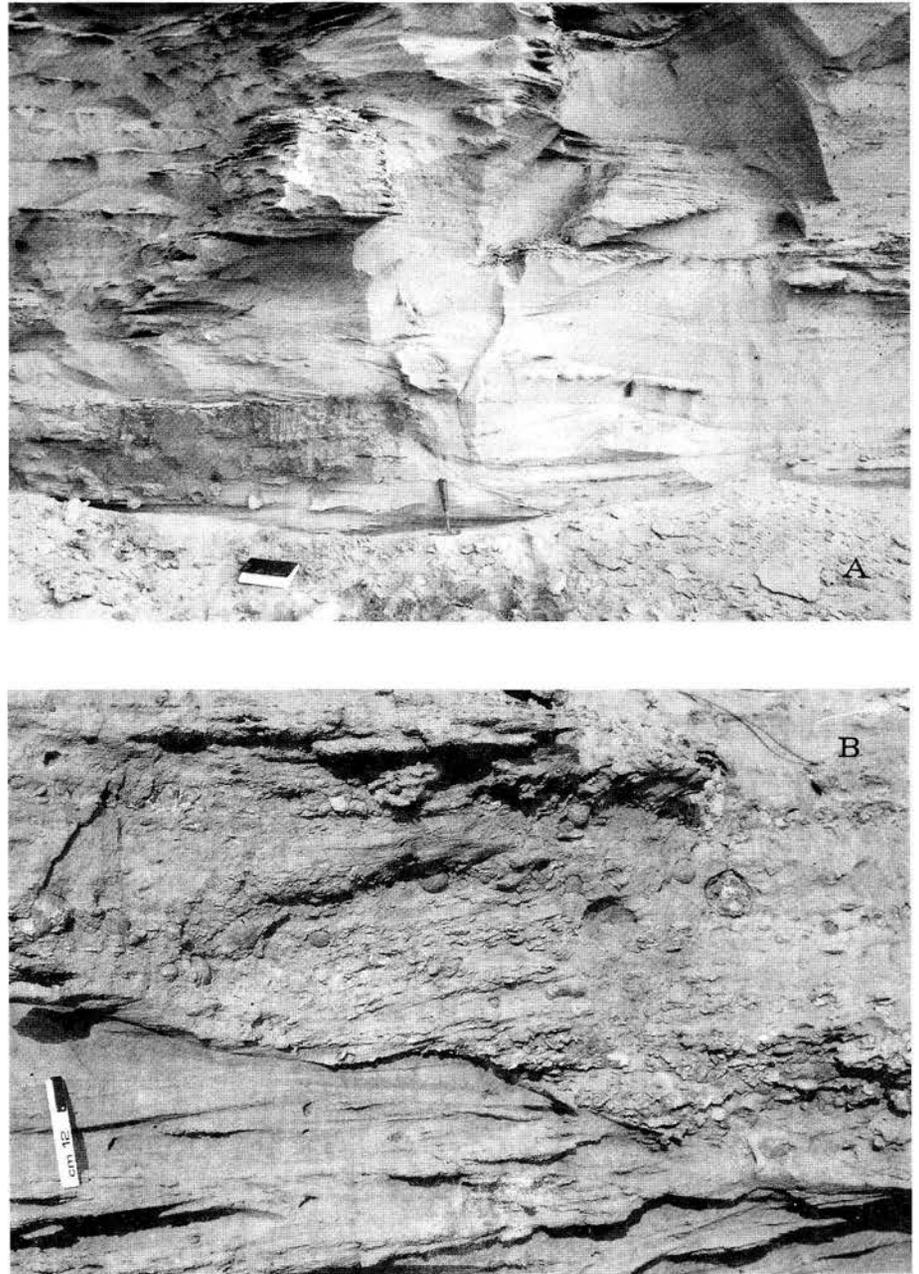
Fig. 15 - Sedimentary structures at Mercure Quarries. A) Facies A in the lower part of Mercure Quarry. Hummocky cross-stratification and a truncated clayey layer (above hammer) indicate the storm regime. B) Armoured balls, pebbles and clay chips in sandy matrix in the fill of a scour, all within the upper part of facies A. Mercure Sud Quarry.
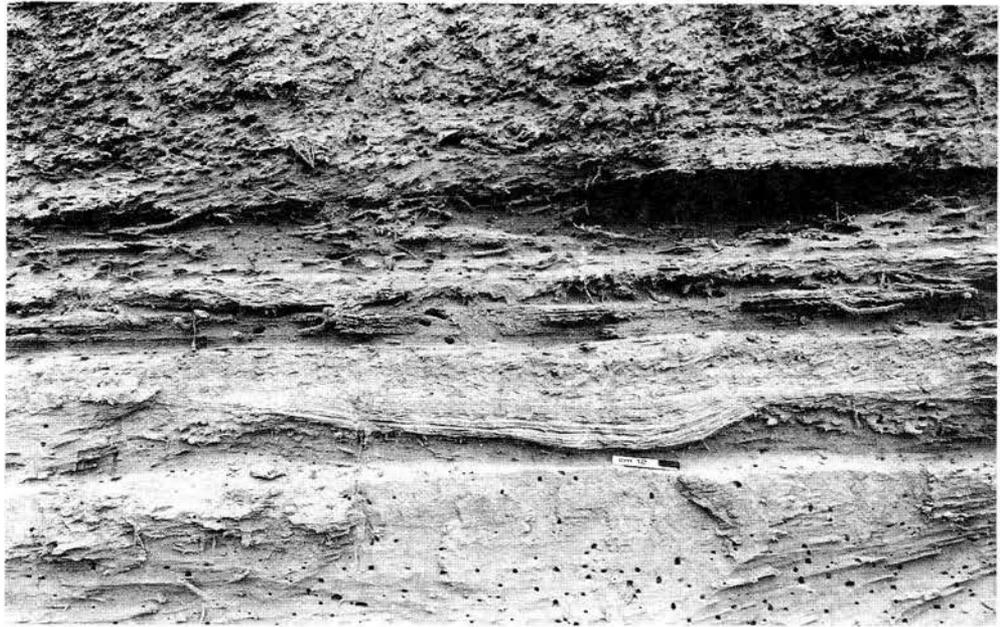
Fig. 16 - The lower bioturbated interval is the topmost unit of facies A. The scale bar, 12 cm, lies on the boundary between facies A and B. A small trough, cutting ? *Polykladichnus-Terebellina* suite traces, can be observed above the scale.

Facies D. This facies (Fig. 3, 12) is exposed for a limited thickness of a few metres, and is represented by poorly sorted red sands having a sharp channel-formed erosive base that cuts down into all the other facies. Its post-omission *Taenidium* suite represents a homogeneous ichnocoenosis totally dominated by *Taenidium* isp. that causes almost total bioturbation of the channel fill sediments at their base, as well as at the top of the underlying facies throughout an overall thickness of about 1 m. Consequently, the features of the erosive contact have been obliterated (Fig. 9, 12) and the boundary between the facies has moved down with the base of bioturbation; i.e., the present facies boundary is the base of the zone of intense bioturbation and not the original erosion surface. Downward from this bioturbated zone, the number of trace fossils rapidly decreases, some root-casts and more abundant *Taenidium*-rhizolith structures penetrate deeply (Fig. 2, 3). Higher in the facies the sand is massive and locally contains pebbles scattered or in lenses.

Conclusions.

The following sequence of palaeoenvironments is envisaged.

Facies A. The coarsening upward trend of sands through this facies, increasing amounts of pebbles and armoured balls on the floors of scours, and stronger erosion

surfaces, all suggest progradational shallowing and the proximity of a river. Some of the clayey layers apparently have a continental source and represent exceptional flood events, when large amounts of clay were rapidly discharged into the sea. Distribution of the trace fossils indicates local and frequent erosion of a shifting sand bottom. A physically stressful marine environment is also inferred by the low diversity of the *Thalassinoides* suite. This is further demonstrated by the presence of deep scour into a thick clay bed, which testifies to rip currents and storm events of particular severity. The Mercure area was closer to the coastline than San Salvatore, as is shown by thick lenses of armoured balls at Mercure Sud. A wave-dominated, lower to upper shoreface of an exposed coastline is assumed; comparison may be made with the "lower hummocky-bedded facies" of Bourgeois (1980).

Facies B initiated possibly at depths shallower than facies A, but nevertheless, there is no transgressive lag at its base. Distribution of the traces suggests changing rates of sedimentation. Pulses of rapid deposition were followed by brief periods of gradual seafloor accretion during which rapid colonization by burrowing animals occurred, as is documented by the numerous dwelling and dwelling-feeding structures. The similarity with the "parallel-laminated and burrowed sandy siltstone facies" of Bourgeois (1980) could result from a lower hydrodynamic energy rather than from a deepening of the water. Indeed, the presence of thin cyclic units, minor scouring and sheet erosion, together with suspension-feeder activity, suggest a shallow to very shallow, protected marine environment. It is likely that some of the *Taenidium* and plant roots originated from a bedding plane in the lower part, thereby indicating occasional local emergence.

The upper part of the unit contains more burrows, which belong to the *Thalassinoides-Skolithos* suite, and it may represent a deeper, shoreface environment, characterized by cyclic variations in the rate of sedimentation and in the hydrodynamic conditions. In general, the intensity of the erosive events is higher than in the lower interval, although their frequency decreases so that the periods of slow continuous sedimentation are longer.

Facies C represents upper shoreface to foreshore environments in moderate energy conditions, dominated by sediment derived from land. A regressive trend is evident, as we pass from occurrences of the marine *Scolicia* suite to the continental *Taenidium* suite, which comes to dominate the upper part of the sequence. At San Salvatore, the uppermost sandy unit of the facies and its associated clay bed are interpreted as representing supratidal dunes and interdune ponds, colonized by sparse vegetation and burrowing animals, as recorded by the rhizoliths and *Taenidium* isp., whereas at Mercure, closer to the river, fluviatile environments are represented.

Facies D. It is probable that this facies belongs to the continental interval before the following T2 terrace. Large and deep channels, indicating flood-plain environ-

ments, are filled with bioturbated sediment containing *Taenidium* isp. No indication of marine conditions is suggested by the ichnofossils but rather a moist or wet terrestrial environment such as abandoned channels and/or ponded water on the floodplain, which passes up into dry continental conditions.

The environmental evolution of the Pleistocene terrace T3 of the Ionian coast is more complicated than Massari & Parea (1988a, b) envisaged in their general model. The sediments of this terrace show an unmistakable trend from shallow marine upward into terrestrial environments. This trend is clearly documented by trace fossil assemblages and plant roots.

The *Taenidium* suite is particularly interesting because it is easily identifiable and appears to represent an indicator for damp terrestrial conditions. The close relationship between long vertical plant roots and deeply emplaced backfill trace fossils should be readily recognizable in similar situations elsewhere. Where channels and roots are not present, the large *Taenidium* isp., even where emplaced in sediments deposited in a marine environment, should indicate periods of emergence that might otherwise go unrecognized.

In sediments older than Pleistocene, the trace fossil *Ancorichnus coronus* appears to represent a closely similar indicator of moist continental conditions.

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