

RESPONSE OF MACROBENTHOS TO CHANGES IN PALAEOENVIRONMENTS IN THE LOWER-MIDDLE PLEISTOCENE (LUCANIA BASIN, SOUTHERN ITALY)

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ABSTRACT

The Lucania Basin is part of the Bradano Trough, whose internal sectors were subject to continuous subsidence during the Early Pleistocene. This led to the deposition of a muddy sequence with a thickness in excess of 500 m in the Montalbano Jonico area (Lucania). During the Middle Pleistocene, a general shallowing took place, starting from the more internal sectors of the Lucania Basin. The regressive succession exposed in the badland area of Montalbano is candidate of the Early/Middle Pleistocene boundary stratotype. The restored sequence was obtained from selected partial sections correlated by means of nine volcanoclastic layers, each of them characterised by distinct macrofauna assemblages. A gap of unknown thickness (probably a few tens of metres) divides the succession in two intervals: the lower one (A) consists of muddy deposits, the upper one (B) of muddy to sandy deposits, overlain by organogenic calcarenites in the uppermost part. Integrated palaeoecologic, taphonomic and ichnologic analyses were performed in order to reconstruct bathymetric fluctuations and environmental changes, based on biotic responses. Palaeocommunities from the lower interval point to background environments with moderate sedimentation rate, low hydrodynamic level and low oxygen content, punctuated by numerous events of mass deposition. Palaeodepths range from the upper bathyal to the shelf break. Through interval B, palaeodepths range from the shelf break to the inner shelf-nearshore. This interval includes genetically different shell beds. The inferred background environments are characterised by sedimentation rates and water-energy ranging from low to high, under fully aerobic conditions. Like in the lower interval, blanketing events are numerous. Within the general regressive trend, several fifth- and sixth-order cyclothems are recognised throughout the sequence. Vertical changes in the fossil communities within individual cycles indicate changes in water depth that parallel climatic fluctuations, as proved by climatic indicators in interval B. Further, the sea-level curve proposed in the present work matches well the local oxygen isotope curve, but the bathymetric range of some of the cycles suggests a tectonic control superimposed on the climatic influence.

RIASSUNTO - Il bacino lucano fa parte della Fossa Bradanica i cui settori interni furono interessati, nel corso del Pleistocene inferiore, da una subsidenza pressoché continua che determinò l'accumulo di depositi prevalentemente fangosi, affioranti per uno spessore di oltre 500 m nell'area di Montalbano Jonico (Lucania). Nel Pleistocene medio ebbe inizio una fase regressiva a partire dai settori più interni del bacino. La successione regressiva di Montalbano è candidata come stratotipo per il limite Pleistocene inferiore/medio. La sequenza è stata ricostruita sulla base di numerose sezioni parziali, correlate attraverso nove livelli guida vulcanoclastici, a loro volta caratterizzati da associazioni faunistiche diverse. Un'interruzione di entità non valutabile (probabilmente di poche decine di metri) divide la successione in due intervalli: quello inferiore (intervallo A) è rappresentato da depositi fangosi, quello superiore (intervallo B) è costituito da depositi da fangosi a sabbiosi, passanti a calcareniti organogene nella parte sommitale. Analisi paleoecologiche, tafonomiche ed icnologiche, svolte in maniera integrata, sono state utilizzate per dedurre fluttuazioni batimetriche ed evoluzione paleoambientale. Le paleocomunità dell'intervallo inferiore, permettono di dedurre ambienti di background caratterizzati da tasso di sedimentazione generalmente moderato, bassa energia e basso contenuto di ossigeno, sottoposti a numerosi eventi di deposizioni in massa e localizzati a profondità variabili fra il batiale superiore ed il margine di piattaforma. Nell'intervallo B, le paleobatimetrie variano tra il margine di piattaforma e la transizione al nearshore. La presenza di shell beds di varia genesi è tipica di questo intervallo. Gli ambienti di background sono caratterizzati da tasso di sedimentazione e livello di energia idrodinamica da basso ad alto e da buona ossigenazione. Come nell'intervallo inferiore, sono numerosi gli eventi di blanketing. Nell'ambito di una generale tendenza regressiva, sono stati riconosciuti diversi ciclotemi di quinto e sesto ordine; tale ciclicità è evidenziata dai cambiamenti, in verticale, delle associazioni fossili. Il controllo climatico è confermato dalla presenza di indicatori climatici fra le faune dell'intervallo B. Esiste, inoltre, un buon accordo fra i cicli dedotti sulla base del presente studio e la locale curva isotopica dell'ossigeno, anche se l'ampiezza batimetrica di alcuni cicli suggerisce la sovrapposizione di un controllo tettonico a quello climatico.

Keywords: benthic communities, sea level changes, oxygen changes, Early-Middle Pleistocene, Lucania Basin.

Parole chiave: comunità bentoniche, fluttuazioni del livello marino, fluttuazioni nell'ossigenazione, Pleistocene inferiore e medio, Bacino lucano.

1. INTRODUCTION

The Bradano Trough (Fig. 1) is part of a Foredeep Basin, extending from Molise to the Gulf of Taranto. During the Lower Pleistocene a high sedimentation rate and an almost continuous downlift led to the deposition of thick clastic sequences. Particularly, along the Apenninic margin of the Lucania Basin (i.e. the southernmost part of the foredeep), active subsidence

caused the deposition of hemipelagic clays interfingered with muddy turbiditic deposits. A generalized shallowing phase started in the Middle Pleistocene resulting in a relative shallowing of the basin, testified by a shift from upper slope to shelf depositional environments. The Pleistocene marine succession cropping out in the badlands area of Montalbano (Fig. 2) contains fossil assemblages, that clearly indicate short-term cyclic palaeo-bathymetric changes. As a whole, the sequence shows

a general regressive trend, from upper slope to inner shelf deposition (Ciaranfi *et al.*, 1997).

This succession is over 500 m thick and mostly silty-clayey. Except for an isolated section about 15 m thick, referred to the "large" *Gephyrocapsa* biozone, the sequence is referred to the "small" *Gephyrocapsa* biozone and to the *Pseudoemiliana lacunosa* biozone, providing a reference for the selection of the Lower/Middle Pleistocene boundary stratotype (Ciaranfi *et al.* 1997, Maiorano *et al.*, in press).

The present study investigates the palaeoenvironmental evolution inferred from the fossil assemblages in order to discriminate between the cyclically modulated climatic changes, and the tectonic control. A palaeoecological analysis of the macrofauna has been combined with ichnological and taphonomic observations, with the aim of clarify changes in depth, oxygen content, and sedimentation rate. Molluscs have been primarily used due to their good distribution and abundance in the studied succession; nevertheless, environmental data have been also obtained from other groups (e.g., echinoderms, decapods, bryozoans, planktonic gastropods). Such an integrated approach enables a more detailed stratigraphic resolution within a framework of predictable relations between biota and sedimentation dynamics.

2. STRATIGRAPHY

The "Argille Subappennine" Formation crops out in the Montalbano Jonico area in a monoclinal, gently SE-dipping structure. In spite of several mainly N-S and NE-SW trending faults, a continuous succession (Fig. 3) was reconstructed by numerous partial sections over an area of about 2.5 km² (Ciaranfi *et al.*, 2001, fig. 5).

Nine volcanoclastic beds are present (Fig. 2), ranging from a few centimetres to 50 cm in thickness. They consist of pure ashes or volcanoclastic-rich sands, occasionally with pumice clasts as redeposited material. This volcanic material is referred as have been generated by an alkaline under-saturated volcanism (De Rosa in Ciaranfi *et al.*, 1996). The volcanoclastic beds (V1-V9) are associated to benthic palaeocommunities pointing to different bathymetric trends, and this allows them to be used as marker beds (Ciaranfi *et al.*, 2001, fig. 7).

The recognition of alternating darker and lighter intervals (3-6 m thick) all through the section and the presence of a dark, laminated horizon rich in *Delectopecten vitreus* (GMELIN) provided further tools for correlation (Ciaranfi *et al.*, 2001, figs. 5, 7).

A gap of unknown thickness (probably a few tens of metres) divides the restored succession in two intervals. The lower interval (A), about 180 m thick, consists of dark grey,

massive to locally laminated mud (i.e., silty clay to clayey silt), commonly bioturbated and with dispersed macrofossils. The upper interval (B), over 300 m thick, consists of muddy to sandy shelf deposits, generally with abundant macrofauna, and including thick shellbeds. This interval is capped by transgressive continental conglomerates.

3. METHODS

Three main approaches have been used to unravel the depositional evolution of the study sequence.

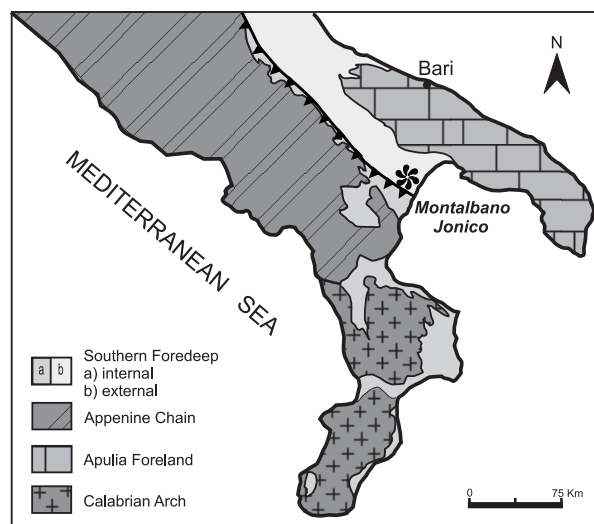


Fig. 1 - Structural map of Southern Italy and location of the Montalbano Jonico sequence.



Fig. 2 - View of the Montalbano Jonico badlands with the thickest volcanoclastic layers V5 (lower arrow) and V7 (upper arrow).

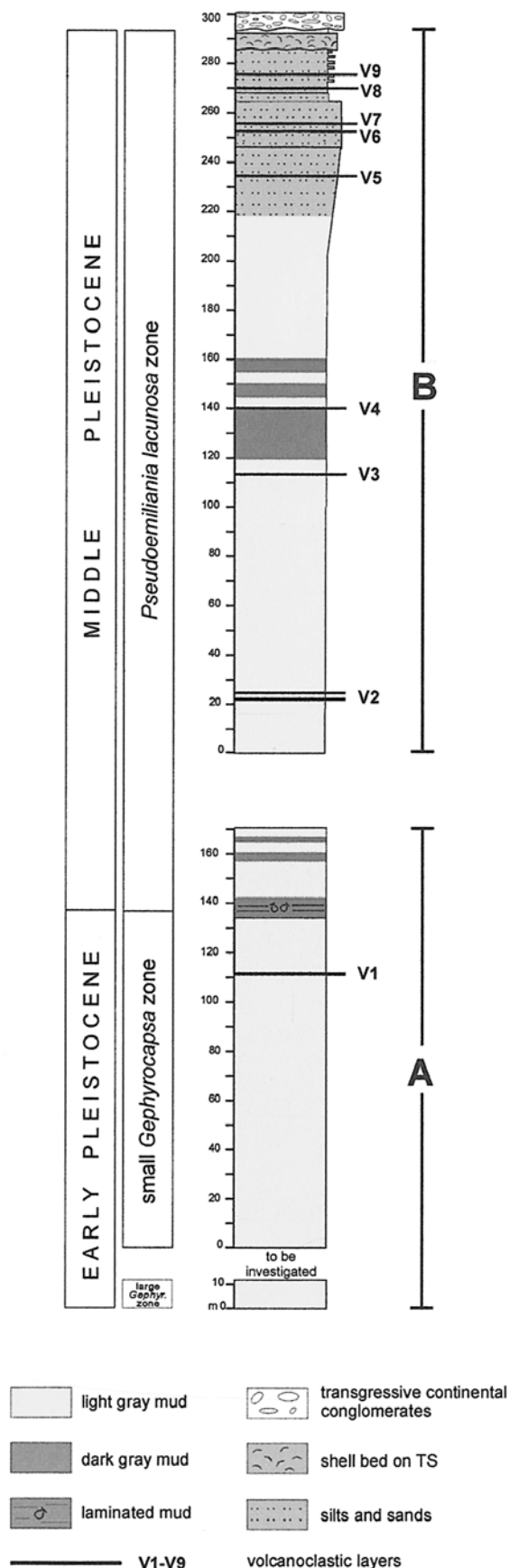


Fig. 3 - Reconstructed sequence of Montalbano Jonico. A and B are the stratigraphic intervals considered in the present work.

Taphonomic observations allowed to infer the main depositional patterns (i.e., background *versus* event depositions, sedimentation rate, etc.). Palaeoichnologic analysis has been useful to infer fluctuations in the oxygen content, and palaeoecology has been mainly applied to reconstruct bathymetric changes.

The main difficulty encountered during this study was the extremely time-consuming field work, due the need of recording in *continuum* taphonomic features, trace fossil distribution, faunal composition and distribution, as well as sedimentological features (raw field data and the list of the taxa are available from the authors on request). The outcrop surface was first cleaned from the weathered part to expose fresh mudrock over a belt 50-100 cm wide throughout the succession. Mudrock was then removed down to a depth of 10-30 cm and examined. Most aragonitic skeletons and, to a less extent, even the calcitic ones, had been weakened by dissolution, frequently fractured by compaction or are preserved as deformed steinkerns. A number of bulk-samples (50-100 kg of sediment) has been taken for a quantitative palaeoecological analysis, although it often turned out that the benthic palaeocommunities (i.e associations) suffered more or less preservational bias. Accordingly, most analyses were carried on a qualitative or semi-quantitative base. Whenever possible, fossil associations were paralleled to Recent Mediterranean biocoenoses or to the Atlantic communities. The Mediterranean biocoenoses were defined (Pérès & Picard, 1964) qualitatively and each of them is identified by a group of characteristic species, irrespective of their abundance. This bionomic approach, successfully adopted in the Mediterranean area, is the most suitable tool for the identification of biotopes (Basso & Corselli, 2002) and for a more precise bathymetric location of palaeocommunities.

4. TAPHONOMY

4.1 Description

Interval A. The main taphonomic feature of this interval is highly dispersed autochthonous fossils. Except for larger specimens, fossils are partly decalcified and preserved as more or less flattened steinkerns, often internally lined by pyrite (Pl. 1, Fig. 1). Pyrite linings, or pyrite steinkerns of the smaller components (Pl. 1, Figs. 4, 7), can occur in several unrelated taxa, e.g. molluscs, echinoids, decapods (Pl. 1, Fig. 10), and foraminifers (Pl. 1, Fig. 14). Fossils, often articulated and without signs of abrasion or encrustation, lack any preferred orientation in plane view and are concordant to bedding plane in transversal view. Numerous loosely packed concentrations have been regarded as intrinsic biogenic concentrations (Kidwell *et al.*, 1986) including three thin, dark, mostly laminated intervals rich in *Delectopecten vitreus*. The mud-pecten shells, concentrated in discontinuous pavements and layers, are pristine, concordant, densely packed, commonly preserved as closed or slightly shifted valves, mostly with an internal pyrite lining, single, and rarely in butterfly position. Extrinsic biogenic concentrations are recorded by several small accumulations of small angular bioclasts due to biological activity (Pl. 2, Fig. 13).

Several obrution events are inferred by completely

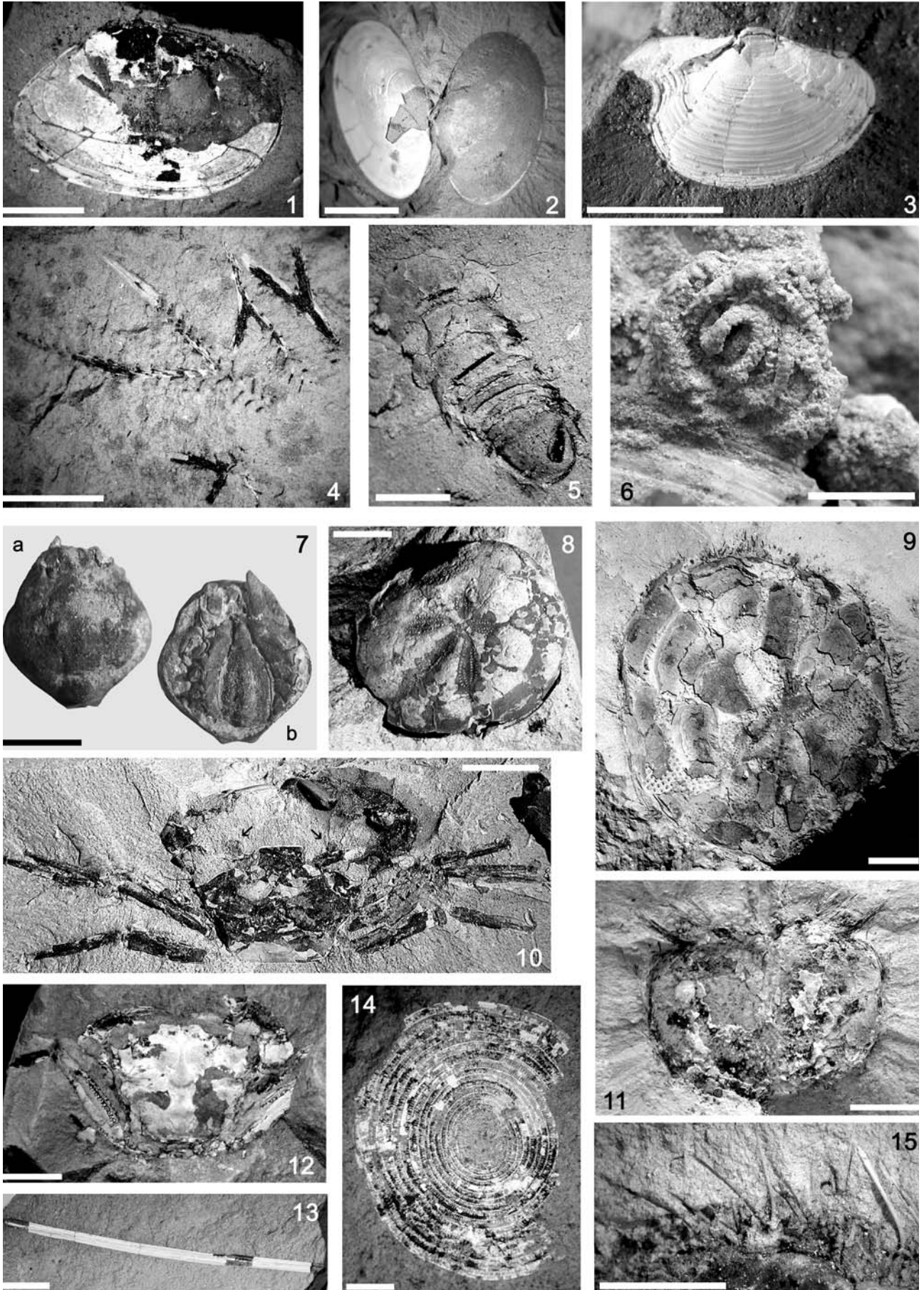


Fig. 1 - *Abra longicallus* (SCACCHI). Articulated, compressed and partially fragmented specimen with internal pyrite lining. Interval A, scale bar 0.5 cm.

Fig. 2 - *Abra nitida* (MÜLLER). Specimen preserved in butterfly position. Interval A, scale bar 0.5 cm.

Fig. 3 - *Bathyspinula excisa* (PHILIPPI). Articulated, compressed and partially fragmented specimen. Interval A, scale bar 0.5 cm.

Fig. 4 - Delicate erect bryozoan colonies with pyrite infilling. Interval B, scale bar 0.5 cm.

Fig. 5 - Undetermined "small shrimp" preserved as a muddy steinkern with minor pyrite mineralization. Interval A, scale bar 2 mm.

Fig. 6 - *Amphiura chiajei* FORBES. Fully articulated specimen with arms closed around the disc. Interval B (top part), scale bar 2 cm.

Fig. 7 - *Ebalia nux* NORMAN & MILNE EDWARDS. Pyritized carapace steinkern with skeletal remains in dorsal (a) and ventral (b) view. This specimen was fully articulated but appendages were lost during the bulk-sample treatment. Interval A, scale bar 2 mm.

Fig. 8 - *Brissopsis lyrifera* (FORBES). Undeformed muddy steinkern. Interval B, scale bar 1 cm.

Figs. 9, 11 - *Brissopsis lyrifera* (FORBES). Strongly compressed and fragmented tests with attached raised spines. Minor pyritization in Fig. 11. Interval A, scale bars 1 cm.

Fig. 10 - *Goneplax rhomboides* (LINNAEUS). Spectacularly preserved and fully pyritized specimen. Note the eyestalks in the cephalic region (arrows). Interval B, scale bar 0.5 cm.

Fig. 12 - *Geryon* sp. Fully articulated specimen with pyrite infilling in the smaller appendage cavities. Interval A, scale bar 1 cm.

Fig. 13 - *Funiculina quadrangularis* (PALLAS). Long fragment with inner pyrite lining. Interval A, scale bar 1 cm.

Fig. 14 - *Discospirina italica* (COSTA). Complete test with pyritized chamber infilling. Interval A, scale bar 2 mm.

Fig. 15 - *Brissopsis lyrifera* (FORBES). Detail of articulated and raised spines. Interval A, scale bar 0.5 cm.

articulated crustacean skeletons and by strongly flattened infaunal echinoid tests, with some diagenetic features, such as pyritization, due to decay of organic matter. Another evidence of obrution events comes from obliquely embedded and deformed echinoid tests, occasionally preserved with articulated and raised spines, which are signs of escape attempts (Pl. 1, Figs. 9, 11, 15).

Erosional, reddish silt-bearing surfaces with or without dispersed shells indicate episodic rise of water-energy. Rare, poorly evident, thin lenses of dispersed to densely-packed biogenic elements occur as sedimentological concentrations, mainly consisting of hard parts of benthic organisms (e.g., small bivalves and large foraminifers, Pl. 2, Fig. 3), pteropods (Pl. 2, Fig. 1), terrestrial leaves (Pl. 2, Fig. 6) and *Posidonia oceanica* (LINNAEUS) leaves (Pl. 2, Figs. 2, 5). Two, 10-20 cm thick, graded beds with erosional base occur in the uppermost part of interval A. They are mud-supported, rhodolith-rich accumulations including large and abraded shell fragments of shelf origin, testifying mass deposition events.

Interval B. Fossils are more abundant and better preserved than in the lower interval, but are still dispersed. The hardparts of epifaunal organisms may be encrusted, moderately bioeroded and locally abraded. The degree of disarticulation is generally low to medium, except for some shell beds in the upper part of the sequence, where bivalves are highly disarticulated and exhibit a moderate degree of fragmentation. Burial events by muddy plumes are numerous and well documented by the same biostratigraphic signatures as in the lower interval associated with common pyrite steinkerns (e.g. minute gastropods, bryozoans, foraminifer tests) or patinas (e.g. pyrite coatings of echinoid spines, internal linings of bivalves, etc.).

Different genetic types of shell beds occur. Some

intrinsic biogenic concentrations, such as the associations of erect bryozoans-small pectinids, *Protula* worms-celleporiform bryozoans, and *Neopycnodonte*, record burial episodes of sessile palaeocommunities. Commonly, the appearance of these concentrations is abrupt, without any evident basal erosional surface. In rare cases, the erect-bryozoan shell beds are complex, showing a thin, sharp-based layer consisting of densely packed fragments of delicate branching, mud-tolerant bryozoans, overlain by clumps of erect bryozoans. Below V3 (Fig. 3), the erect bryozoan-small pectinid shell beds alternate with less fossiliferous intervals containing loosely packed to dispersed *Ditrupa* tubes or, more rarely, articulated shells of *Corbula* (in both cases without preferred orientations). Rare extrinsic biogenic concentrations, produced by scavengers or deposit-feeders, were encountered.

In other cases the original concentration has been partially distorted by high-energy events (e.g. *Hiatella arctica* (LINNAEUS) and *Aequipecten opercularis*-bearing beds), resulting in mixed concentrations. Bivalve remains are densely packed and concordant to bedding, both articulated (closed shells to butterfly position) and disarticulated, complete, and the pectinids are also partially encrusted.

A single case of diagenetic concentration was encountered about 15 m above the V2 volcanoclastic layer. It consists of a population of *Isocardia*, whose shells form a loosely packed pavement. This concentration resulted from compression, as indicated by the strong deformation and fragmentation of closed valves.

Pure sedimentologic concentrations, formed by storm-induced currents, are represented by small lenses of bioclasts, sharp-based silty layers and, upwards, by discontinuous shell pavements (Fig. 4) and by few complex shell beds resulting from multiple events. These

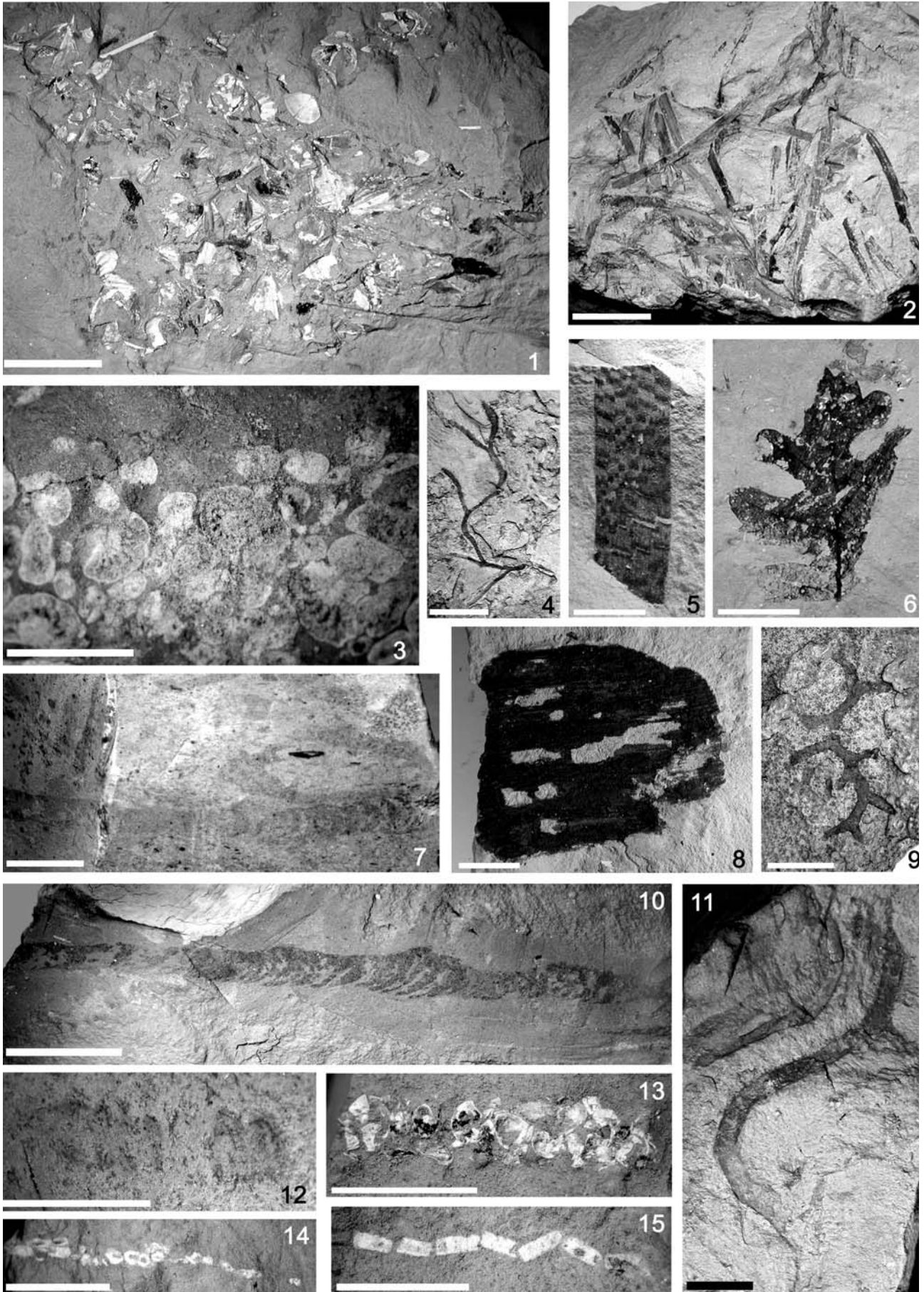


Fig. 1 - Winnowed concentration, mostly consisting of pteropod shells. The dark spots are plant remains. Interval A, scale bar 2 cm.

Fig. 2 - Winnowed concentration of *Posidonia oceanica* (LINNAEUS) leaves. Interval A, scale bar 1 cm.

Fig. 3 - Winnowed concentration of *Cyclammina cancellata* BRADY tests. Interval A, scale bar 0.5 cm.

Fig. 4 - *Chondrites targionii* (BRONGNIART). Interval A, scale bar 1 cm.

Fig. 5 - Leaf fragment of *Posidonia oceanica* (LINNAEUS). Interval A, scale bar 1 cm.

Fig. 6 - *Quercus* sp. leaf. Interval A, scale bar 1 cm.

Figs 7, 10 - Cross-sections of *Zoophycos* spreiten. Interval A, scale bar 1 cm.

Fig. 8 - *Teredolites* isp. in a carbonized wood. Interval A, scale bar 1 cm.

Fig. 9 - *Chondrites patulus* FISCHER-OOSTER. Interval A, scale bar 1 cm.

Fig. 11 - Track-like trace. Interval B, scale bar 1 cm.

Fig. 12 - *Cladichnus* isp. (detail of a polished surface). Interval A, scale bar 0.5 cm.

Fig. 13 - Burrow filled with shell debris (extrinsic concentration). Interval A, scale bar 0.5 cm.

Figs. 14, 15 - Problematica. Interval A, scale bars 0.5 cm.

thick shell beds, occurring in sandy-silty intervals, mainly consist of *Aequipecten opercularis* (LINNAEUS) valves which are closely-packed, highly disarticulated, convex-upward, sometimes stacked, broken and encrusted. Moreover, scattered *Arctica islandica* (LINNAEUS) and ophiuroid lenses occur in the coarser interval. The bivalves consist of articulated and empty valves, and the *Amphiura chjaiei* (FORBES) skeletons are preserved perfectly articulated and with arms closed around the disc (Pl. 1, Fig. 6).

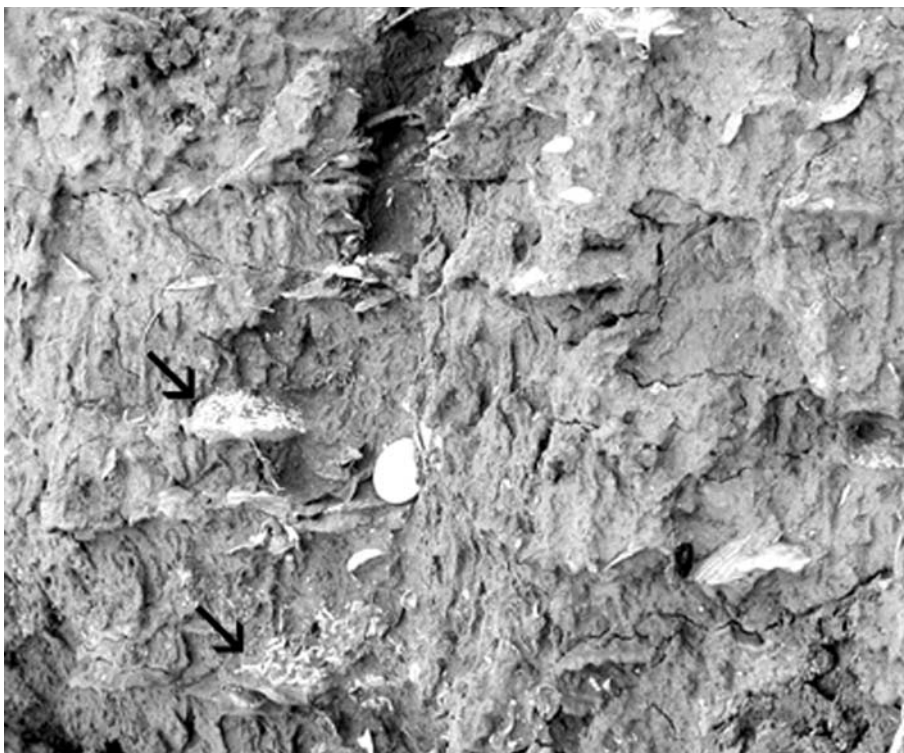


Fig. 4 – Interval B (upper part). Discontinuous pavements of convex-up valves of *Aequipecten opercularis*. Some of them are heavily encrusted by corallineans and/or serpulids (arrows).

4.2 Interpretation

In most cases, background and episodic processes can be clearly distinguished (discrete signatures of Speyer & Brett, 1991). However, in the upper interval, the taphonomic features reflect more complex interactions, mostly due to higher energy settings (on average) and to more diverse biostratigraphic responses to dynamics of sedimentation.

The biostratigraphic signatures in the lower interval allow to infer low-energy background palaeoenvironments located well below the maximum storm wave base and characterized by low to moderate sedimentation rates, soft and, less commonly, soupy substrates. This is clear evidence of frequent mud blanketing events by deposition of muddy plumes and rarer winnowing episodes by weak bottom currents. The diagenetic features, particularly the common pyrite linings and rarer pyrite cores, suggest low dysaerobic conditions within the sediment (Brett & Baird, 1986), not always related to burial events. In the upper interval, the biostratigraphic signatures prevail over the diagenetic ones, thus allowing a greater accuracy when inferring palaeobathymetry. Low- and high-energy taphofacies - the latter indicative of settings located above the maximum storm wave base - alternate. Deeper settings, where taphonomic signatures are less evident and distinctive, are better defined on palaeoecological grounds. The higher energy

taphofacies are indicative of middle and inner shelf settings. Numerous winnowing episodes led to firmer substrates suitable for the settlement of sessile fast-growing bryozoans and their epibionts, which characterise this community. In few cases, event-concentrations of mud-related delicate bryozoans provided the firm substrate colonized by the erect bryozoans (taphonomic feedback). In the uppermost part of sequence, taphonomic features suggest inner shelf, maybe transitional to shoreface, environments. In particular, the *Arctica* and *Amphiura* lenses testify reworking of both dead and living benthic organisms and their catastrophic burials during transgression culminating in a marly sediment with *Neopycnodonte* clumps. The stratigraphic distribution of taphofacies points to clear short-term bathymetric fluctuations, within a general shallowing trend.

Levels with abundant pyrite steinkerns within small skeletal cavities suggests episodic dysaerobic microenvironments due to rapid burial of organic material.

5. PALAEOICHOLOGY

5.1 Description

Interval A. This interval is generally bioturbated with a highly variable bioturbation index (nil to mottled). Distinctive trace fossils are visible only when they contrast in colour with the host rock. Where the sediment is massive, mottling is doubtful, though more than likely. Distribution of ichnotaxa and bioturbation index (BI) are reported in Appendix. All through interval A, a few centimetres-thick layers, highly bioturbated by *Chondrites intricatus* (BROGNIART) may occur near silty surfaces with taphonomic evidence of burial events. In the lower part, some intervals up to few metres thick are characterised by dispersed and diverse ichnotaxa (2-4 BI): *Chondrites* (Pl. 2, Figs. 4, 9), *Cladichnus* (Pl. 2, Fig. 12) and subordinatedly *Alcyonidiopsis* are dominant. In the middle part, *Chondrites-Zoophycos* intervals may alternate with massive (mottled?) beds, or with *Phycosiphon*-bearing strata (BI 5). *Zoophycos* (Pl. 2, Figs. 7, 10), which has a discontinuous stratigraphic occurrence, disappears a few metres above the V2 layer (Appendix). Poorly bioturbated intervals (BI 2 to 3) with small *Thalassinoides*, *Planolites* and undetermined track-like traces (Pl. 2, Fig. 11) are also present. In the upper part, the degree of bioturbation is generally lower and ichnotaxa are mostly represented by different *Chondrites* ichnotaxa.

In three cases, *Chondrites intricatus* is markedly thin and dispersed until its disappearance, which happens in dark, laminated *Delectopecten vitreus*-rich sediment (Fig. 5). The thickest of these intervals (Fig. 6) coincides with the first occurrence of *Gephyrocapsa* sp. 3 (upper part of the interval A).

Interval B. Bioturbation is poorly defined, except for the volcanoclastic beds, where *Scolicia* (BI 3-5) or *Thalassinoides* (BI 2-3), due to the highly contrasting colour, are clearly evident. More generally, *Thalassinoides* and *Planolites*, sometimes associated with track-like traces, are present, although uncommonly. Bioerosion is abundant in the middle-upper part of the sequence and, more generally, in the shallower settings.

5.1 Interpretation

Ichnologic features of interval A (i.e., high abun-

dance and diversity of chemichnia) point to general dysoxic conditions in the muddy sediment, except for the well oxygenated *Phycosiphon*-rich massive package. An increasing oxygen content in the bottom water and/or in the pore water may be inferred by the decrease of chemichnia diversity, as well as by the increased size of traces in the middle-upper part of the sequence. *Zoophycos* has been found in regressive tracts (inferred by the palaeoecological analysis), thus confirming its relation with raising sedimentation rates (Brett, 1998). The thin layers with minute *Ch. intricatus* that occur throughout the muddy interval, are interpreted as colonization episodes triggered by abrupt burial of organic matter.

The aforementioned, laminated, *Delectopecten vitreus*-rich sediment are an interesting case, since this situation records the exaerobic biofacies of Savdra & Bottjer (1987): i.e. depletion of oxygen and sealing of the mud bottom by biomats allow specialized chemosymbiotic epifauna to live in an abenthic regime (Savdra, *et al.*, 1991). The bacterial mats might have provided a suitable bottom for the epibyssate life habit of *D. vitreus*. This hypothesis envisages *D. vitreus* as a facultative chemosymbiotic organism, although no data are found in the literature on this habit. However, Hickman (1984) reports a deep-water facies, characterised by mud-pectens, in laminated, organic matter-rich sediments. A second hypothesis suggests colonization by opportunistic shelled organisms during short oxic pulses (Sageman *et al.*, 1991), but the absence of any kind of infauna remains unexplained.

For interval A, an oxygen curve (Fig. 5) has been reconstructed, based on the vertical distribution of oxygen-related ichnoassociations. For the *D. vitreus* interval containing the first occurrence of *Gephyrocapsa* sp.3, a more detailed curve (Fig. 6) was constructed based also on macrobenthic organisms sensitive to oxygen conditions.

The ichnologic features of interval B point to fully aerobic conditions. Rare cases of moderate dysaerobic conditions are suggested by the occurrence of abundant *Alcyonidiopsis* and small concentrations of faecal pellets, which may be related to local obrution events (blanketing).

6. PALAEOECOLOGY

6.1 Description

Interval A. Most of the invertebrate macrofauna consists of dispersed molluscs and, subordinately, of burrowing echinoids, macroforaminifers, decapods, and octocorals. The most typical bathyal molluscs are *Bathyspinula excisa* (PHILIPPI) (Pl. 1, Fig. 3), *Katadesmia confusa* (SEGUENZA), *Delectopecten vitreus*, *Abra longicallus* (SCACCHI) (Pl. 1, Fig. 1), *Dentalium agile* SARRS, and *Entalina tetragona* (BROCCHI), taxa also known from other coeval bathyal sequences (Di Geronimo & La Perna, 1997, Di Geronimo *et al.*, 1997). In the short basal section, these species are particularly common, but they become more and more dispersed upwards until they are replaced by a monotypic *Chondrites intricatus* (BI 4-5) association. In the remaining part of the interval, the strictly bathyal species and their palaeo-communities exhibit a somewhat discontinuous vertical

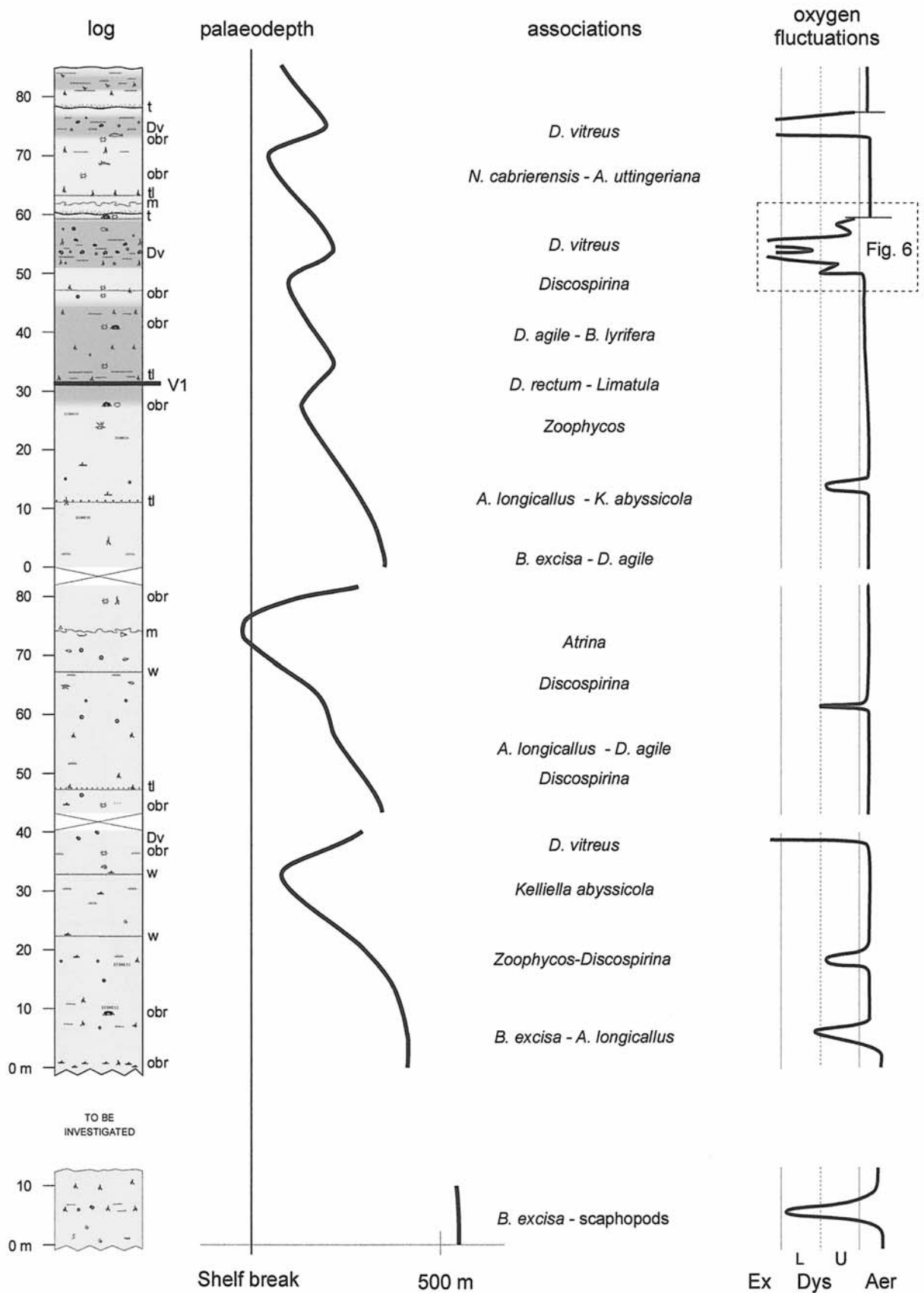


Fig. 5 - Interval A. Palaeobathymetric curve, main palaeocommunities and oxygen curve. Each palaeo-community is named after the most typical faunal component(s). Oxygenation levels in the bottom water are according to Bromley (1996, fig. 12.1): Aer = aerobic, Dys = dysaerobic (Upper and Lower), Ex = exaerobic. Log abbreviations: Dv = Delectopecten shell-beds, m = mottling, obr = obrutions (main events), t = turbidites, tl = thin muddy turbidites (main events), w = winnowing (main events).

distribution, alternating with taxa characteristic of shallower slope facies such as *Aporrhais uttingerianus* (RISSE), *A. serresianus* (MICHAUD), *Nassarius cabrierensis* (FONTANNES), *Kelliella abyssicola* (FORBES), *Parvicardium minimum* (PHILIPPI), *Hyalopecten similis* (LASKEY), and *Fissidentalium rectum* (GMELIN). *D. vitreus* exhibits a peculiar distribution. It is uncommon throughout interval A, but forms closely packed concentrations in three cases (see taphonomy), giving rise to a monotypic palaeocommunity preserved in laminated layers. Shells mostly belong to fully grown individuals. This species belongs to a group of thin-shelled pectinids with a deep-water distribution on muddy bottoms and facultative epibyssate habits. There is a certain systematic confusion about *D. vitreus* (GMELIN, 1791) due to the supposed existence of a distinct species, *D. abyssorum* (SARS, 1878), which would have slightly different ecologic needs. Robba (1996) kept these two species distinct, but there is no general agreement about this distinction. In the present paper, both taxa are considered as a single mud-tolerant species referred to as *D. vitreus*.

Echinoids are almost exclusively represented by *Brissopsis lyrifera* (FORBES). Decapods include the bathyal species *Ebalia nux* NORMAN & MILNE EDWARDS and the eurybathic *Goneplax rhomboides* (LINNAEUS). In some thin intervals (1-2 m), a monospecific association of the macroforaminifer *Discospirina italica* (COSTA) (Pl. 1, Fig. 14) occurs as loosely packed concentrations. Bathyal octocorals are recorded by rare remains of *Funiculina quadrangularis* (PALLAS) (Pl. 1, Fig. 13) and *Isidella elongata* (ESPER), the latter being locally common.

Interval B. Fauna from this interval is richer and referable to several palaeocommunities of clearly different bathymetric settings. However, changes in palaeocommunity composition are mostly gradual, making any clear-cut separation of different palaeocommunities rather difficult. Moreover, the biotic response to environmental changes, particularly to edaphic factors, is so marked in shelf settings, that fossil associations highly differ from each other, and it is neither possible to outline general compositional features, nor to describe each community one by one. In this paper, a few case studies

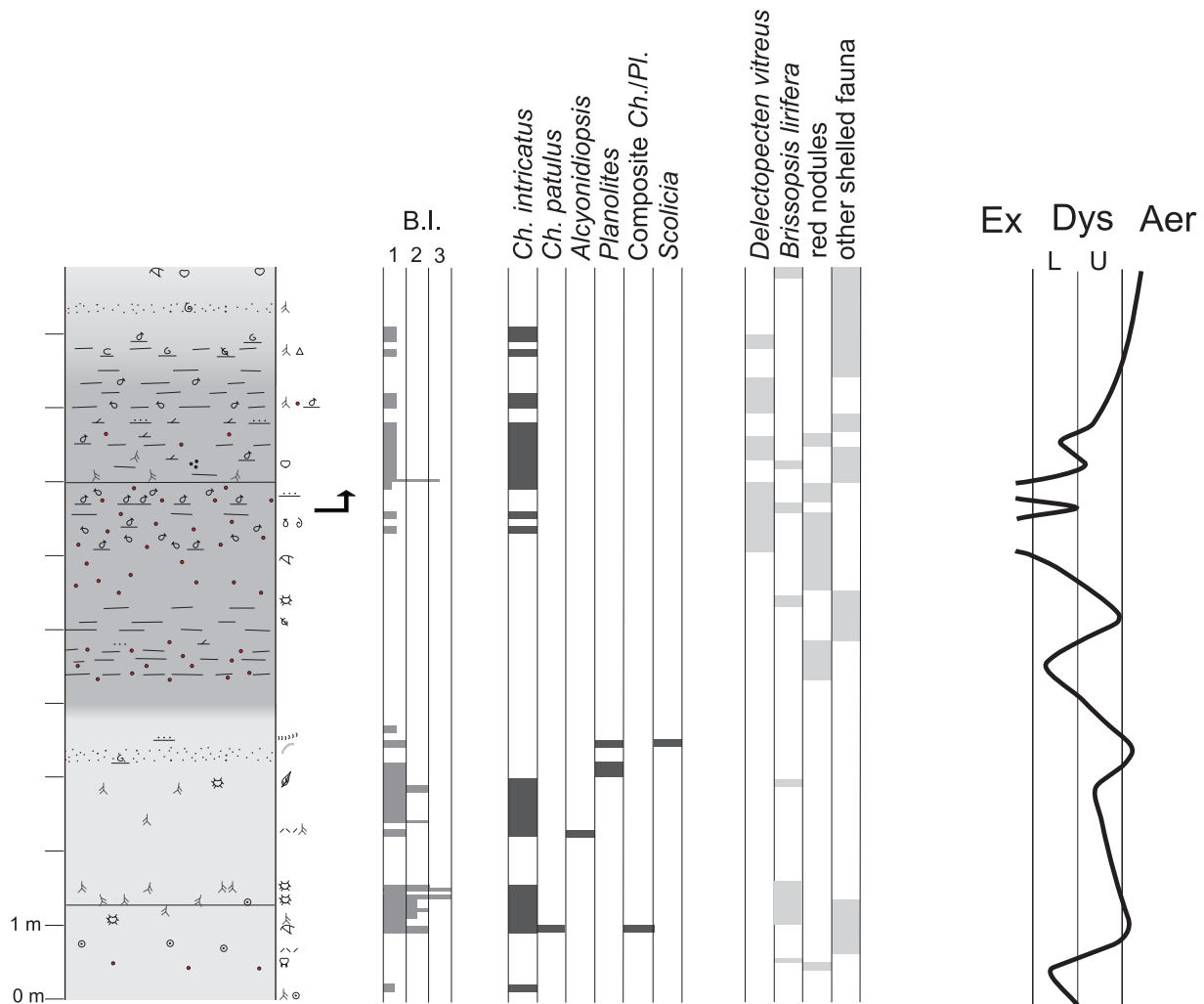


Fig. 6 - Interval A. Oxygen curve for the *Delectopecten vitreus* package containing the FO (arrow) of the calcareous nannofossil *Gephyrocapsa* sp. 3 (sensu Rio, 1983). The curve is based on the vertical distribution of oxygen-related trace fossils and on other faunistic and taphonomic features.

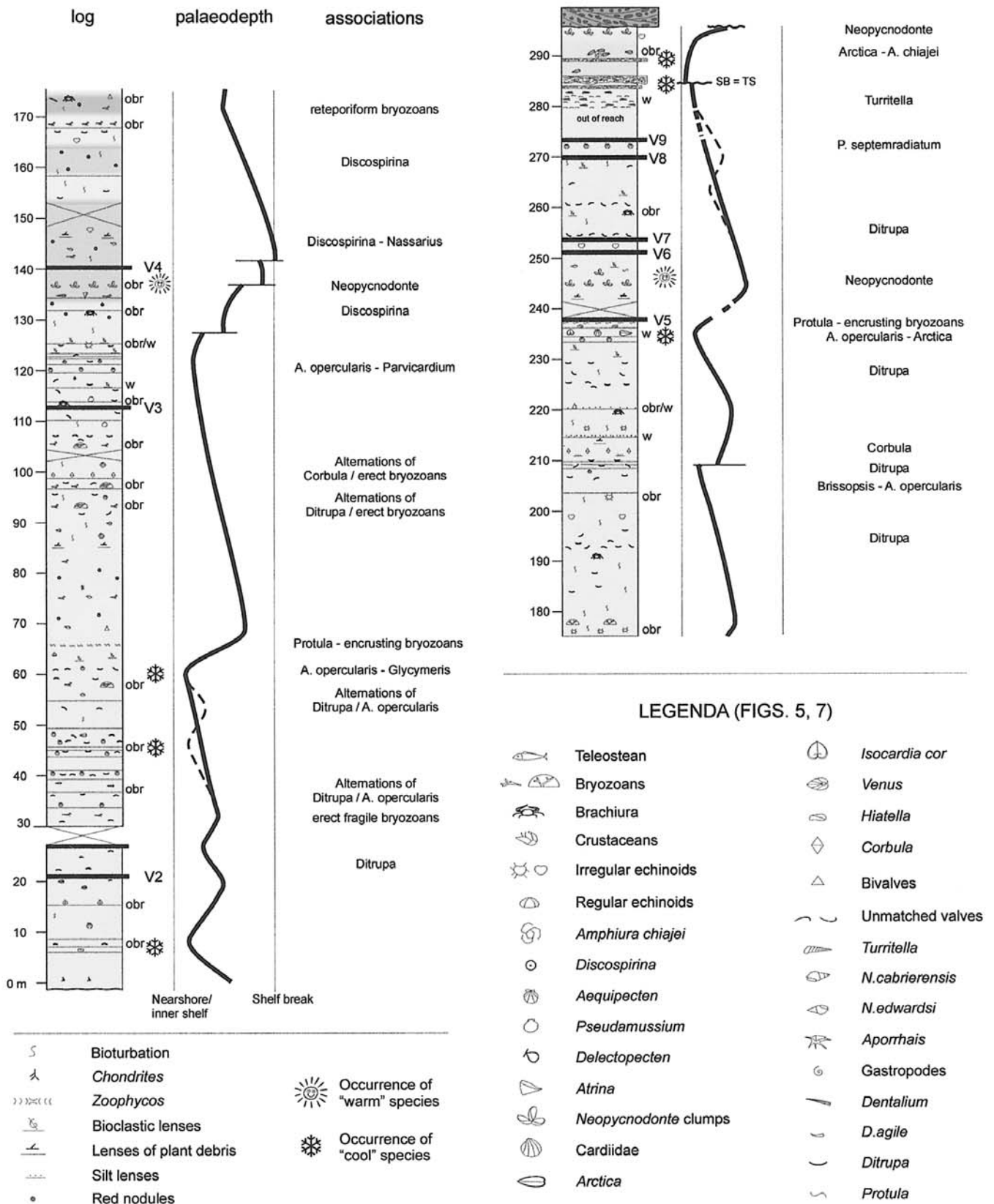


Fig. 7 - Interval B. Palaeobathymetric curve and main associations. Each association is named after the most typical faunal component(s). Log abbreviations: Dv = Delectopecten shell beds, m = mottling, obr = obrutions (main events), t = turbidites, w = winnowing (main events), BS = sequence boundary, TS = transgressive surface. Symbols: sun = interglacial peak, snowflake= glacial peak.

are reported to characterise the main environments, related to sea-level fluctuations and encompassing different system tracts of sequence stratigraphy.

A polyspecific middle-inner shelf molluscan palaeocommunity (between V2 and V3) contains *Aequipecten opercularis* (LINNAEUS), *Venus multilamella* (LAMARCK), *Plagiocardium papillosum* (POLI), *Turritella ex gr. communis* RISSO, *T. mediterranea* MONTEROSATO, trochids (commonly encrusted by bryozoans), and small rhodoliths. Below V5, another similar community is represented by *Arctica islandica*, *Isocardia cor* (LINNAEUS), large cardiids, and *A. opercularis*. Near the top of the sequence, a sharp environmental change is recorded by a middle shelf muddy bottom palaeocommunity (*Turritella ex gr. communis* association) abruptly replaced by an inner shelf-shoreface sandy bottom palaeocommunity (*A. opercularis*-*A. islandica* association). The latter is recorded by parautochthonous elements packed in a thick shell bed with complex internal structure, overlying an irregular erosional surface.

A *Protula*-encrusting bryozoan palaeocommunity is referred to outer shelf low-stress biotopes with cohesive substrates and low sedimentation rates. Upwards, near the V5 layers, the *Protula*-bryozoan palaeocommunity evolves into a palaeocommunity characterised by large-sized *Hiatella arctica*, a weak borer in stiff sediments. This ecological succession culminates with the *Neopycnodonte cochlear* palaeocommunity. *Nassarius edwardsi* (P.FISCHER) is an associated species which, in this upper part of the succession, replaces the deeper taxon *N. cabrierensis*.

Another case study are erect bryozoan-small pectinid palaeocommunities, dominated by adeoniform and retroporiform growth forms. They alternate with opportunistic soft-bottom palaeocommunities characterised by *Ditrupa arietina* (MÜLLER) or *Corbula gibba* (OLIVI).

6.2 Interpretation

In the Montalbano succession, palaeocommunities and their stratigraphic successions provide the best tool to identify cyclic sea-level changes and key surfaces of the short-time cyclothems. Such changes are recorded throughout the succession.

Benthic palaeocommunities

from interval A are clearly indicative of upper slope environments, with a maximum depth of about 500 m. Only near the middle part of this interval, the fauna suggests a shelf-margin setting (Fig. 5). Within this bathymetric range, several cyclic fluctuations involving changes in sedimentation rate and substrate consistency, are recorded. In these deep water settings, the fluctuations are mainly recognised basing on the relative dominance or abundance of typically bathyal species vs shelf margin and deep shelf species in the associations.

Palaeocommunities from interval B record outer-to inner-shelf palaeocommunities, except for a *Nassarius cabrierensis*-dominated palaeocommunity, located a few metres above the volcanoclastic layer V4, which suggests a transitional-to-slope setting, as is also indicated by the presence of rare bathyal species. Like in the lower interval, palaeoecological evidence indicates cyclic sea-level changes (Fig. 7), by a distinct change of shelf palaeocommunities. The occurrence, in the shallower phases, of the so-called "Boreal Guests" *Arctica islandica* and *Pseudamussium septemradiatum* (MÜLLER) together with numerous *Hiatella arctica* specimens, whose size is similar to that of the Recent North Atlantic ones, suggests a climatic control for these fluctuations.

Sea-level lowstands are recorded by the polyspecific molluscan palaeocommunities occurring in thin horizons between V2 and V3 and below V5. Near the top, the lowstand is represented by an erosional surface (TS, Fig. 8) capped by a thick shell-rich bed.

During deepening phases, *Protula* worms-celleporiform bryozoan palaeocommunities flourished in outer



Fig. 8 – Interval B (top). A = silts with *Turritella ex gr. communis*. B = simple shell bed with *Arctica islandica*, *Aequipecten opercularis* and *T. ex gr. communis*. SB = sequence boundary. TS = transgressive surface. C = complex shell bed. D = sands with *A. islandica* and *Amphiura chiajei* lenses.

shelf low-stress biotopes characterised by cohesive substrates and a low sedimentation rate. Near the V5 layers, the ecological replacement starting with faunas indicative of inner shelf environments, culminates with the *Neopycnodonte cochlear* palaeocommunity that indicates the maximum flooding surface. The inversion of the trend up section is pointed out by gradually shallower palaeocommunities related to higher sedimentation rates. The *Neopycnodonte* palaeocommunity is recurrent in interval B and highlights the positions of the maximum flooding surfaces in several cyclothem.

Conversely, shallowing phases are highlighted by the *Ditrupa arietina* or *Corbula gibba* opportunistic communities that flourish in condition of high turbidity (Di Geronimo & Robba, 1989) and high sedimentation rate and inhabit soupy-soft substrates. These conditions are common during the late highstand system tracts. The frequent intercalations within these communities of erect-bryozoan communities (that have contrasting ecological needs) can be explained by periodic winnowing that removed the soupy boundary layer and exposed firmer substrates suitable for such sessile communities of fast-growing organisms. The vertical succession of communities confirms the upwards shallowing trend.

7. DISCUSSION

Changes in the taphonomic and palaeoecological features allowed to infer a sea-level curve for the Early-Middle Pleistocene (Figs. 5, 7). The curve is composed of short-term fifth- (100 Ka) and sixth-order (40Ka) cycles, as evaluated from the local oxygen isotope curve (Brilli in D'Alessandro *et al.*, 2002). The bathymetric range of cycles is about 100 m, although in some cases it considerably exceeds (over 200 m) this value.

Throughout interval B, the climatic control is proved by the occurrence of "cool water" molluscs indicators in the shallower phases and, occasionally, by "warm water" indicators in the deeper ones, i.e. two teleosteans (Girone & Varola, 2001) and a serpulid (Sanfilippo, in press). Conversely, no palaeoclimatic indicator occurs in the lower interval. However, there is a good match between the sea level curve and the oxygen isotope curve, which at present does not cover all the sequence. The same type of control can be then supposed for the whole sequence of Montalbano.

However, in some intervals, the bathymetric range is too high to be exclusively ascribed to climatic effects; therefore, a tectonic control must be an additional factor. The best example occurs near the volcanoclastic layer V4, where the bathymetric range exceeds 200 m and the kind of palaeocommunities - i.e., palaeocommunities dominated by attached forms preserved as loosely to closely packed concentrations *versus* palaeocommunities of mostly vagile elements, occurring as dispersed assemblages - are indicative of a low and high sedimentation rate respectively. The high sedimentation rate events occur during abrupt deepening phases (as inferred by the palaeocommunity succession) or follow them, thus contrasting with the expected sedimentation pattern during the transgressive system tract. This can be attributed to uplift of the continental areas surrounding the foredeep basin and resulting in increased terrigenous supply. Hence, the "cycle" is exalted in magnitude

and broken down in tectonically controlled steps.

In interval A, palaeobathymetric ranges of sea level fluctuations are less detailed due to the intrinsic features of both deep-water fauna and biotopes. Anyway, in analogy of the upper interval, the largest cycles are also regarded as partially tectonic-controlled.

The ichnological assemblages from the lower interval allowed to draw a curve of changes in the bottom water oxygen content (Figs. 5, 6). It is worth noticing that the dysaerobic/anaerobic events occur during maximum flooding phases, as a result of the decreased oxygen supply to the bottom water during interglacial periods.

The present study also allows to elucidate the palaeoecological significance of two types of associations hitherto unknown in the literature, i.e. the *Delectopecten vitreus* and the *Discospirina italica* communities. In the studied sequence, *D. vitreus* is commonly present in muddy bottom, bathyal palaeocommunities, as is known in the literature (D'Alessandro & De Marco, 1993; Robba, 1996; Di Geronimo & La Perna, 1997), but this species, when recorded in monotypic palaeocommunities, seems to be related to exaerobic conditions, as suggested by ichnofossil analysis. The "exaerobic model" may be thus adequate to explain the absence of all kind of infauna, including the *Chondrites-makers*. This hypothesis would entail a facultative chemosymbiotic feeding mode for *D. vitreus*.

Discospirina italica is an unusual deep-water macroforaminifer (Adams, 1973, 1976; Hottinger, pers. comm., 2001), whose ecology is poorly known. Monotypic associations of *Discospirina*, in the studied sequence, have been found during the early highstands, in slope (interval A) and outer shelf/slope settings, characterising an increased sedimentation rate related to shallowing.

There is an overall good match between the inferred cycles and those obtained from other palaeontological studies, although at different degree of resolution. Benthic foraminifers provide a detailed reconstruction of bathymetric changes in particular for the upper interval, while the same group allows a better resolution of oxygen changes through the interval A (Stefanelli, in press), giving a curve more or less equivalent to that inferred by the ichnofossils. Fish otoliths are a fairly good bathymetric indicators in the deeper settings (Girone, 2000). Tapho-facies analysis was particularly useful in shallower environments (Soldani, 2000; Ciaranfi *et al.*, 2001).

The integrated palaeontological analyses applied to the Montalbano sequence support the statement by Brett (1998) that fossils provide a good tool to identify key surfaces and sedimentation dynamics within sequences, while the sequence stratigraphy model provides a predictive framework to interpret probable causes of biotic changes.

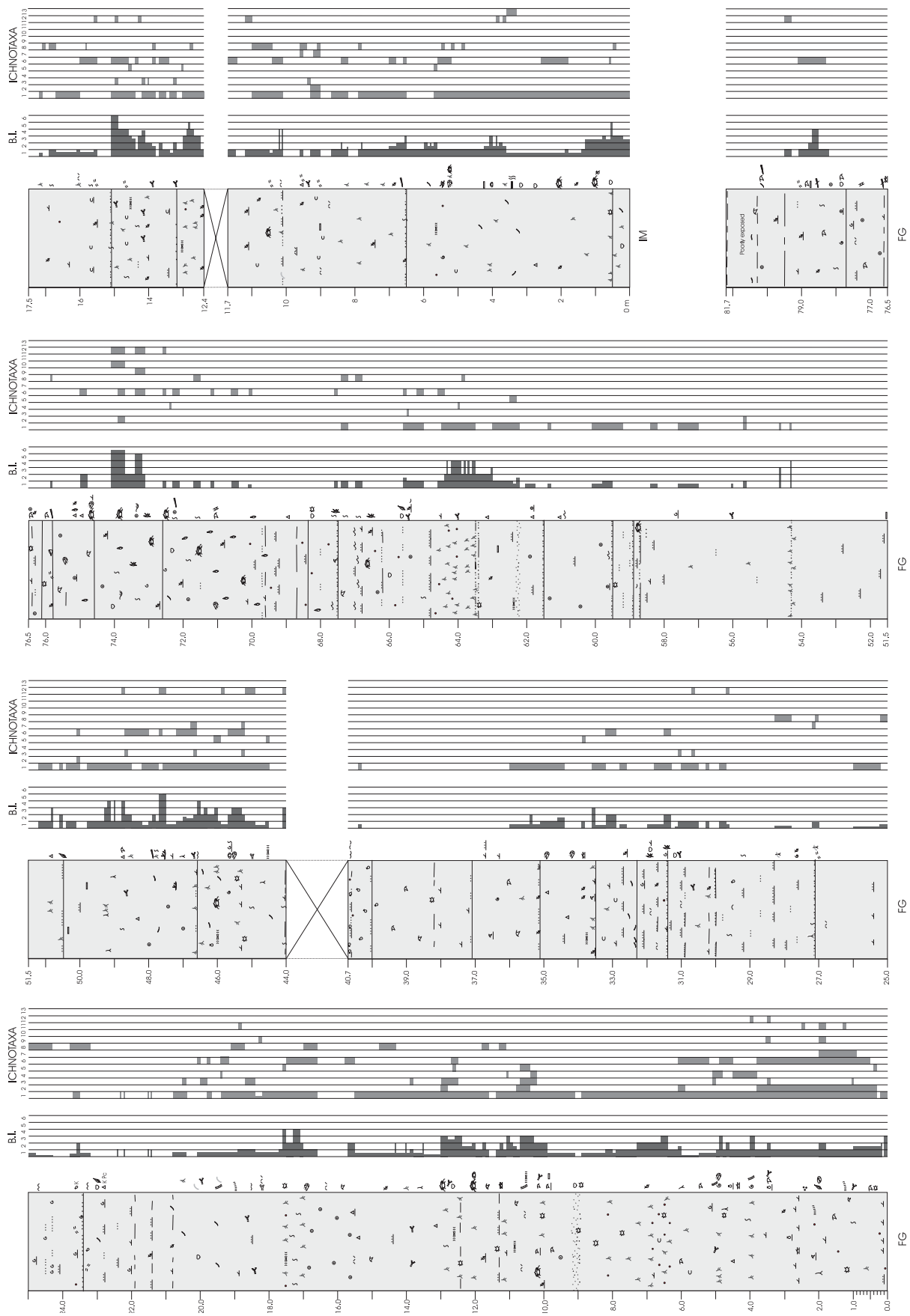
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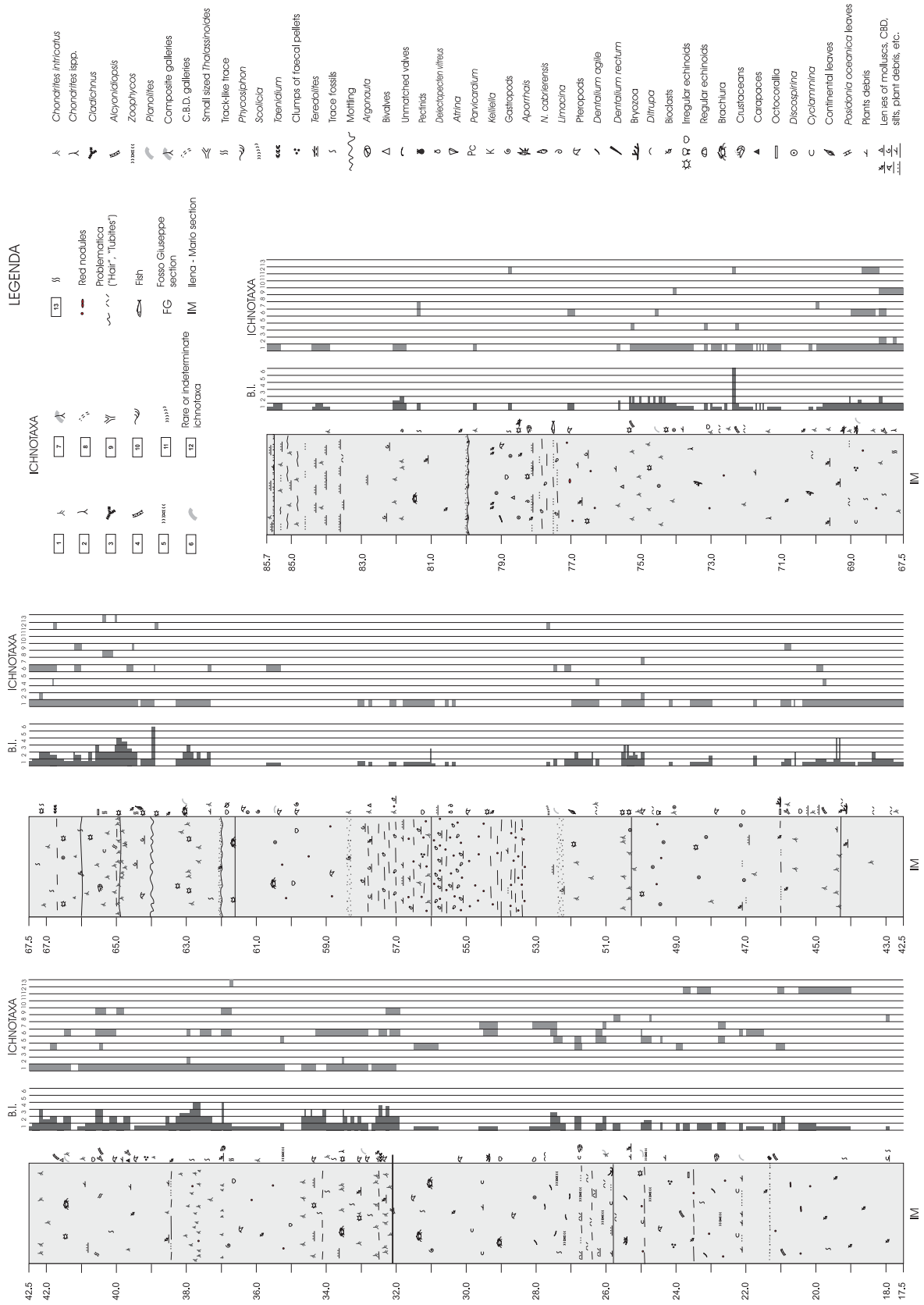
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Appendix



Appendix



Appendix - Bioturbation index (BI) and distribution of ichnotaxa in interval A. - *Indice di bioturbazione (BI) e distribuzione degli ichnotaxa nell'intervallo A*