

Benthic and planktonic Foraminifera of the Paleogene Epiligurian succession (Northern Apennines, Italy): a tool for paleobathymetric reconstruction

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ABSTRACT – A paleobathymetric reconstruction, based on benthic and planktonic foraminiferal assemblages, has been carried out for the Epiligurian Succession of the Northern Apennines chain (Middle Eocene-Early Miocene).

The paleobathymetric interpretation has been obtained from the integration and comparison of four parameters used separately by previous authors: i) Plankton/Plankton+Benthos ratio; ii) benthic morphogroups, both infaunal and epifaunal, iii) planktonic "paleobathymetric indexes"; iv) relative abundance of benthic index species belonging to depth-dependent habitats. The applied method has been carefully discussed with respect to the studied geological setting. Moreover, the possible impact of taphonomic processes, such as selective preservation, transport and redeposition, has been evaluated. It resulted absent or limited and than, no influential on the reliability of the obtained data.

The main results can be summarized as follows: an overall shallowing upwards trend is observed; in particular, a lower bathyal depth (over 2000 m to about 1000 m) has been determined for the "varicoloured facies" of the Monte Piano Marls. Lower to middle bathyal depths (about 1000 m to 600 m) have been obtained for the "grey facies" of the same formation and for the sandstones of the Ranzano Fm. Finally, the Antognola Marl Fm. (and its lateral equivalent units) contains foraminiferal assemblages indicating an upper bathyal paleodepth (about 600 m to 200 m).

This shallowing up trend is tentatively related to the history of vertical motion ("geohistory") of the underlying Ligurian orogenic wedge from the Middle-Late Eocene to the Early Miocene, in response to tectonics and sedimentary load.

RIASSUNTO – [I foraminiferi planctonici e bentonici della Successione Paleogenica Epiligure (Appennino Settentrionale, Italia): uno strumento per le ricostruzioni paleobatimetriche] – Attraverso lo studio delle associazioni a foraminiferi planctonici e bentonici, viene proposta una ricostruzione paleobatimetrica per i sedimenti epiliguri della catena Nord Appenninica (Eocene medio-Miocene inferiore).

Questa ricostruzione viene ottenuta grazie alla integrazione e al confronto di quattro parametri, utilizzati singolarmente da altri autori: i) rapporto Plancton/Plancton+Benthos; ii) morfogruppi bentonici dell'infauna e dell'epifauna; iii) indici paleobatimetrici planctonici, iv) abbondanza relativa di specie indice bentoniche, che presentano una stretta dipendenza con l'ambiente di vita occupato. La metodologia utilizzata viene inoltre attentamente discussa in relazione al contesto geologico studiato. È stato valutato anche il possibile impatto dei processi tafonomici, come la conservazione selettiva, il trasporto o la rideposizione, che però è risultato scarso o nullo e quindi ininfluenza sull'attendibilità dei dati e dei risultati ottenuti. Questi ultimi possono essere così sintetizzati: è stata documentata una graduale diminuzione di profondità a partire dai sedimenti eocenici delle Marne di Monte Piano fino ai depositi miocenici delle Marne di Antognola. In particolare è stata proposta una paleobatimetria batiale inferiore (da oltre 2000 m a circa 1000 m) per i sedimenti appartenenti alla facies varicolore delle Marne di Monte Piano. Passando alla soprastante facies grigia della medesima formazione ed ai sedimenti torbiditici delle Arenarie di Ranzano la profondità diminuisce con una batimetria corrispondente al batiale medio (da circa 1000 m a 600 m). Infine con le soprastanti Marne di Antognola (e le corrispondenti unità laterali) le associazioni a foraminiferi analizzate diventano indicative di ambienti batiali superiori (da circa 600 m a 200 m).

Infine, si è tentato di mettere in relazione questa graduale diminuzione di profondità con i movimenti verticali subiti dal sottostante substrato liguride, in risposta all'aumento del carico sedimentario e delle spinte tettoniche, al fine di fornire la "geohistory" dell'area indagata nell'intervallo di tempo Eocene Medio-Miocene Inferiore.

INTRODUCTION

The study of both benthic and planktonic foraminiferal assemblages is of great use in marine environmental-paleoecological investigations; foraminifera are in fact the only ubiquitous microfossils which form species assemblages related to specific marine environments. Much of the basis for paleoenvironmental interpretations is provided by the study of living foraminiferal communities in their natural environment and in laboratory culture (Bè & Tolderund, 1971; Bè & Hutson, 1977; Murray, 1984; Hemleben *et al.*, 1989; 1991; Mackensen *et al.*, 1995; Schmiel *et*

al., 1997; 2000; Loubere, 1997; De Rijk *et al.*, 1999; Martin, 1999). Such studies have the advantage, over fossil assemblages studies, in that they provide direct evidence of foraminiferal distribution with respect to know environmental parameters. By contrast, the fossil record shows some limiting factors, such as foraminiferal assemblages produced over periods of up to thousands of years, under different ecological conditions and in various sedimentary microenvironments and modified by taphonomic processes (De Rijk & Troelstra, 1999; Jorissen & Wittling, 1999). Thus, their influence must be carefully evaluated to provide good paleoenvironmental reconstructions.

The primary aim of this study is to propose a valid methodology for paleobathymetric reconstruction, in order to interpret foraminiferal assemblages in wide geological contexts, both spatial and temporal. This methodology has been applied to the Northern Apennines Epiligurian Succession and the eastern sediments of the Piedmont Tertiary Basin (PTB).

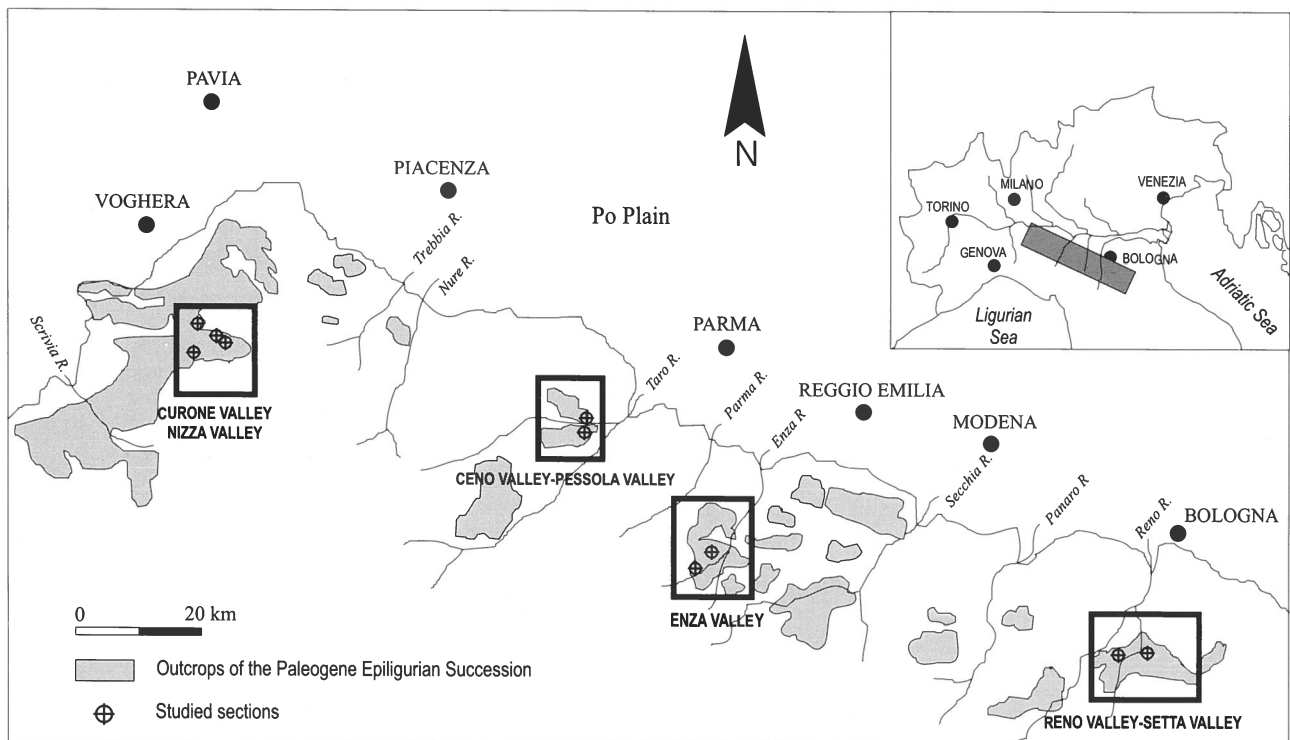
GEOLOGICAL SETTING

The studied Epiligurian Succession (Middle Eocene to Lower Miocene; Mancin & Pirini, 2001 and references therein) crops out along the Northern Apennine chain in isolated outcrops, spread over a distance of about 250 km, Text-fig. 1. The succession includes various facies associations (Text-fig. 2): it begins with the Monte Piano Marl Formation (Upper Bartonian-Lower Rupelian), mainly consisting of pelagic and hemipelagic sediments, subdivided into lower varicoloured marly clays and upper grey silty marls, through transitional grey-hazel silty marl facies. These sediments are lithologically homogeneous all over the study area and show a total thickness from 116 m to about 40 m.

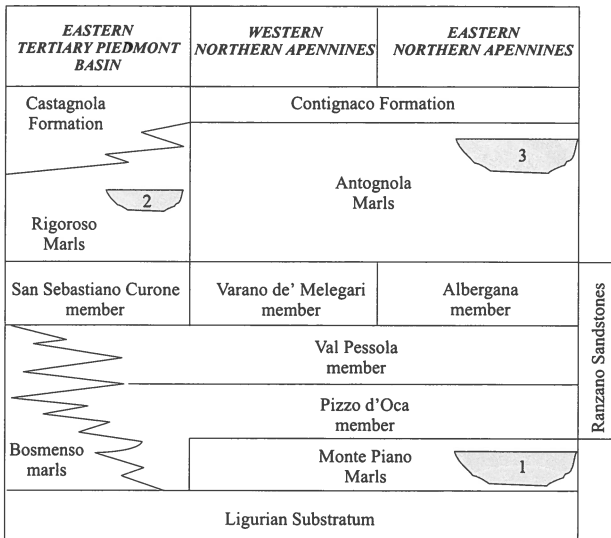
Above the M. Piano Marls or, in the eastern PTB, directly on the Ligurian substratum, the Ranzano Formation generally occurs. This is a very thick turbiditic unit subdivided into five informal members on

the basis of the sandstone composition and sedimentological features (Pizzo d'Oca, Val Pessola and the San Sebastiano Curone, Varano de' Melegari and Albergana heteropic members; Di Giulio, 1991; Cibir, 1993; Martelli *et al.*, 1993; 1998). In the study areas, this formation covers a chronostratigraphic interval spanning 4 to 6 my, from the Priabonian/Early Rupelian to the Late Rupelian (Mancin & Pirini, 2001 and references therein). In the westernmost outcrops (Curone Valley) it can be heteropic with the local Bosmenso marls (Cavanna *et al.*, 1989). The Ranzano Formation, over 750 m thick, has been studied in its lower and upper portions only, where pelitic or pelitic-arenaceous sediments, more suited to foraminiferal preservation, crop out.

Above the Ranzano Fm., an Upper Rupelian-Lower Burdigalian marl-dominated, mostly hemipelagic unit follows (Antognola Fm. and Rigoroso Marls in the Epiligurian and eastern PTB respectively). These sediments show a maximum thickness of about 150 m and can also include coarse-grained, relatively small, lens-shaped turbiditic bodies at several stratigraphic levels (e.g. Nivione Sandstone and Anconella Sandstone; Di Giulio *et al.*, 1997). The top of the Antognola Fm. consists of cherty marls (Contignaco Formation auct.). Furthermore, in the eastern PTB, a rather thick Aquitanian-Lower Burdigalian turbiditic unit onlaps the underlying



Text-fig. 1 - Geologic sketch map of Paleogene Epiligurian Succession and location of the studied sections (from Mancin, 2001, modified).



1 = Loiano Sandstones 2 = Nivione Sandstones 3 = Anconella Sandstones

Text-fig. 2 - Stratigraphic relations of the studied lithostratigraphic units (from Bettelli *et al.*, 1987, modified).

Rigoroso Marls (Castagnola Formation; Andreoni *et al.*, 1981; Cavanna *et al.*, 1989; Stocchi *et al.*, 1992).

MATERIALS

Ten sections (Fontanelle, San Michele, Nivione, Monteacuto, Fosio, Rio Boccolo, Campora, Antognola, Cava dell'Albergana and Torrazza) have been analysed. Laboratory techniques, as well as field collection, have been based on standard methods. Quantitative analysis have been performed on about 400 samples, where in each fraction (>425, >180, >125 and >75 µm), 300 specimens have been counted. The best observations have been made on the three larger and medium fractions; the finest one (> 75 µm), consisting mostly of juvenile benthic and planktonic specimens not recognisable and usually poor preserved, has not been used for interpretation. Abundance curves of the selected most common paleobathymetric indexes (abundance > 1%) were plotted using the counting of the >125 mm fractions only. The resulting curves (Text-fig. 6 to 15) and the range charts of each section may be obtained from one of the authors (N. Mancin).

Planktonic and benthic species were taxonomically identified using published figures and descriptions and by comparison with material collected in the Department of Earth Science, at Pavia University (Plates 1-6).

APPLIED METHODOLOGY

The proposed paleobathymetric interpretation is the result of the integration and comparison of the

following bathymetric parameters, used separately by previous authors: i) Plankton/Plankton + Benthos (P/P+B) ratio (Gibson, 1988; 1989; Van Der Zwaan *et al.*, 1990; 1999; Lüning *et al.*, 1998); ii) the subdivision of planktonic assemblages into "paleobathymetric indexes" (Boersma & Premoli Silva, 1991; Corfield & Cartlidge, 1991; Van Eijden, 1995; Lu & Keller, 1996); iii) the subdivision of the benthic assemblages into morphogroups, both infaunal and epifaunal (Corlis & Fois, 1990; Jones & Charnock, 1985); iv) the relative abundance of benthic index species belonging to depth-dependent microhabitats (Van Morkhoven *et al.*, 1986; Kawagata & Ujiè, 1996; Lundquist *et al.*, 1997; Gooday *et al.*, 1997; de Stigter *et al.*, 1998; De Rijk *et al.*, 1999; 2000). Moreover, the taphonomic processes (such as selective preservation, transport and redeposition) and the other limiting factors of the bathymetric parameters, have been carefully evaluated.

BATHYMETRIC PARAMETERS

- i) *P/P+B ratio*: generally there is an increase in the number of planktonic foraminifera with depth or more precisely, with increasing distance from the coast (Gibson, 1988; 1989). Vice versa, benthic foraminiferal number increases from the near shore area to the continental edge and then it decreases rather drastically at bathyal and abyssal depth (Berger & Diester-Haass, 1988).
- ii) "*Planktonic paleobathymetric indexes*": three categories are recognised, such as deep-water, intermediate water and shallow-water indexes (Tab. 1; Pls. 1 and 2). Modern planktonic foraminifera occur in more or less the same depth stratification in all oceans; foraminifera are usually more abundant

		PLANKTONIC TAXA		
		DEEP-WATER INDEXES > 500 m depth	INTERMEDIATE-WATER INDEXES 50-500 m depth	SHALLOW-WATER INDEXES < 50 m depth
OLIGO-MIOCENE	Large Globigerinids (<i>G. venezuelana</i> , <i>G. euapertura</i> , <i>G. praesepis</i>) <i>Catapsydrax</i> spp. <i>Globoquadrina</i> spp. (<i>G. sellii</i> , <i>G. rohri</i> , <i>G. tripartita</i> , <i>G. tapuriensis</i> , <i>G. dehiscens</i>) <i>Globorotaloides</i> spp.	<i>Paragloborotalia opima opima</i> , <i>P. opima nana</i> , <i>P. siakensis</i> , <i>P. semivera</i> <i>T. angustiumblicata</i> , <i>Globigerina ampliapertura</i> <i>Turborotalia pseudoampliapertura</i>	<i>Paragloborotalia</i> spp. <i>Fohsella</i> spp. <i>Cassigerinella</i> spp. <i>Tenuitella</i> spp. <i>Chiloguembelina cubensis</i> <i>Globigerina ciperoensis</i> <i>Globigerina angulissuturalis</i> <i>Globoquadrina globularis</i> <i>Globigerinoides</i> spp.	
EOCENE	<i>G. venezuelana</i> <i>Subbotina</i> spp. (<i>S. eocaena</i> , <i>S. linaperla</i> , <i>S. utilisindex</i>) <i>Catapsydrax</i> spp. <i>Globoquadrina tapuriensis</i> <i>Planorotalites</i> spp. <i>Streptochilus</i> spp.	<i>Hantkenina atabamensis</i> <i>Globorotalia increbescens</i>	<i>Acarinina</i> spp. <i>Truncorotaloides</i> spp. <i>Morozovella</i> spp. <i>Globigerinatheka</i> spp. <i>Turborotalia cerroazulensis</i> lineage <i>Pseudohastigerina</i> spp.	

Tab. 1 – Subdivision of the analysed planktonic foraminifera into paleobathymetric indexes. Literature data from Boersma & Premoli Silva (1991), Corfield & Cartlidge (1991), Van Eijden (1995) and Lu & Keller (1996).

between 10 to 50 m water depth, coincident with highest phytoplankton concentrations, then rather rapidly decrease in abundance (Bè & Tolderund, 1971; Hemleben *et al.*, 1989). Moreover a relationship between test morphology and water column depth has been observed in modern oceans (Hemleben *et al.*, 1989; 1991). Thus, fossil planktonic foraminifera could be divided into morphogroups indicative of depth. Isotopic ranking of the Paleogene planktonic foraminifera from DSDP sites and with size >180 µm indicates the presence of three isotopically and morphologically distinct assemblages related to paleodepth (Lu & Keller, 1996). They are: the shallow-water indexes that include all the species with pustulate-muricate, cancellate-pitted and smoothed-granulated wall textures (e.g. species of the genera *Morozovella*, *Acarinina*, *Truncorotaloides*, *Globigerinatheka*, *Turborotalia*, *Pseudohastigerina*, *Paragloborotalia*, *Globigerina* and *Globigerinoides*); the intermediate-water indexes, including species with cancellate and smoothed-granulate wall textures (e.g. *Paragloborotalia opima opima*, *Turborotalia pseudoampliapertura*, *Hantkenina alabamensis* and *Tenuitella angustiumbilicata*) and deep-water indexes, that include species with pitted non spinose wall textures (e.g. species of the genera *Planorotalites*, *Catapsydrax*, *Globoquadrina*, *Globorotaloides* and *Subottina*). Therefore, the relative abundance of these indexes, related to the total planktonic assemblage, can provide further informations about paleodepth of the studied sediments, especially for the shallowest localities.

iii) *Benthic morphogroups*: fifteen types are used, such as rounded planispiral, conical, cylindrical, sphaerical, ovoidal, conical-flattened, elongate-flattened, biconvex, planoconvex, rounded trochospiral and miliolids for calcareous taxa (Text-figs. 3 and 4; Tab. 2, Pls. 3-6), and morphogroups A, B, C and D for agglutinated species (Text-fig. 5; Tab. 3; Pl. 6), respectively. Benthic foraminiferal morphology is a complex issue, but in our opinion it is a usable method to reconstruct bathymetry. As depth controls the distribution of the flux of organic matter to the sea floor and as the organic fluxes are inversely proportional to depth

(Berger & Diester-Haass, 1988), the fluctuations in abundance of both infaunal and epifaunal morphogroups can be related to a peculiar paleodepth (Carney, 1989).

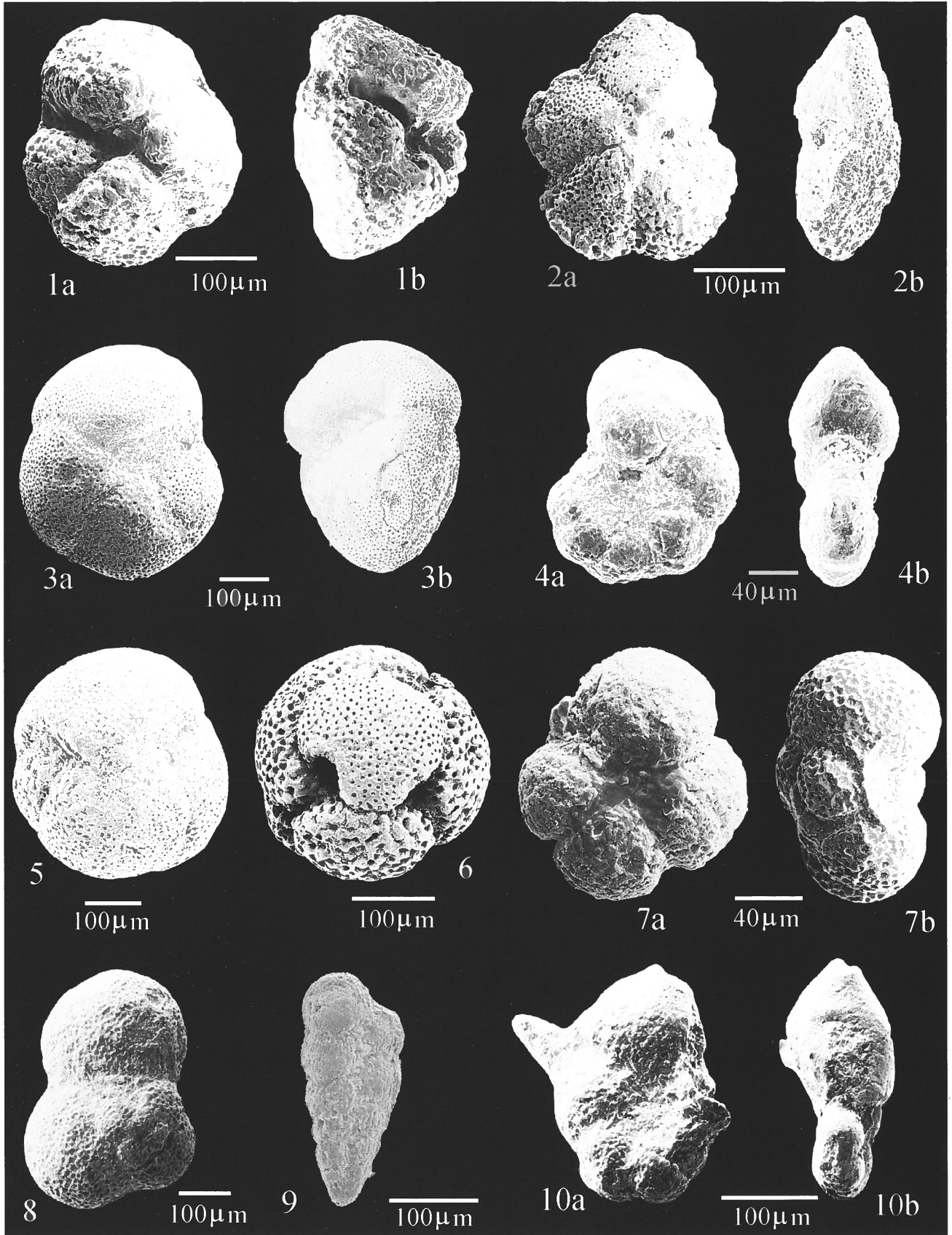
iv) *Benthic indexes*: peculiar benthic species, such as *Abyssammia* spp., *Anomalina pompilioides*, *Anomalinoides ammophilus*, *Bulimina curtissima*, *B. socialis*, *Cibicidoides pseudoungerianus*, *Eponides abatisae*, *Globocassidulina subglobosa*, *Glomospira charoides*, *Gyroidinoides girardanus*, *Heterolepa grimsdalei*, *H. mexicana*, *H. perlucida*, *Bathysiphon* spp., *Rhabdammina* spp., *Nuttalides trümpyi*, *Oridorsalis umbonatus*, *Pullenia bulloides*, *Reticulophragmium amplectens*, *Siphonina reticulata*, *Sphaeroidina bulloides*, *Stilostomella nuttalli*, *Uvigerina mexicana* and *Vulvulina* spp., show clearly depth-dependent microhabitats, thus their relative abundance can provide further informations about paleodepth (Brasier, 1981; Jones & Charnock, 1985; Van Morkhoven *et al.*, 1986; Kaminski *et al.*, 1988 a, 1999; Corliss & Fois, 1990; Corliss, 1991; Loubere *et al.*, 1993; Gooday, 1994; Kawagata & Ujiie, 1996; Kuhnt *et al.*, 1996; Gooday *et al.*, 1997; Lundquist *et al.*, 1997; Schmiel *et al.*, 1997; 2000; de Stigter *et al.*, 1998; De Rijk *et al.*, 1999; 2000; Kaiho, 1999).

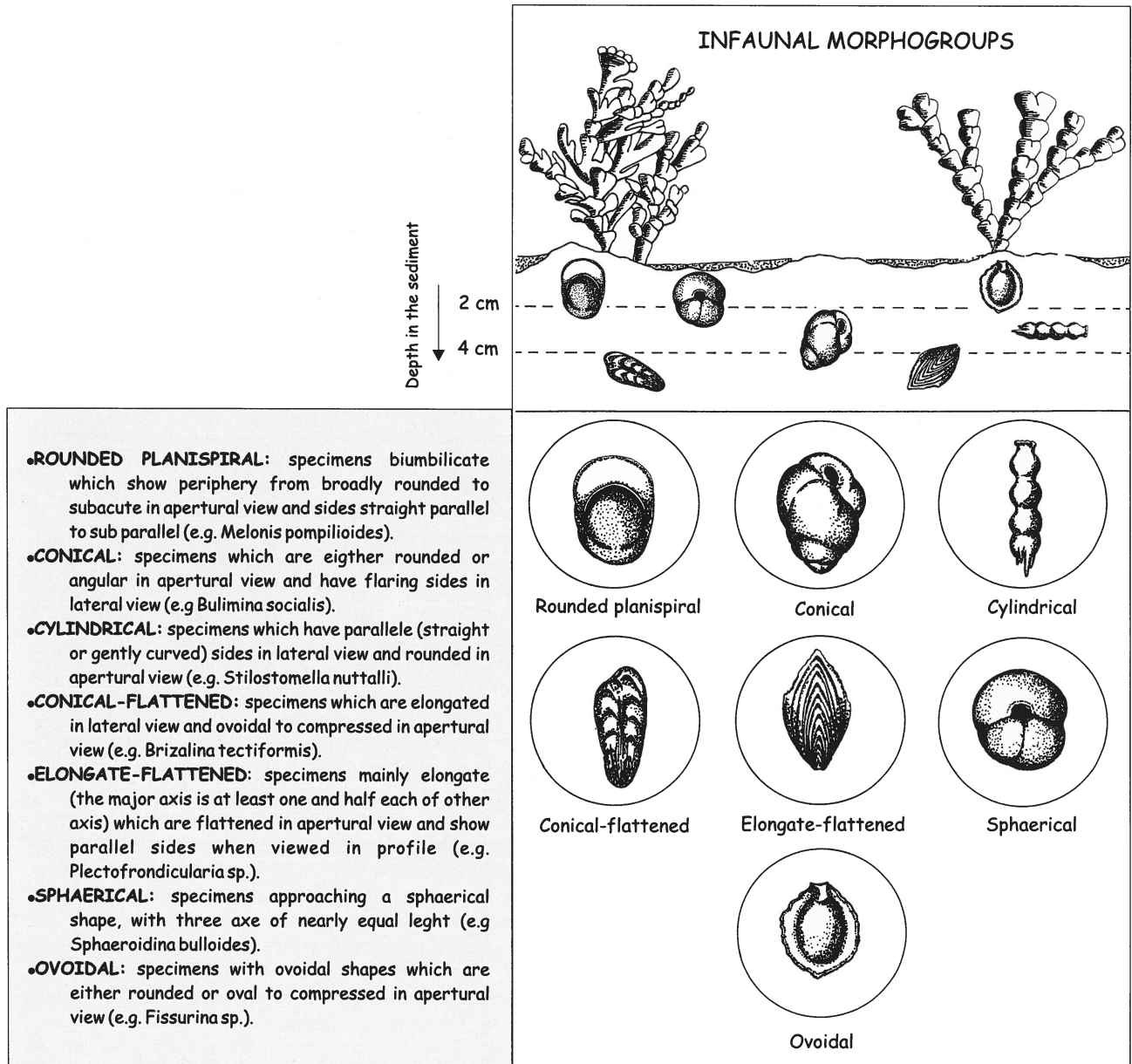
ANALYSIS OF THE LIMITING FACTORS

Adequate knowledge of limiting factors is essential for the delineation of unequivocally interpretable relationship between specific fossil foraminiferal assemblages and their environment. Several workers have suggested a close relationship between foraminiferal test morphology and microhabitat ("morphogroup concept", e.g. Corliss, 1985; Jones & Charnock, 1985; Corliss & Fois, 1990; Corliss, 1991, Bernard & Bowser, 1999). This relationship is very significant, as it enables us to infer essential information about fossil ecosystems; some researchers, however, are questioning its validity and applicability to the fossil record as it is quite complex and with significant exceptions (Jorissen, 1999). For example, fossil morozovellids are "homeomorphs" of modern higher spired globorotalids but they are not "ecomorphs": the former indicate shallow-warm waters, whereas the latter indicate cold-deep waters.

EXPLANATION OF PLATE 1

- Figs. 1-9 - Shallow-water planktonic indexes: 1) *Acarinina bulbrookii* (Bolli), 1945, Monte Piano Marl "varicoloured facies", Bartonian; 2) *Morozovella lehneri* (Cushman & Jarvis), 1929, Monte Piano Marl "varicoloured facies", Bartonian; 3) *Turborotalia cerroazulensis cerroazulensis* (Cole), 1928, Monte Piano Marl "grey facies", Bartonian; 4) *Pseudohastigerina micra* (Cole), 1927, Ranzano Sandstones, Priabonian; 5) *Globigerinatheka mexicana mexicana* gr. (Cushman), 1925, Monte Piano Marl "grey facies", Bartonian; 6) *Globigerinatheka subconglobata luterbacheri* Bolli, 1972, Monte Piano Marl "varicoloured facies", Bartonian; 7a,b) *Globigerina angulisuturalis* Bolli, 1957, Nivione Sandstones, Chattian; 8) *Globigerinoides primordius* Blow & Banner, 1926, Antognola Marls, Chattian; 9) *Chiloumbelina cubensis* (Palmer), 1934, Rigoroso Marls, Rupelian.
- Fig. 10 - Intermediate-water planktonic indexes: *Hatkenina alabamensis* Cushman, 1925, Ranzano Sandstones, Priabonian.





Text-fig. 3 - Calcareous hyaline infaunal morphogroups (from Corliss & Fois, 1990, modified).

Also low-spired subbotinids little resemble the non-spinose modern neogloboquadrinids, even if they both live in cool waters (Boersma & Premoli Silva, 1991). Moreover, morphologically similar benthic species, sometimes of the same genus, can belong to different microhabitats. For example, some calcareous hyaline species, (as *Gyroidinoides girardanus*, *Heterolepa mexicana*, *Heterolepa grimsdalei* and *Nuttalides trümpyi*), are grouped in the rounded trochospiral morphogroup on the basis of their similar morphology, although they have different depth-dependent habitats (Van Morkhoven *et al.*, 1986). To

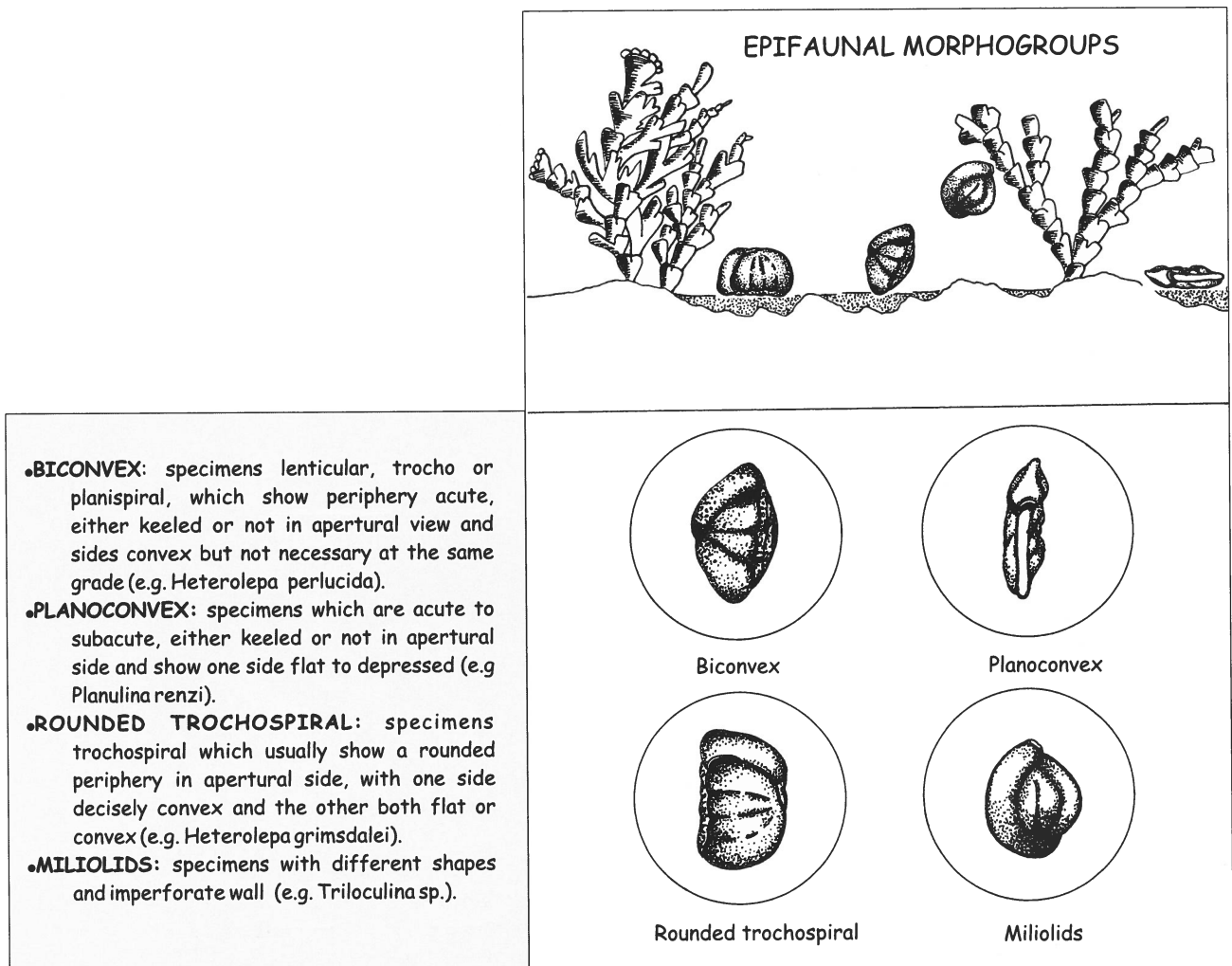
overcome to this problem, inside of each morphogroup the relative abundance of benthic indexes must be always evaluated. Finally, the terms epifaunal and infaunal suggest a different life strategy, but the distinction between the two groups is sometimes arbitrary (de Stigter *et al.*, 1998; Jorissen, 1999). A particular species, considered fixed for a peculiar environment, can expand or compress its microhabitat when life conditions change (e.g. Kaminski *et al.*, 1997). For example, in the Japan Sea the distribution of *Globobulimina* spp. and *C. ovoidea* varies seasonally and appears to be correlated to the depth of the

oxygenated layer. These data show clearly how deep-sea benthic foraminifera can migrate vertically through the sediments on a seasonal time scale (Ohga & Kitazato, 1997). The bathymetric distribution of modern foraminifera results, in fact, governed by the interaction between water depth and other parameters, such as organic flux and food supply, substratum, sediment oxygenation, etc. (Van der Zwaan *et al.*, 1990; 1999; Linke & Lutze, 1993; Jorissen *et al.*, 1995; De Rijk *et al.*, 1999; 2000; Schmiedl *et al.*, 2000). In modern oceanic sediments, it is primarily the supply of food, which governs the abundance of foraminifera rather than depth itself, and other related factors (Van Der Zwaan *et al.*, 1990; 1999; Schmiedl *et al.*, 19997; De Rijk *et al.*, 2000). However, as depth controls the distribution of the flux of organic matter to the sea floor (Berger & Diester-Haass, 1988), we believe that even the abundance of foraminifera can be related to depth (albeit indirectly) and thus used to provide good paleodepth

reconstruction.

Even post-mortem and taphonomic processes can change the composition, diversity and density of the original foraminiferal assemblages, hampering an adequate interpretation of the fossil record in bathymetric reconstruction. Because of their small size, foraminifera are prone to perturbing processes, such as selective preservation, transport and redeposition of tests (De Rijk & Troelstra, 1999; Jorissen & Wittling, 1999; Goldstein & Watkins, 1999).

Selective preservation can comprise test disintegration and destruction, and selective dissolution. For example, many agglutinated foraminifera, whose tests are only weakly cemented with easily degradable organic cement, usually disintegrate completely after death (necrolysis of the organic cement), (Almogi-Labin *et al.*, 1996; Murray & Alve, 1999 a, b; Edelman-Furstenberg *et al.*, 2001). Partially corroded and weakened tests become more vulnerable to mechanical destruction by burrowing organisms and



Text-fig. 4 - Calcareous hyaline epifaunal morphogroups (from Corliss & Fois, 1990, modified).

CALCAREOUS HYALINE TAXA			
EPIFAUNAL MORPHOTYPES		INFAUNAL MORPHOTYPES	
BICONVEX	<i>Anomalinoidea ammophilus</i> <i>Cassidulina</i> spp. <i>Cibicoides pseudoungerianus</i> <i>Cibicoides robertsonianus</i> <i>Eponides abatissae</i> <i>Heterolepa perfulcra</i> <i>Oridorsalis umbonatus</i> <i>Parella mexicana</i> <i>Siphonina reticulata</i> <i>Lenticulina</i> spp. <i>Cancris</i> spp.	<i>Melonis</i> spp. <i>Pullenia quinqueloba</i> <i>Abysammina</i> spp.	ROUNDED LAINSPHERAL
		<i>Bulimina alazanensis</i> , <i>B. alsatica</i> , <i>B. carmenensis</i> , <i>B. curtissima</i> , <i>B. jarvisi</i> , <i>B. palmerae</i> , <i>B. socialis</i> , <i>Pleurostomella brevis</i> , <i>Uvigerina</i> <i>auberiana</i> , <i>U. galloway</i> , <i>U. havanensis</i> , <i>U. mexicana</i>	CONICAL
PLANOCONVEX	<i>Anomalinoidea alazanensis</i> <i>A. alazanensis</i> var. <i>spissiformis</i> <i>Heterolepa</i> spp. <i>Planulina marialana</i> <i>Planulina renzi</i>	<i>Dentalina</i> spp., <i>Nodosaria longiscata</i> , <i>Nodosariella robusta</i> , <i>Pleurostomella</i> <i>alternans</i> , <i>Stilostomella curvatura</i> , <i>S. nuttalli</i> , <i>S. verneuilli</i> .	CYLINDRICAL
		<i>Lagena</i> spp. <i>Pullenia bulloides</i> <i>Sphaeroidina bulloides</i>	SPHERICAL
ROUNDED TROCHOSPHERAL	<i>Anomalinopsis pompilioides</i> <i>Anomalinoidea granosus</i> <i>Anomalinoidea venezuelanus</i> <i>Gyrogoninoides girardanus</i> <i>Heterolepa grimsdalei</i> <i>Heterolepa mexicana</i> <i>Nuttalides trumpi</i>	<i>Fissurina scarenaensis</i> <i>Globobulimina</i> spp. <i>Globocassidulina subglobosa</i>	OVOIDAL
		<i>Bolivina</i> spp. <i>Brizalina tectiformis</i> <i>Vaginulina</i> spp.	CONICAL- FLATTENED
MILIOLIDS	Multi-species	<i>Planularia</i> spp. <i>Plectofrondicularia</i> spp.	LENGTHENED- FLATTENED

Tab. 2 – Subdivision of the analysed calcareous hyaline foraminifera into infaunal and epifaunal morphogroups. Literature data from Corliss & Fois (1990), Corliss (1991).

later by compaction of the sediment (De Stiger *et al.*, 1999). Biological activity is an other important cause of the destruction of calcareous and agglutinated tests. Etching and boring by bacteria and others micro-organisms and passive ingestion by sediment-feeding macrofauna can lead to weakening or complete destruction of tests (Edelman-Furstenberg *et al.*, 2001). Moreover, calcitic and aragonitic tests are destroyed by dissolution in carbonate-undersaturated deep-sea waters; it is known that calcareous benthic foraminifera are usually more resistant to selective

dissolution than planktonic ones (Corliss & Hojo, 1981). Transport is an other limiting factor: usually it mainly affects the smaller size categories (Van Der Zwaan *et al.*, 1990; Lüning *et al.*, 1998), and this is one of the reasons for choosing the fractions larger than 125 µm for our interpretations.

In summary a simplified morphogroup concept with several categories is a very useful and convenient for paleoenvironmental reconstructions, in spite of some exceptions and problems. These can be in fact overcome: first, using and comparing four bathymetric parameters, derived from the study of different groups of foraminifera (e.g planktonic, benthic calcareous-hyaline and agglutinated); second, knowing and evaluating the impact of their limiting factors.

In the current study, considering the wide depth range proposed and utilised, the reliability of the produced data comes from the homogeneity and harmony of all the data and the limited influence of taphonomic processes

ANALYSES AND RESULTS

The collected data are here reported in order of their stratigraphic succession.

1) MONTEPIANO MARLS

"varicoloured facies"

References sections are (from W to E): Fosio (samples FMP12 base to FMP18, Text-fig.6), Campora (samples CMP1 to CMP8, Text-fig.7) and Cava dell'Albergana (samples AMP1 to AMP8, Text-fig.8).

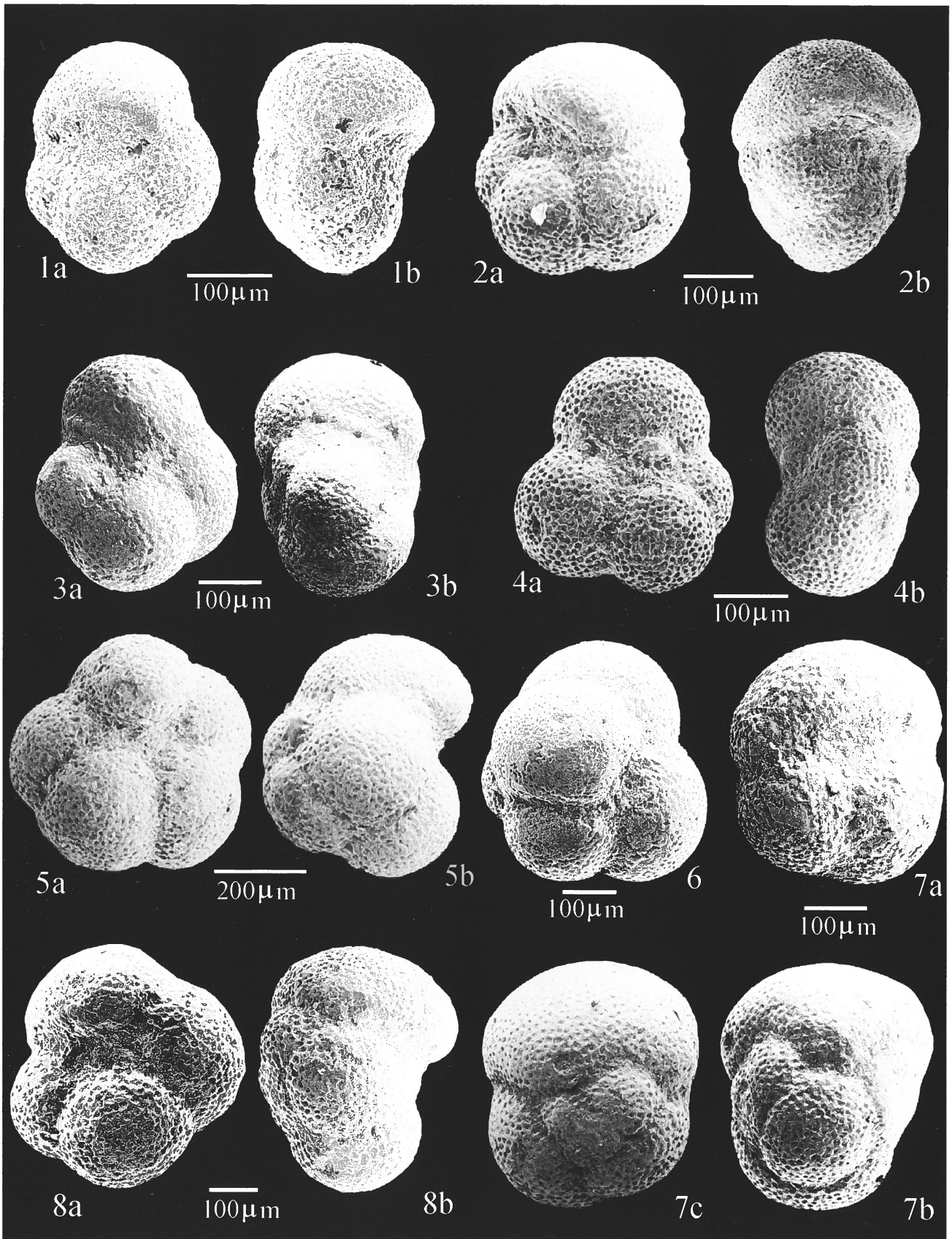
The P/P+B ratio is very low (usually less than 10%) therefore the planktonic paleobathymetric indexes are considered statistically less significant.

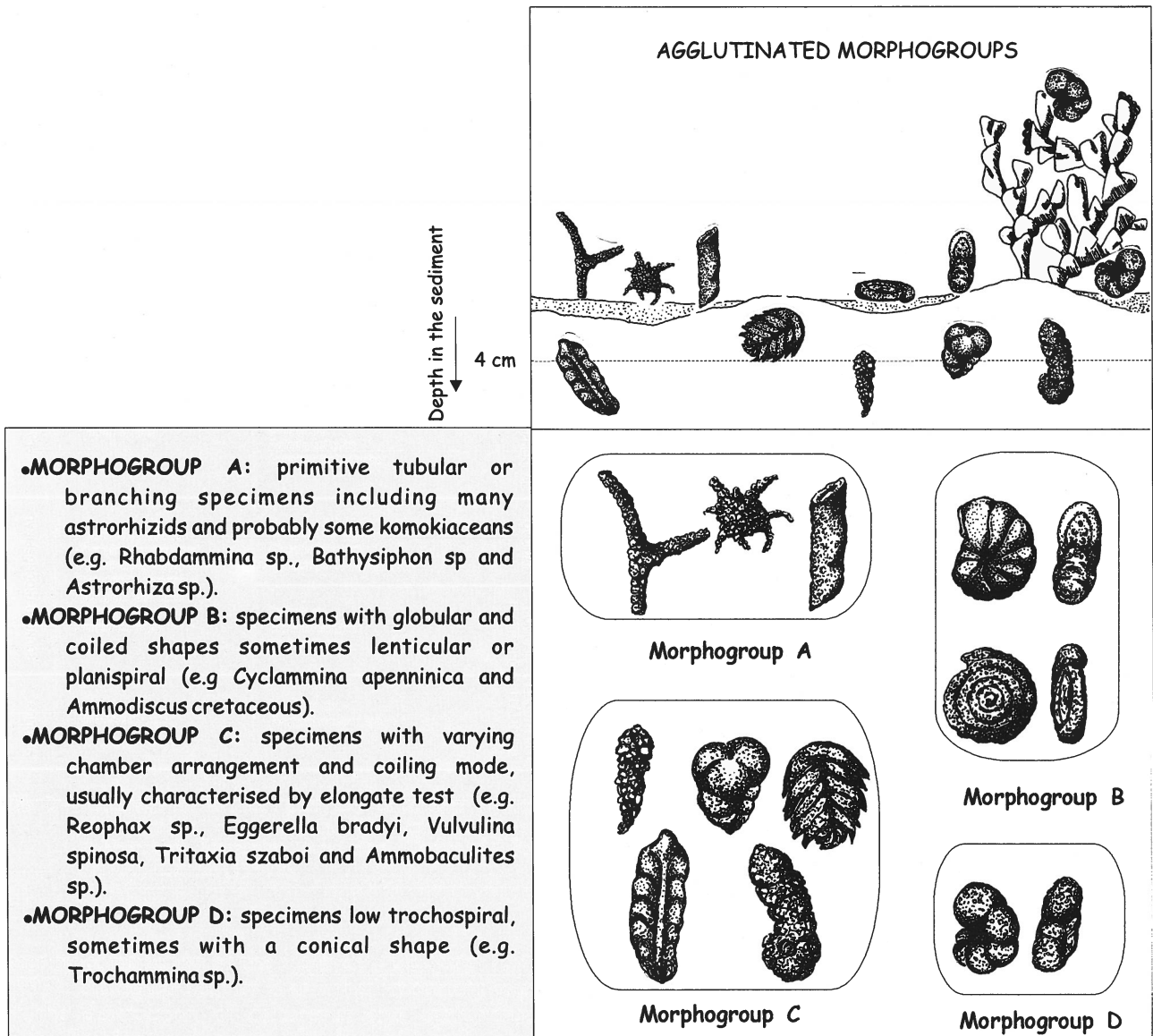
The benthic foraminiferal assemblages show common calcareous hyaline species, while agglutinated ones are in subordinate numbers; porcellaneous species are absent. Agglutinated species are particularly abundant (from 100% to 55%) only in the Albergana section.

The calcareous hyaline species are dominated by epifaunal morphotypes (rounded trochospiral and biconvex: *Nuttalides truempyi*, *Heterolepa grimsdalei*, *Oridorsalis umbonatus* and *Eponides abatissae*); the planoconvex morphotype (*Anomalinoidea alazanensis*,

EXPLANATION OF PLATE 2

- Figs. 1-3 - Intermediate-water planktonic indexes: 1a,b) *Globigerina ampliapertura* Bolli, 1957, Monte Piano Marl "grey facies", Rupelian; 2a,b) *Turborotalia pseudoampliapertura* (Blow & Banner), 1926, Ranzano Sandstones, Rupelian; 3a,b) *Paragloborotalia opima opima* (Bolli), 1957, Nivione Sandstones, Chattian.
- Figs. 4-8 - Deep-water planktonic indexes: 4a,b) *Subbottina eocaena* (Guembel), 1868, Monte Piano Marl "grey facies", Bartonian; 5a,b) *Globoquadrina altispira globosa* Bolli, 1957, Rigoroso Marls, Rupelian; 6) *Catapsydrax dissimilis* (Cushman & Bermudez), 1937, Antognola Marls, Chattian; 7a-c) *Globoquadrina sellii* Borsetti, 1959, Antognola Marls, Rupelian; 8a,b) *Globigerina venezuelana* Hedberg, 1937, Rigoroso Marls, Chattian.





Text-fig. 5 - Agglutinated foraminifera morphogroups (from Jones & Charnock, 1985, modified).

A. venezuelanus) is generally less abundant or absent. Infaunal assemblages are characterised by the conical morphotype (*Bulimina socialis* and subordinately *B. curtissima* and *B. jarvisi*) and by the rounded planispiral (*Melonis* spp. and *Abyssammina* spp.), cylindrical (*Stilostomella nuttalli*), sphaerical (*Pullenia bulloides*) and ovoidal (*Globocassidulina subglobosa*) morphotypes, in suborder.

This facies is also characterised by the dominance of the agglutinated epifaunal Morphogroups A (*Rhabdammina* spp.) and B (*Ammodiscus latus*, *Glomospira charoides*, *Glomospira gordialis*, *Psammosphaera fusca*, *Reticulophragmium amplexens* and *Trochamminoides proteus*).

"grey facies"

References sections are: Montecuto (samples MMP1 to MMP57, Text-fig.9), Fosio (samples FMP19 to FMP41, Text-fig.6), Campora (samples CMP9 to CAR23a, Text-fig.7) and Cava dell'Albergana (samples AMP9 to AMP17, Text-fig.8).

The P/P+B ratio is very high (from 40% to 80%, with peaks of 100%). The planktonic assemblages are dominated by deep-water paleobathymetric indexes (catapsydracids, *Globigerina venezuelana*, *Subbottina eocaena*, *Subbottina linaperta*, *S. utilisindex*, *Planorotalites pseudoscitula*) and subordinately by shallow-water indexes (*Turborotalia cerroazulensis* lineage, *Pseudohastigerina micra*, *Globigerinatheka* spp.); intermediate-water indexes (*Globigerina ampliapertura*,

AGGLUTINATED TAXA			
INFAUNAL MORPHOGROUP		EPIFAUNAL MORPHOGROUPS	
Morphogroup C	<i>Ammobaculites</i> spp. <i>Arenobulimina ovoidea</i> <i>Dorothia inflata</i> <i>Eggerella brady</i> <i>Gaudryina</i> spp. <i>Karriella obscura</i> var. <i>robusta</i> <i>Reophax nevini</i> <i>Textularia adalta</i> <i>Tritaxia szaboi</i> <i>Vulvulina chirana</i> <i>V. jarvisi</i> <i>V. pennatula</i> var. <i>cuneata</i> <i>V. pennatula</i> var. <i>italica</i> <i>V. spinosa</i>	<i>Astrhoriza</i> spp. <i>Bathysiphon</i> spp. <i>Hyperammina elongata</i> <i>Rhabdammina</i> spp.	Morphogroup A
		<i>Ammodiscus cretaceus</i> , <i>A. latus</i> , <i>Cyclammina apenninica</i> <i>Glomospira charoides</i> , <i>G. gordialis</i> , <i>Psammosphaera fusca</i> , <i>Recurvoides</i> spp., <i>Reticulophragmium amplexans</i> <i>Trochamminoides proteus</i>	Morphogroup B
		<i>Haplophragmoides</i> spp. <i>Trochammina</i> spp.	Morphogroup D

Tab. 3 – Subdivision of the analysed agglutinated foraminifera into infaunal and epifaunal morphogroups. Literature data from Jones & Charnock (1985).

Globorotalia increbescens) are very rare to absent.

The benthic foraminiferal assemblages are dominated by common calcareous hyaline species and in subordinate numbers of agglutinated taxa, while porcellaneous species are absent to very rare.

Calcareous hyaline species are characterised by the epifaunal morphotypes. The biconvex morphotype (*Heterolepa perlucida*, *Oridorsalis umbonatus*) becomes more abundant together with the rounded trochospiral (*Heterolepa grimsdalei*, *Gyroidinoides girardanus*,

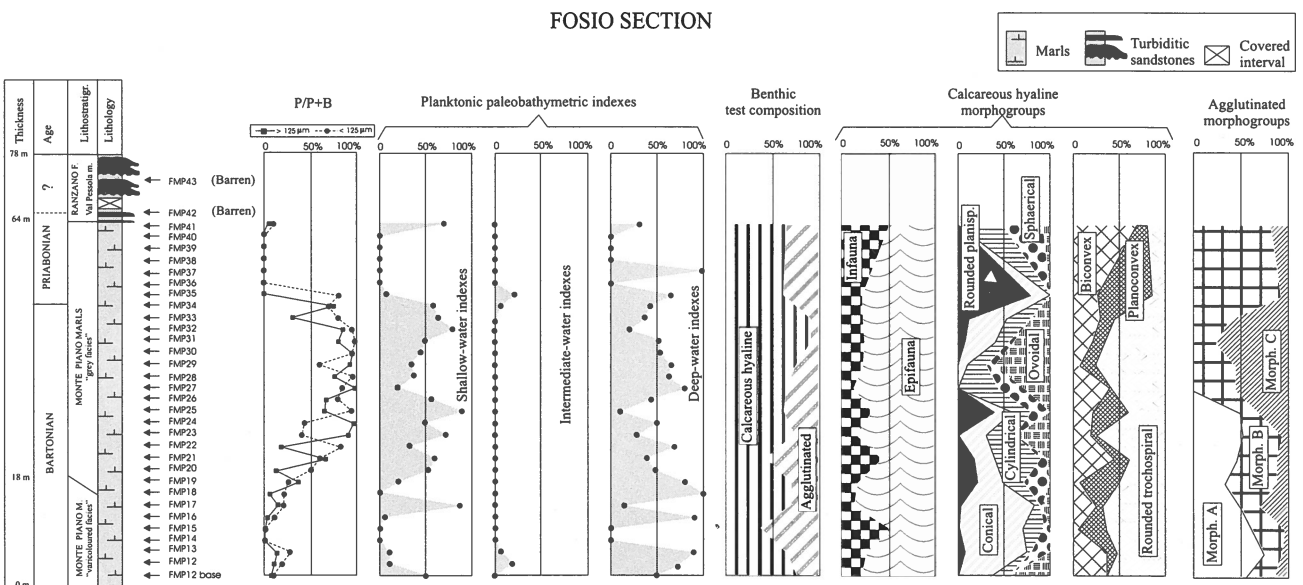
Eponides abatissae and *Nuttalides truempyi*), while the planoconvex morphotype (*Anomalinoidea alazanensis*) is usually less abundant. In the infaunal assemblages the conical morphotype (*Bulimina socialis* and subordinately *B. jarvisi*) sharply decreases, while the cylindrical (*Stilostomella nuttalli*) and ovoidal (*Globocassidulina subglobosa*) morphotypes increase in abundance.

In the agglutinated assemblages the infaunal Morphogroup C (*Karriella obscura* var. *robusta*, *Reophax nevini*, *Vulvulina* spp., *Gaudryina* spp., *Textularia adalta* and *Tritaxia szaboi*) increases in number and becomes dominant, while in contrast the epifaunal Morphogroups B (*Ammodiscus cretaceus*, *Cyclammina cancellata*, *Recurvoides* spp. and *Trochamminoides proteus*) and above all the Morphogroup A (*Rhabdammina* spp., *Hyperammina* spp. and *Bathysiphon* spp.), decrease in abundance.

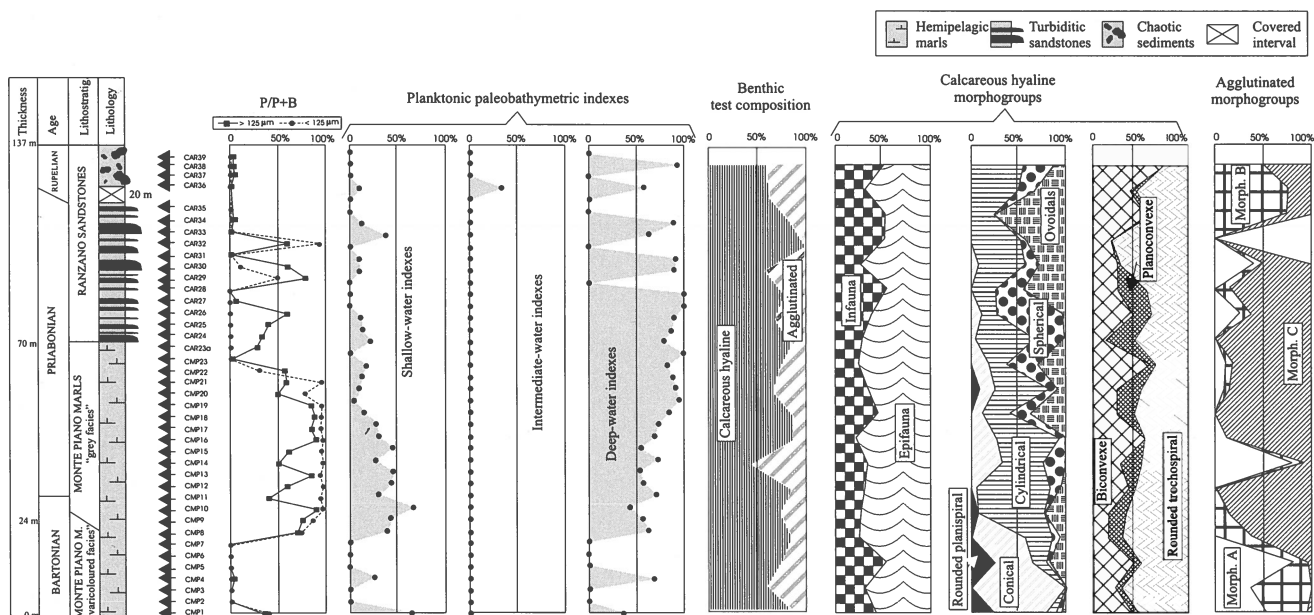
II) RANZANO SANDSTONES

References sections are: Fontanelle (samples FAR1 to FAR20, Text-fig.10), Rio Boccolo (samples Br1 to Br10, Text-fig. 11), Campora (samples CAR24 to CAR39, Text-fig.7) and Cava dell'Albergana (samples AMP18 to AMP32, Text-fig.8).

The P/P+B ratio is usually rather high, but numerous samples are barren. This is due to the selected sampling adopted for this unit. The planktonic assemblages are dominated by deep-water indexes (catapsydracids, *Globigerina venezuelana*, *G. euapertura*, *Globoquadrina sellii*, *G. tripartita*, *G. rohri* and *Globorotaloides* spp.) and only subordinately by shallow-water indexes (*Chiloguembelina cubensis*, *Cassigerinella chipolenis*, *Globigerina ciperoensis* and *G.*



Text-fig. 6 - Fosio Section (Pessola valley, PR): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.



Text-fig. 7 - Campora Section (Enza valley, PR): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

angulisuturalis); intermediate-water indexes (*Globigerina ampliapertura*, *Turborotalia pseudoampliapertura*, *Tenuitellinata angustiumbilitata* and *Paragloborotalia opima opima*) are rare to very rare.

In benthic foraminiferal assemblages the calcareous hyaline species are dominant, while the agglutinated taxa are rare. The former are characterised by the epifaunal morphotypes: the planoconvex morphotype (*Anomalinoidea alazanensis*, *Planulina renzi*, *P. marialana*) becomes more abundant; the rounded trochospiral (*Heterolepa grimsdalei*, *H. mexicana*, *Gyroidinoides girardanus*, *Eponides abatissae* and *Anomalina pompilioides*) and the biconvex morphotypes (*Heterolepa perlucida*, *Oridorsalis umbonatus*) are usually abundant to common. The infaunal assemblages are characterised by the ovoidal (*Globocassidulina subglobosa* and *Globobulimina* spp.) and cylindrical (*Stilostomella* spp.) morphotypes, while conical (*Uvigerina mexicana* and *U. havanensis*) and rounded planispiral (*Melonis* spp.) morphotypes decrease in abundance. The conical flattened morphotype (*Brizalina tectiformis*) is usually rare to very rare.

The agglutinated assemblages are characterised by

infaunal Morphogroup C (*Karreriella obscura* var. *robusta*, *Reophax nevini*, *Vulvulina* spp., *Gaudryina* spp., *Textularia adalta* and *Tritaxia szaboï*), while in contrast the epifaunal Morphogroups B (*Ammodiscus cretaceus*, *Cyclammina cancellata*, *Recurvoides* spp. and *Trochamminoides proteus*) and, especially, A (*Hyperammina* spp. and *Bathysiphon* spp.), decrease in abundance.

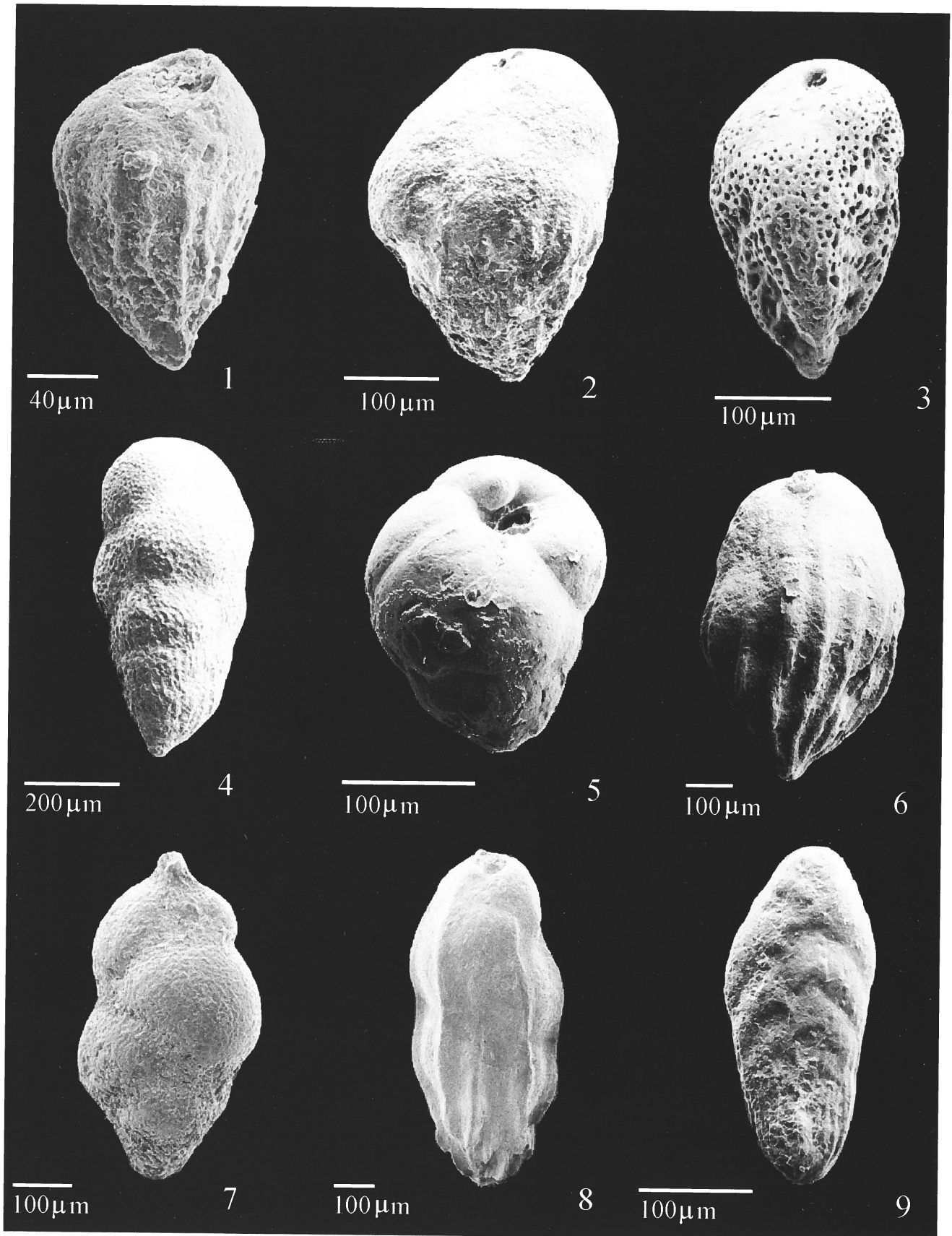
III) ANTOGNOLA MARLS AND ITS LATERAL EQUIVALENT UNITS (RIGOROSO AND CASTAGNOLA FM.)

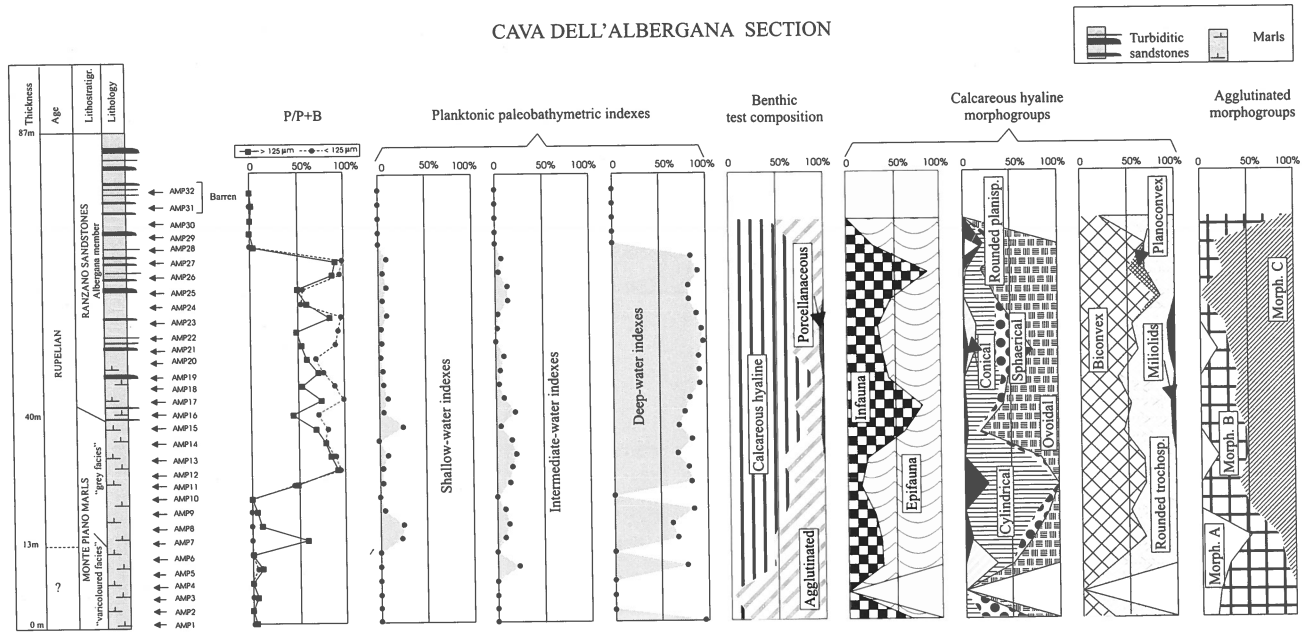
References sections are: San Michele (samples Mm'R1 to Mm'R30, Text-fig.12), Nivione (samples m'R1 to C53, Text-fig. 13), Rio Boccolo (samples Ba12 to Ba34, Text-fig. 11), Antognola (samples AAR1 to AANT52, Text-fig.14) and Torrazza (samples TANT1 to TANT18, Text-fig.15).

The P/P+B ratio is always very high (from 50% to 100%). The planktonic assemblages are characterised by deep-water (catapsydracids, *Globigerina venezuelana*, *G. euapertura*, *Globoquadrina* spp. and *Globorotalia* spp.) and intermediate-water indexes (*Paragloborotalia opima opima*, *P. opima nana* and *P. siakensis*). The shal-

EXPLANATION OF PLATE 3

- Figs. 1-8 - Conical morphogroup: 1) *Bulimina alazanensis* Cushman, 1927, Monte Piano Marl "grey facies", Upper Bartonian; 2) *Bulimina alsatica* Cushman & Parker, 1937, Rigoroso Marls, Rupelian; 3) *Bulimina carmenensis* Petters & Sarmiento, 1956, Monte Piano Marl "varicoloured facies"; Upper Bartonian; 4) *Bulimina jarvisi* Cushman & Parker, 1936, Ranzano Sandstones, Rupelian; 5) *Bulimina socialis* Bornemann, 1855, Monte Piano Marl "varicoloured facies"; Upper Bartonian; 6) *Uvigerina mexicana* Nuttall, 1932, Bosmeno marls, Rupelian; 7) *Uvigerina auberiana* d'Orbigny var. *attenuata* Cushman & Renz, 1941, Antognola Marls, Chattian; 8) *Uvigerina galloway* Cushman 1929, Ranzano Sandstones, Rupelian.
- Fig. 9 - Conical-flattened morphogroup: *Brizalina tectiformis* (Cushman), 1926, Antognola Marls, Rupelian.





Text-fig. 8 - Cava dell'Albergana Section (Setta valley, BO): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

low-water indexes (*Globigerina ciperoensis*, *G. angulissuturalis*, *Paragloborotalia kugleri*, *P. pseudokugleri* and *P. semivera*) increase in abundance upwards.

The benthic foraminiferal assemblages are dominated by common calcareous hyaline species with subordinate agglutinated taxa, with porcellaneous species absent or very rare. Calcareous hyaline species are characterised by the epifaunal morphotypes: biconvex (*Heterolepa perlucida*, *Anomalinoidea ammophilus*, *Cibicidoides pseudoungerianus* and *Siphonina raeticulata*) and rounded trochospiral (*Heterolepa mexicana*, *Gyroidinoidea girardanus*, and *Anomalina pompilioides*); the planoconvex morphotype (*Anomalinoidea alazanensis* var. *spissiformis*, *Planulina renzi* and *Planulina marialana*) increases in abundance from the bottom upwards. In the infaunal assemblages the ovoidal (*Globocassidulina subglobosa*) and subordinately *Globobulimina*) and spherical morphotypes (*Pullenia bulloides* and *Sphaeroidina bulloides*) increase in abundance, while cylindrical

(*Stilostomella* spp., *Nodosariella robusta* and *Nodosaria longiscata*) and conical morphotypes (*Uvigerina havanensis* and *U. auberiana* var. *attenuata*) usually decrease. Rounded planispiral (*Melonis* spp.) and conical flattened (*Brizalina tectiformis*) morphotypes become very rare to absent.

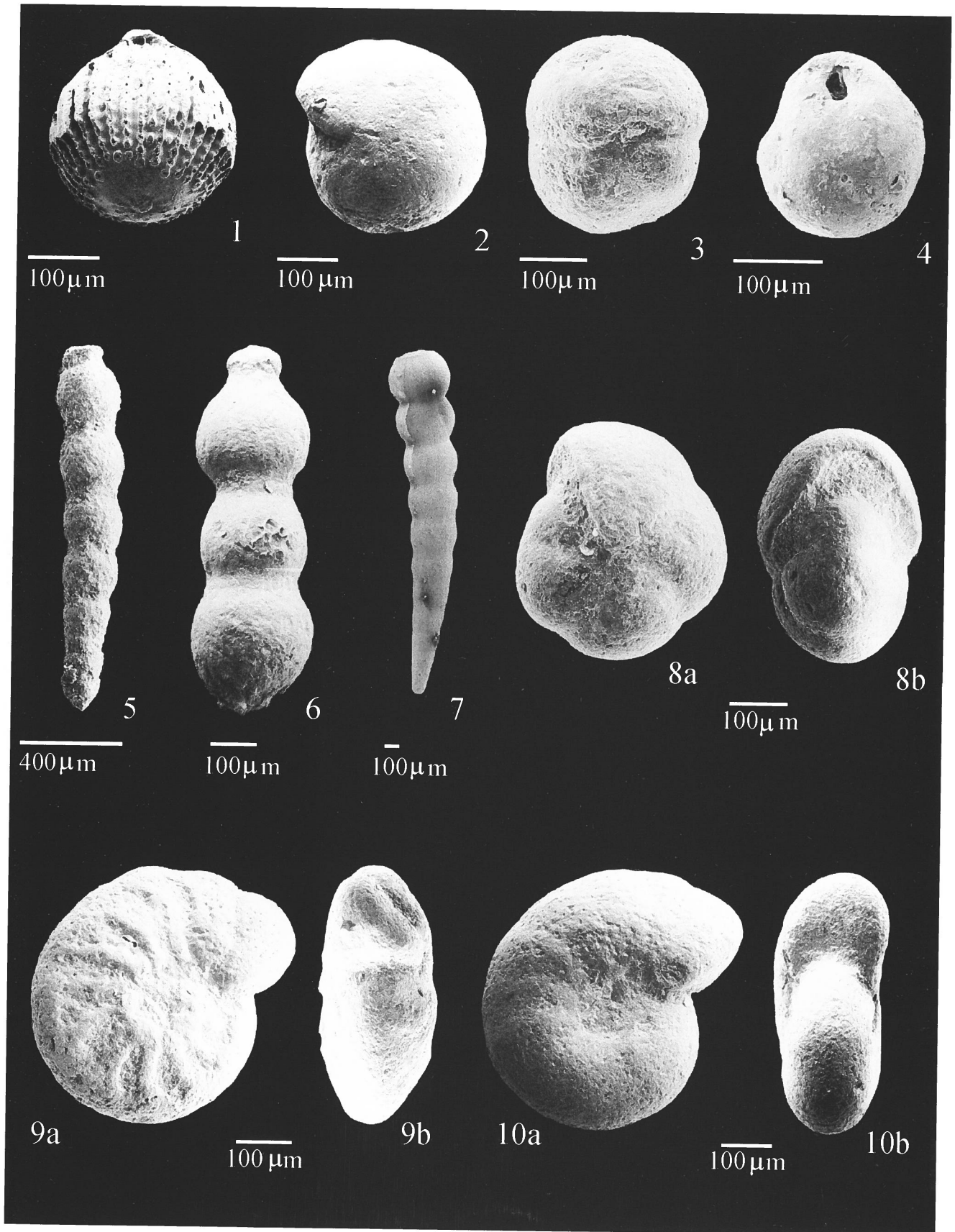
The agglutinated assemblages are very similar to that found in the Ranzano Formation: the infaunal Morphogroup C (*Vulvulina* spp., *Karrerella obscura* var. *robusta*, *Gaudryina* spp. and *Textularia adalta*) are common, while the epifaunal Morphogroup B (*Ammodiscus cretaceus*, *Cyclammina cancellata*, *Recurvoides* spp. and *Trochamminoides proteus*) decreases in abundance.

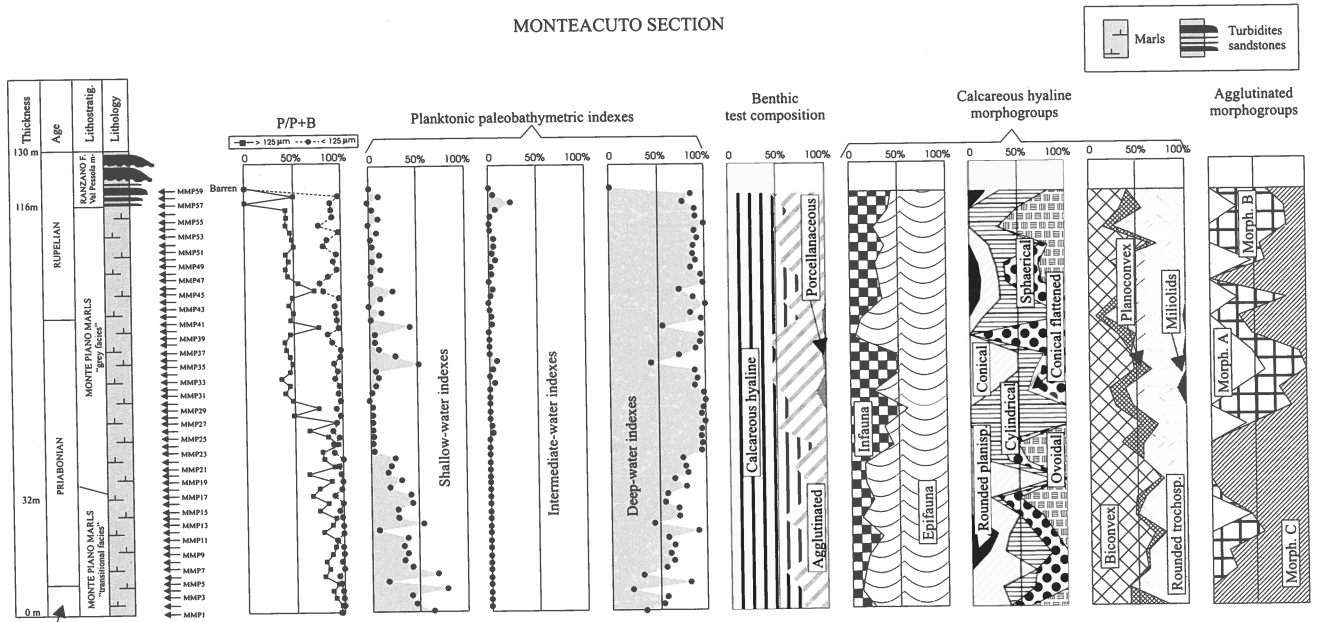
DISCUSSION AND PALEOBATHYMETRIC INTERPRETATION

The data presented above and partially summarized in Text-fig. 16 enable us to provide a valid paleobathymetric reconstruction for the Paleogene

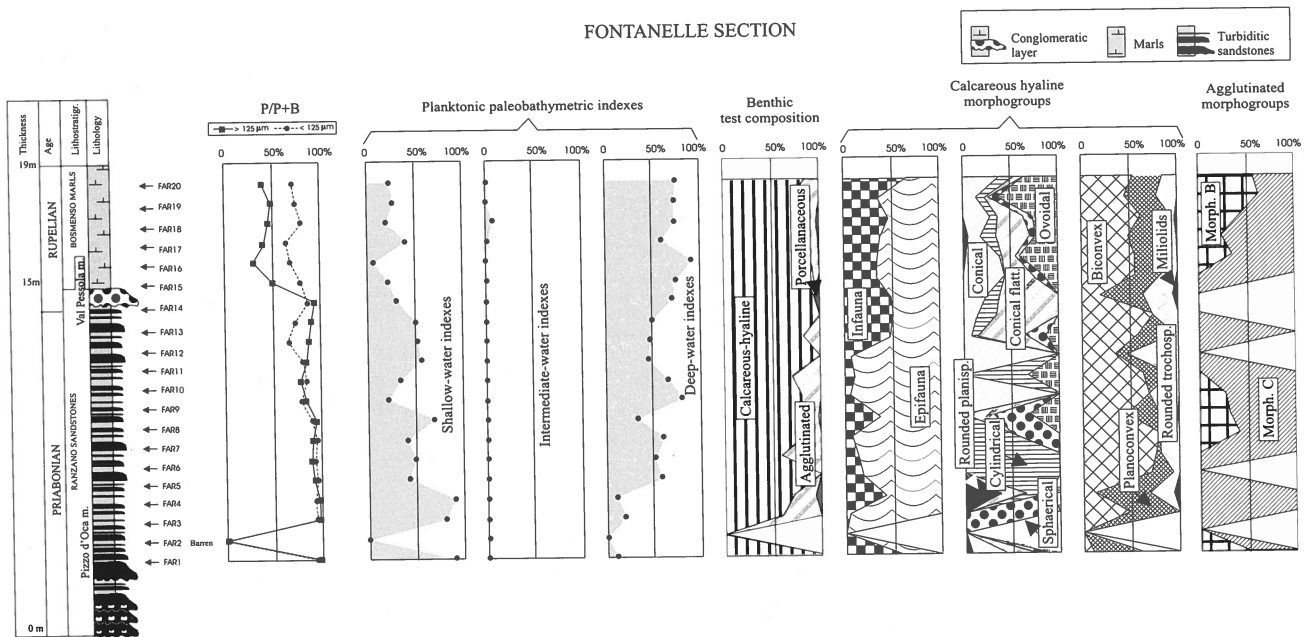
EXPLANATION OF PLATE 4

- Figs. 1-3 - Spherical morphogroup: 1) *Oolina* sp., Monte Piano Marl "varicoloured facies", Upper Bartonian; 2) *Pullenia bulloides* (d'Orbigny), 1846, Ranzano Sandstones, Rupelian; 3) *Sphaeroidina bulloides* d'Orbigny, 1826, Rigoroso Marls, Chattian.
- Fig. 4 - Ovoidal morphogroup: *Globocassidulina subglobosa* (Brady), 1881, Ranzano Sandstones, Rupelian.
- Figs. 5-7 - Cylindrical morphogroup: 5) *Stilostomella curvatura* (Cushman), 1939, Rigoroso Marls, Chattian; 6) *Stilostomella nuttalli* Cushman & Jarvis, 1934, Antognola Marls, Rupelian; 7) *Stilostomella verneuli* (d'Orbigny), 1846, Monte Piano Marl "grey facies", Rupelian.
- Fig. 8 - Rounded planispiral morphogroup: *Pullenia quinqueloba* (Reuss), 1851, Rigoroso Marls, Chattian.
- Figs. 9-10 - Planoconvex morphogroup: 9a,b) *Anomalinoidea alazanensis* (Nuttall), 1932, Antognola Marls, Rupelian; 10a,b) *Anomalinoidea alazanensis* (Nuttall) var. *spissiformis* Cushman & Stainforth, 1945, Antognola Marls, Rupelian.





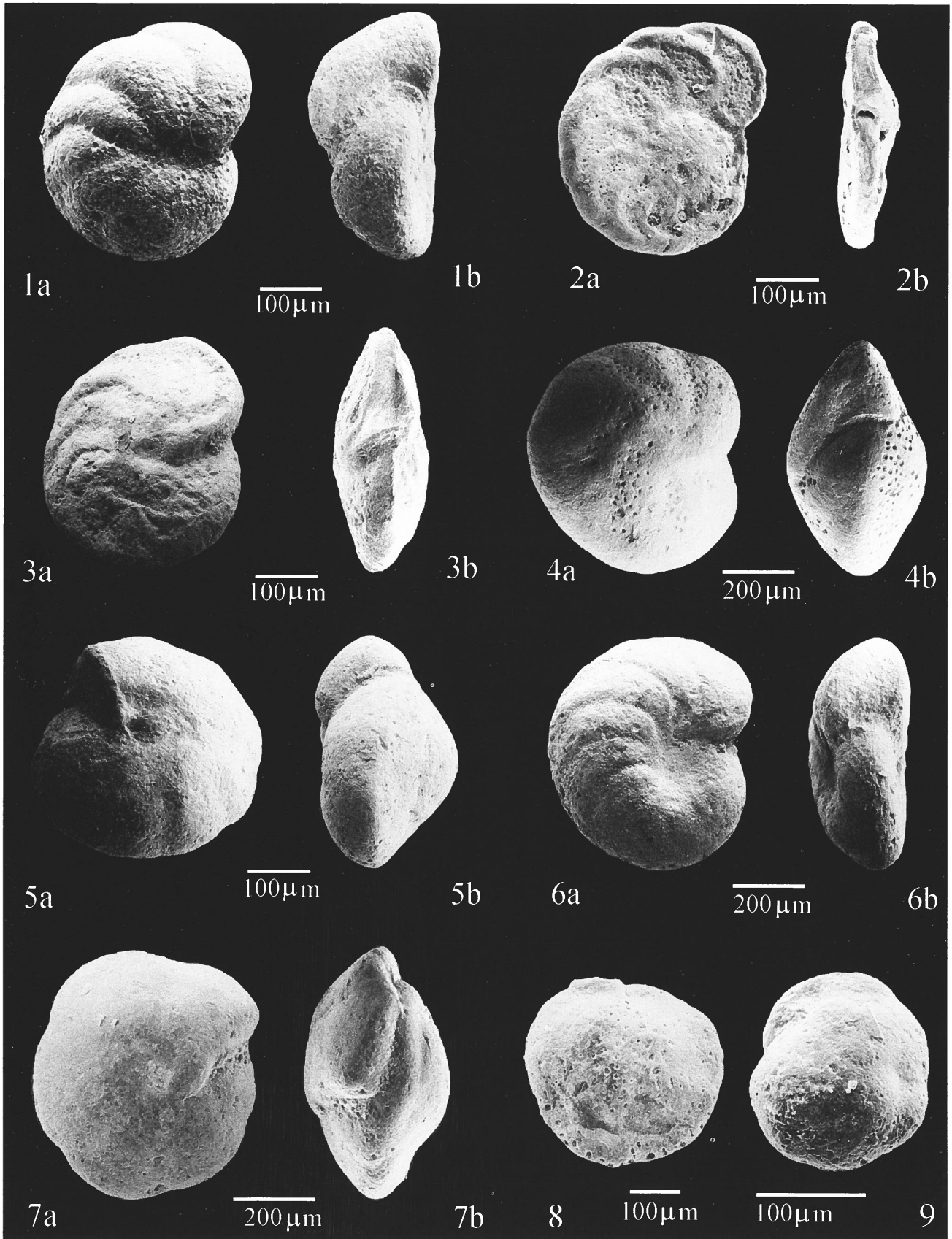
Text-fig. 9 - Montecuto Section (Nizza valley, PV): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

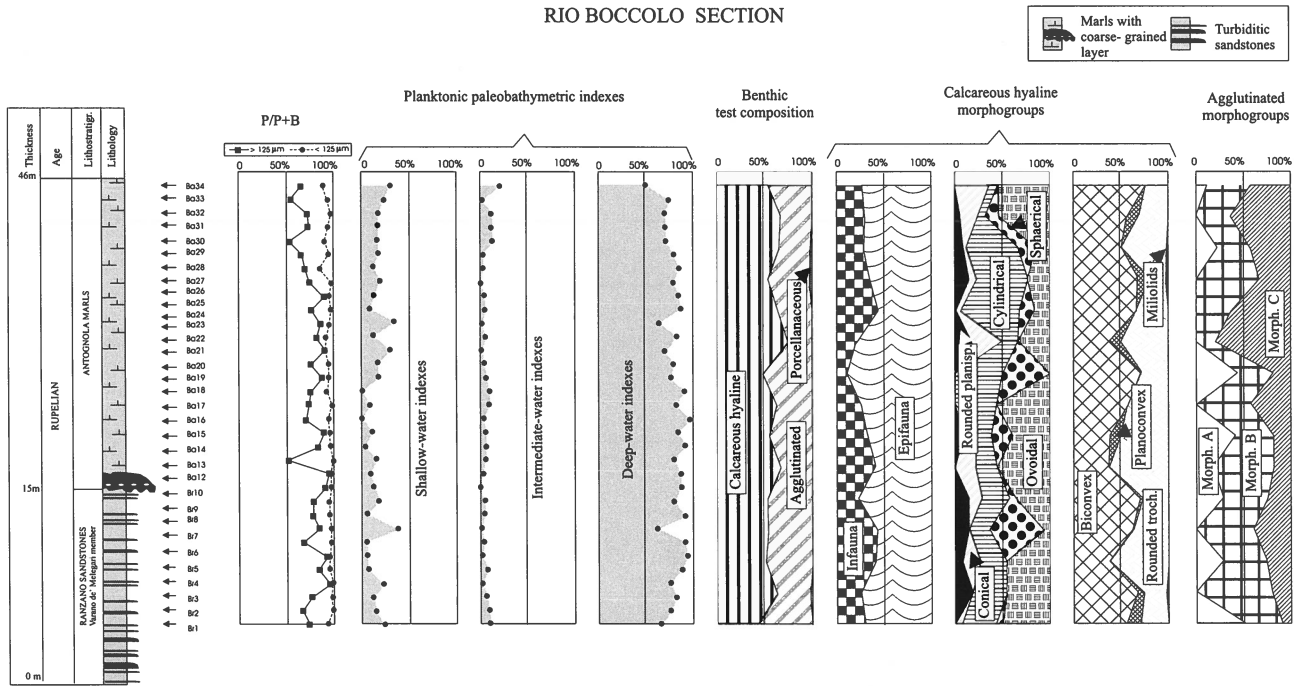


Text-fig. 10 - Fontanelle Section (Curone valley, AL): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

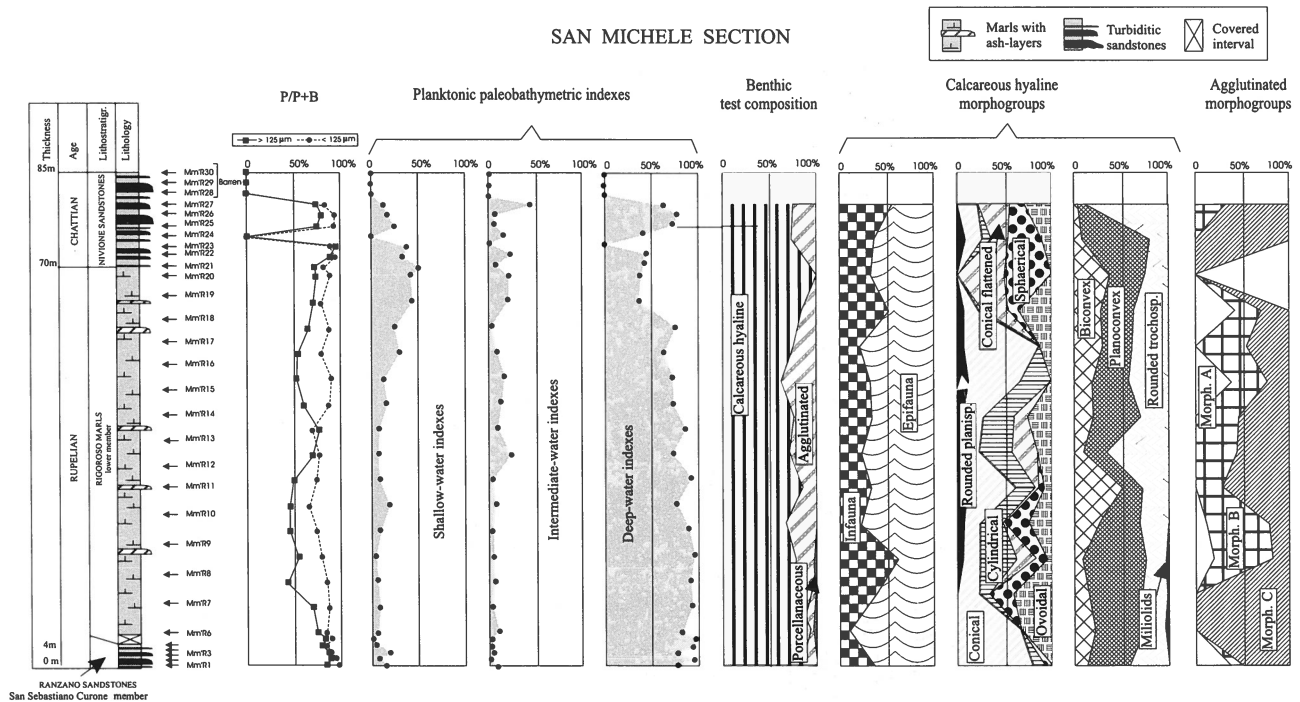
EXPLANATION OF PLATE 5

- Figs. 1-3 - Planoconvex morphogroup: 1a,b) *Heterolepa* sp., Rigoroso Marls, Chattian; 2a,b) *Planulina marialana* Hadley, 1934 Monte Piano Marl "varicoloured facies", Upper Bartonian; 3a,b) *Planulina renzi* Cushman & Stainforth, 1945, Bosmenso marls, Rupelian.
- Figs. 4-9 - Biconvex morphogroup: 4a,b) *Heterolepa perlucida* (Nuttall), 1932, Antognola Marls, Rupelian; 5a,b) *Eponides abatissae* (Selli), 1930, Antognola Marls, Rupelian; 6a,b) *Anomalinoidea ammophilus* (Gümbel), 1868, Rigoroso Marls, Rupelian; 7a,b) *Oridorsalis umbonatus* (Reuss), 1851, Monte Piano Marl "grey facies", Upper Bartonian; 8) *Siphonina reticulata* (Czjzek), 1848, Rigoroso Marls, Chattian; 9) *Cassidulina* sp., Rigoroso Marls, Rupelian.





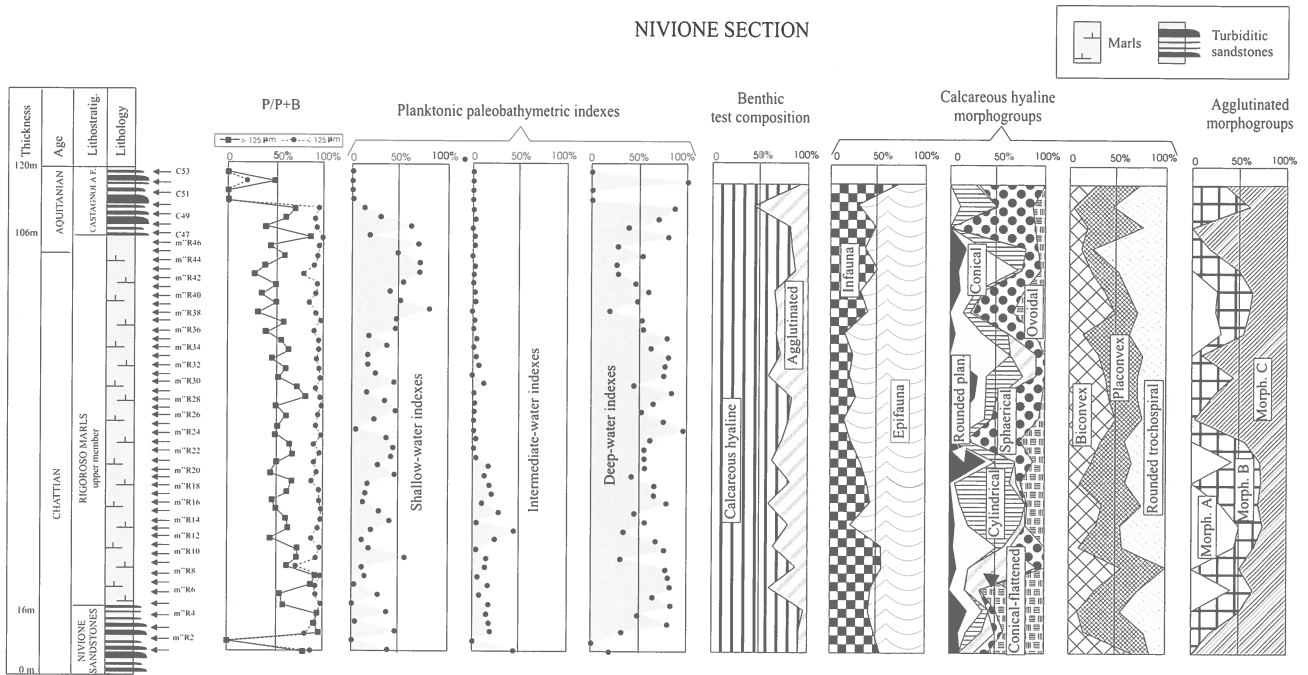
Text-fig. 11 - Rio Boccole Section (Pessola valley, PR): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.



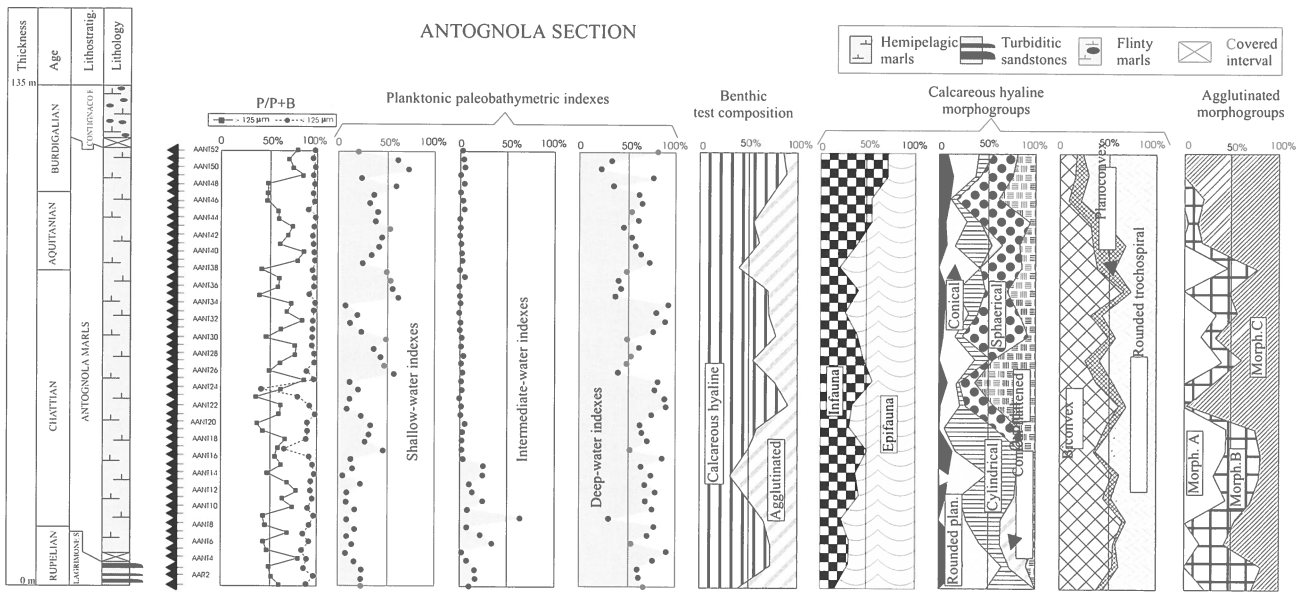
Text-fig. 12 - San Michele Section (Curone valley, PV): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

Epiligurian Succession. Foraminiferal assemblages significantly diversify through the stratigraphic succession and their distribution shows a clear shallow-

ing upwards trend. The reliability of the results has been obtained by the homogeneity and harmony of the produced data, coming from the integration and



Text-fig. 13 - Nivione Section (Curone valley, PV): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.



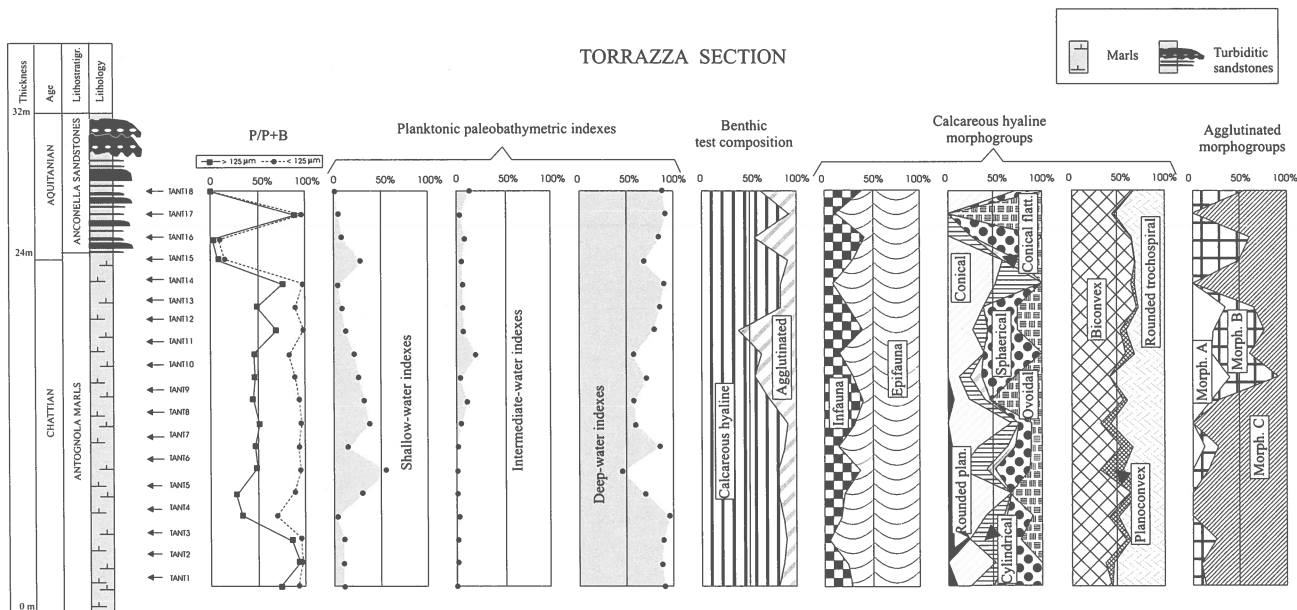
Text-fig. 14 - Antognola Section (Enza valley, PR): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

comparison of four bathymetric parameters, by the wide depth range proposed and finally by the absence or limited presence of taphonomic processes.

MONTE PIANO MARL FORMATION

The studied samples indicate that benthic and planktonic foraminiferal assemblages are significantly

different in the lower varicoloured facies, compared with the upper grey facies. The foraminiferal assemblages of the varicoloured facies are usually less diversified, with a low P/P+B ratio, and are composed of dominant benthic species indicative of abyssal-lower bathyal paleodepth (Text-fig. 16). These sediments are interpreted as deposited from the lower slope to the abyssal plain (over 2000-1000 m depth). This



Text-fig. 15 - Torrazza Section (Reno valley, BO): stratigraphic log and quantitative analyses of planktonic and benthic foraminifera.

paleodepth has been already recognised by Mancin (2001) through the study of test microstructures of the agglutinated species. These peculiar microstructures (“silica cement and dominant quartz and feldspar grain test composition”) have been in fact related to lower bathyal environments, probably located in calcium carbonate deficient waters, but not below the CCD (Gooday, 1990). Even the remarkable occurrence, in our assemblages, of *Glomospira charoides* is consistent with this paleodepth. This species is found today in high relative abundance (about 40%) only in the deepest part (below 2000 m depth) of the two most oligotrophic areas of the eastern Mediterranean Sea (De Rijk *et al.*, 2000). Moreover, live faunas in central oceanic areas are characterised by a much lower percentage of calcareous foraminifera (even above the CCD) and by a large proportion of agglutinated taxa, with the pre-

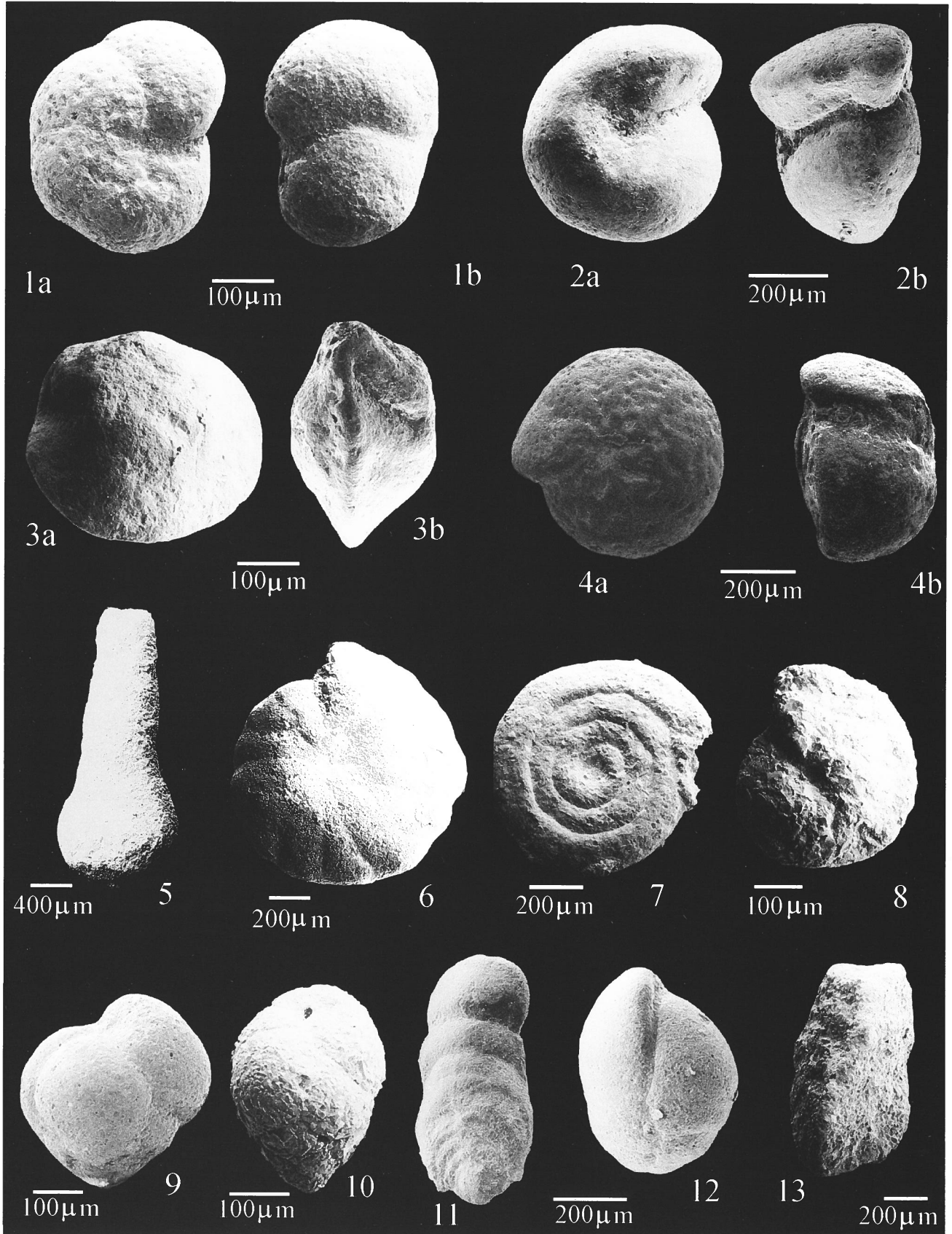
dominant calcareous ones composed by near-surface dwelling (epifaunal) species (Gooday & Rathburn, 1999) and a low P/P+B ratio (Brasier, 1981).

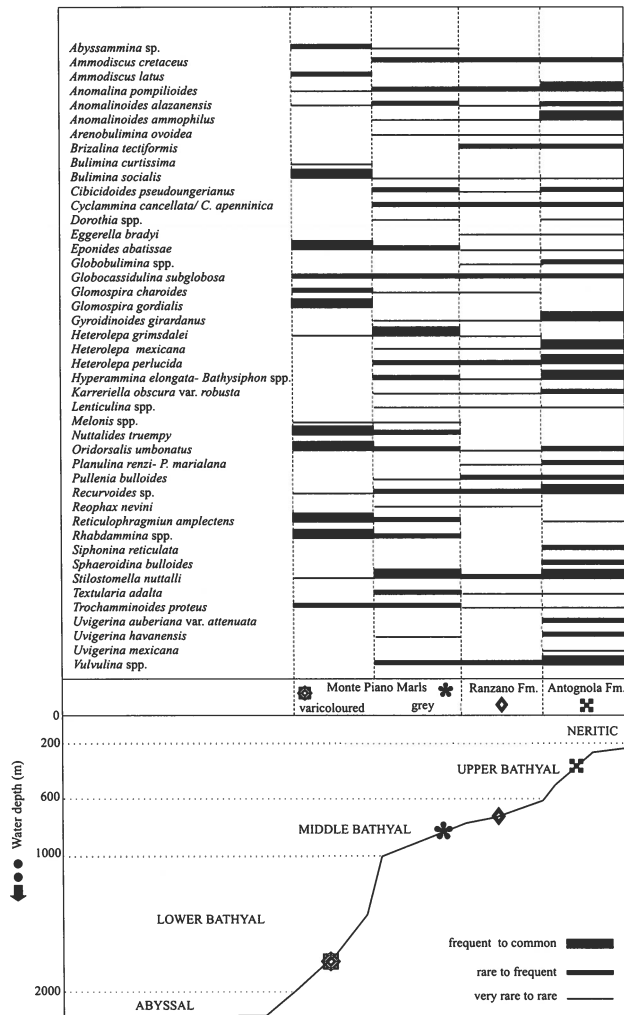
As regard to taphonomical processes, our assemblages do not show significant traces of selective dissolution that could justify the low P/P+B ratio. Easily dissolvable planktonic species (such as the muricate ones) are rare, but present in all the fractions (even in the finest ones) without dissolution surfaces or abraded tests. Moreover these assemblages are also characterised by very abundant deep-water calcareous-hyaline species that exclude under-saturated waters or selective dissolution post-mortem. No signs of significant transport were found either, as the samples are absolutely devoid of shelf organisms and the studied assemblages are usually well preserved and without wear marks.

The grey facies is characterised by foraminiferal assemblages that are more diversified when compared

EXPLANATION OF PLATE 6

- Figs. 1-4 - Rounded trochospiral morphogroup: 1a,b) *Anomalina pompilioides* Galloway & Heminway, 1941, Rigoroso Marls, Rupelian; 2a,b) *Gyroidinoides girardanus* (Reuss), 1851, Antognola Marls, Rupelian; 3a,b) *Nuttalides trümpyi* (Nuttall), 1930 Monte Piano Marl “varicoloured facies”, Upper Bartonian; 4a,b) *Heterolepa grimsdalei* (Nuttall), 1930, Monte Piano Marl “varicoloured facies”, Upper Bartonian.
- Fig. 5 - Morphogroup A: *Hyperammina elongata* Brady, 1878, Monte Piano Marl “grey facies”, Priabonian.
- Figs. 6-8 - Morphogroup B: 6) *Cyclammmina apenninica* Emiliani, 1954, Monte Piano Marl “varicoloured facies”, Bartonian; 7) *Ammodiscus cretaceus* (Reuss), 1845, Ranzano Sandstones, Rupelian; 8) *Reticulophragmiun amplexens* (Grzybowski), 1898, Monte Piano Marl “varicoloured facies”, Bartonian.
- Figs. 9-13 - Morphogroup C: 9) *Eggerella brady* (Cushman), 1911, Ranzano Sandstones, Rupelian; 10) *Arenobulimina ovoidea* Marie, 1941, Antognola Marls, Chattian; 11) *Vulvulina jarvisi* Cushman, 1932, Antognola Marls, Chattian; 12) *Dorothia inflata* Colom, 1945, Antognola Marls, Rupelian; 13) *Tritaxia szabo* (Hantken), 1868, Monte Piano Marl “grey facies”, Priabonian.





Text-fig. 16 - Distribution of selected benthic foraminifera in the lithostratigraphic units of the Epiligurian Succession and proposed paleobathymetric ranges.

to the underlying varicoloured ones, with a very high P/P+B ratio, and composed of dominant deep-water planktonic and benthic index species. It is worth of note that many of the abyssal and lower bathyal index species (*Abyssammina* sp., *Bulimina socialis*, *Eponides abatissae*, *Glomospira charoides*, *G. gordialis*, *Nuttalides trümpyi* and *Oridorsalis umbonatus*), that characterized the underlying varicoloured facies, rapidly decrease in abundance and are replaced by *Anomalinoidea alazanensis*, *Heterolepa grimsdalei* and *Stilostomella nuttalli*, that are indicative of shallower waters. Therefore these deposits can be interpreted as middle bathyal continental slope (1000-600 m depth). A similar paleobathymetric range (greater than 500 m) has also been proposed by Morlotti & Kuhnt (1992) for coeval adjacent sediments (Pessola Valley, Parma province) and is also consistent with modern slope assemblages, from areas with a normal organic matter flux (Goody & Rathburn, 1999).

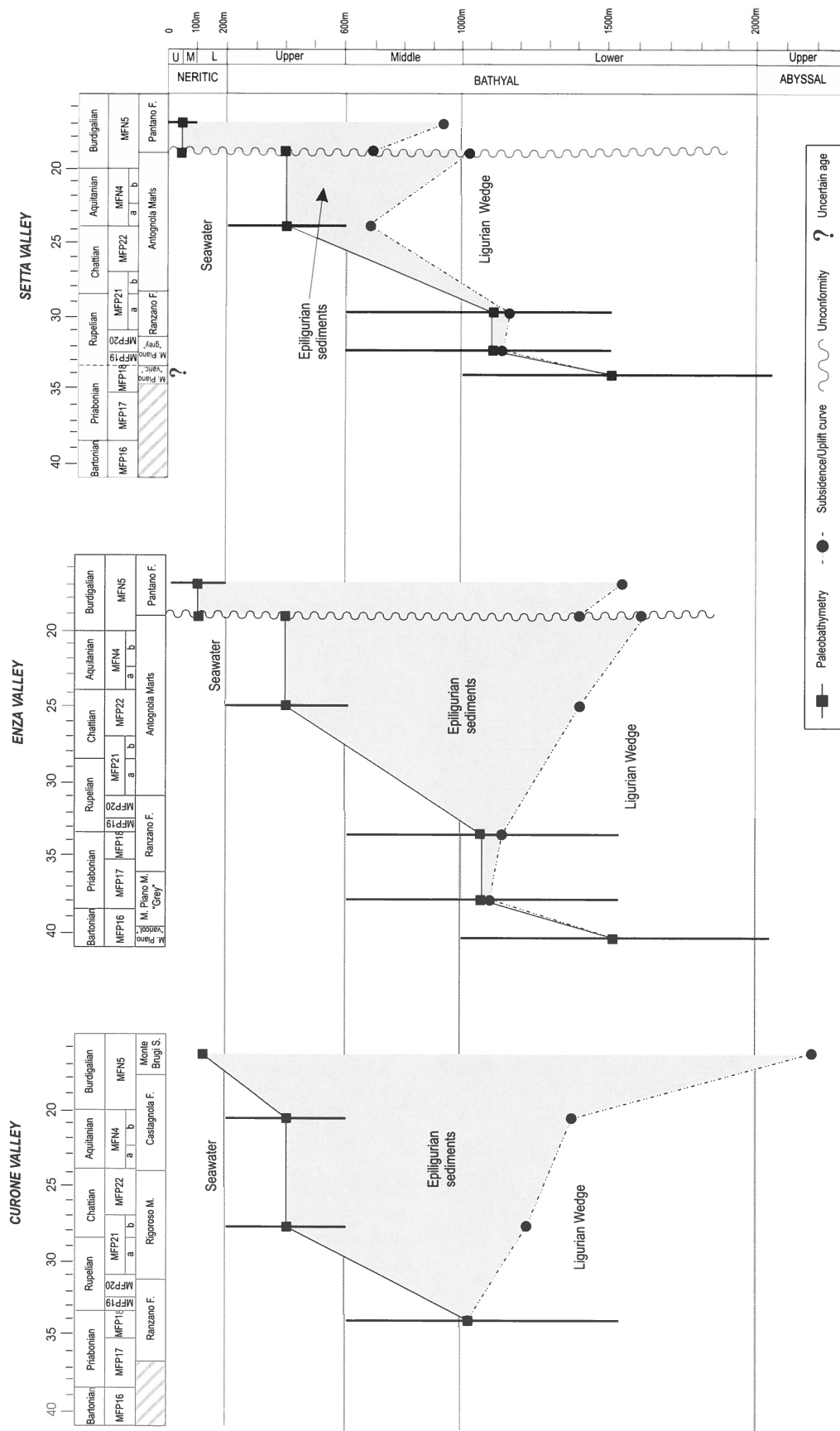
The boundary between the two facies is therefore better characterised by both planktonic and benthic foraminiferal assemblages rather than lithologies. The lithologies in fact do not show any visible change except for the colour (from red to grey) and a gradual increase in the silt content.

RANZANO SANDSTONE FORMATION

Foraminiferal assemblage results are very similar to those obtained for the "grey" Monte Piano Marls, only the benthic assemblage shows an increase of shallow and intermediate infaunal taxa, such as *Globocassidulina subglobosa*, *Globobulimina* spp., *Stilostomella* spp., *Vulvulina* spp. and subordinate *Uvigerina mexicana* and *Uvigerina havanensis*. This change is probably related to an increase of organic matter supplied by the turbiditic event. Most of these species, in fact, are usually associated with fine grained and organic rich sediments in meso- to eutrophic environments (Schmiedl *et al.*, 1997; 2000). Even in the studied agglutinated assemblages, the tubular epifaunal, such as *Hyperammina*, *Rhabdammina* and *Bathysiphon* decrease in abundance. According to some authors (Kaminski *et al.*, 1988 b; Kuhnt, 1990; Kaminski & Kuhnt, 1995) these opportunistic species are less suited to recolonise substrata after destructive events (such as a turbiditic flow), whereas are usually very common in stable hemipelagic sediments (e.g. "grey" Monte Piano Marls and overlying Antognola Marls). Therefore the studied foraminiferal assemblages are consistent not only with a middle-bathyal environment, as the underlying "grey" Monte Piano, but are also indicative of turbiditic facies. As regard to post-mortem processes, our assemblages do not show significant traces of selective dissolution or signs of significant transport, as the studied assemblages are usually homogeneous, absolutely devoid of shelf organisms, well preserved and without wear marks. This is even related to the sampling in the Ranzano Fm. of the more pelitic levels in its lower and upper portion only; these sediments are more suited to foraminiferal preservation and are less influenced by turbiditic events.

ANTOGNOLA MARLS AND ITS LATERAL EQUIVALENT UNITS

These units are lithologically very similar to the grey facies of the Monte Piano Marls, but their foraminiferal assemblages are quite different. The assemblages are always well diversified and with a very high P/P+B ratio, but planktonic and benthic indexes are indicative of upper bathyal paleodepth (Text-fig. 16). Planktonic shallow-water indexes, in fact, increase in abundance upwards and typical upper-bathyal benthic species dominate the assemblages. They are: *Anomalina pompilioides*, *Anomalinoidea ammophilus*, *Gyroidinoidea girardanus*, *Hetero-*



Text-fig. 17 - Geohistory diagrams of the Bartonian-Burdigalian succession in the study areas. The upper lines show water-depth history recorded by foraminiferal assemblages; the lower lines show the uplift/subsidence history of the Ligurian substratum (from Di Giulio *et al.*, 2001). Biostratigraphic zonation is referred to Mancin & Pirini, 2001.

lepa mexicana, *Heterolepa perlucida*, *Stilostomella nuttalli* and numerous large deep-sea agglutinated foraminifera such as species of the genera *Hyperammina*, *Bathysiphon* and subordinately *Rhabdammina*. Thus, these sediments are interpreted as deposited in the upper portion of the continental slope (600–200 m depth). Observations on Recent agglutinated taxa from the NE Atlantic support these data (Gooday *et al.*, 1997). In particular, large astrorhizaceans predominate on the continental slope (particularly in the upper part of the slope, 200–600 m depth), where the food supply originates from strong surface primary production, currents or down slope transport (Gooday *et al.*, 1997). However the proposed paleodepth is not only related to eutrophication: in the studied samples, assemblages are characterised by epifaunal morphogroups such as biconvex (*Heterolepa perlucida*, *Anomalinoidea ammophilus*, *Cibicidoides pseudoungerianus* and *Siphonina raeticulata*) and rounded trochospiral (*Heterolepa mexicana*, *Gyroidinoides girardanus*, and *Anomalina pompilioides*). Moreover, in the infaunal assemblages the shallow-dwelling ovoidal (*Globocassidulina subglobosa* and subordinately *Globobulimina*) and spherical morphogroups (*Pullenia bulloides* and *Sphaeroidina bulloides*) increase in abundance, while the deep-dwelling cylindrical (*Stilostomella* spp., *Nodosariella robusta* and *Nodosaria longiscata*), conical (*Uvigerina havanensis* and *U. auberiana* var. *attenuata*) and conical flattened (*Brizalina tectiformis*) morphogroups, become very rare to absent. On the contrary, in eutrophic continental margins, where oxygen is limiting factor, benthic foraminiferal faunas are dominated by infaunal, high productivity/low-oxygen tolerant species (Gooday & Rathburn, 1999). Even taphonomic processes, such as selective dissolution and transport are absent, as the studied faunas are usually homogeneous, well preserved and without wear marks. The same paleobathymetric range has also been proposed by Turco *et al.* (1994) for coeval adjacent sediments of the Rigoroso Marl Formation, located in the western Tertiary Piedmont Basin (Alessandria province) on the basis of very similar foraminiferal assemblages.

DEPOSITIONAL EVOLUTION

The proposed paleodepth can be used to reconstruct the history and origin of vertical movements (“geohistory”, Di Giulio *et al.*, 2001) affecting the Ligurian wedge from the Late Bartonian to the Early Burdigalian.

In the Enza Valley and Setta Valley areas (Text-fig. 17), the general shallowing upwards trend has been related to an initial (Bartonian) strong uplift of the Ligurian substratum followed by fairly uniform subsidence (Priabonian–Early Burdigalian). In both sections the subsidence was overbalanced by deposition, leading to a progressive decrease in accommodation

space and the filling up of the sedimentary basin. This last phase has been observed even in the Curone Valley, but here, sedimentation started in the Priabonian and consequently the Bartonian uplift was not documented.

CONCLUSIONS

The proposed paleobathymetric reconstruction, based on quantitative and qualitative analyses of both benthic and planktonic foraminiferal assemblages, can be summarised as follows:

- 1) the reliability of the applied method comes from i) the agreement of all the data obtained by the utilization and comparison of four bathymetric parameters and discussed with respect to the studied geological context; ii) the absence or limited presence of post-depositional alterations and taphonomic processes, or of monospecific foraminiferal assemblages indicative of anoxic or strongly dysoxic environments and finally iii) the wide range of depth proposed.
- 2) the utilized method consists of the integration and comparison of four parameters: P/P+B ratio, planktonic paleobathymetric indexes, benthic morphogroups and benthic index species belonging to depth-dependent microhabitats. The collected data record an overall shallowing up trend. A lower bathyal depth (over 2000 m to about 1000 m) has been determined for the Bartonian “varicoloured facies” of the Monte Piano Marls; middle bathyal depth (about 1000 m to 600 m) have been obtained for the Priabonian–Upper Rupelian grey marls and turbiditic sandstones of the Monte Piano and Ranzano Formations, respectively. Finally, the Upper Rupelian–Lower Burdigalian Antognola Marl Formation (and its lateral equivalent units) contains foraminiferal assemblages indicating an upper bathyal paleodepth (about 600 to 200 m).
- 3) The shallowing upwards trend has been related to the geohistory of the sedimentary basin: to a Bartonian uplift (Enza and Setta Valley) a gradual subsidence follows, overbalanced by the sediment deposition, which leads to a progressive decrease in accommodation space and the filling up of the sedimentary basin.
- 4) We believe that the proposed approach can be validly applied to other geological settings and different time intervals, providing also the basis for interpreting paleobathymetry and basin history. This work reinforces the utility of the study of all the aspects of foraminiferal assemblages and their applicability to paleoenvironmental reconstruction.

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