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MIDDLE EOCENE TO EARLY MIOCENE FORAMINIFERAL BIOSTRATIGRAPHY IN THE EPILIGURIAN SUCCESSION (NORTHERN APENNINES, ITALY)

NICOLETTA MANCIN* & CAMILLA PIRINI**

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Riassunto. Uno studio biostratigrafico quantitativo è stato condotto sulle associazioni a foraminiferi di 15 sezioni stratigrafiche della successione epiligure (Eocene medio-Miocene inferiore), affioranti lungo un tratto di catena nord appenninica di circa 250 Km, dalla provincia di Alessandria alla provincia di Bologna.

Questo lavoro ha permesso di riconoscere alcuni dei bioeventi standard e di notare che alcuni di essi sono invece assenti o presentano una diversa distribuzione cronostratigrafica. Sono stati però individuati altri bioeventi che, ricorrendo costantemente nelle sezioni esaminate, assumono un significato regionale e possono sostituire gli eventi standard assenti. I più significativi comprendono l'estinzione massiccia delle specie a guscio muricato in corrispondenza del limite Bartoniano/Priaboniano; il marcato aumento in abbondanza di *Paragloborotalia opima opima* in prossimità del limite tra le sottozone P21a e P21b e quindi del limite Rupeliano/Cattiano ed infine la comparsa di *Globoquadrina dehiscens* per identificare il limite tra le sottozone N4a ed N4b.

Sulla base di quanto esposto sopra è stato proposto uno schema biozonale per il Paleogene dell'area esaminata. Questo schema è inoltre facilmente correlabile con quelli standard per la quasi generale corrispondenza dei limiti zonali.

Abstract. A quantitative biostratigraphical study was performed on the foraminiferal assemblages from 15 stratigraphic sections of the Epiligurian Succession (Middle Eocene-Early Miocene, Northern Apennines, Italy).

This study enabled us to identify the presence of some of the standard bioevents and to note that other bioevents are absent or show a different chronostratigraphic range. Other additional bioevents, identified throughout the area, have therefore been utilised to improve the biostratigraphical resolution of the Epiligurian sediments.

These bioevents include the massive extinction of the muricate species at the Bartonian/Priabonian boundary; the increasing abundance of *Paragloborotalia opima opima* near Subzone P21a/P21b and the Rupelian/Chattian boundaries; and the FO of *Globoquadrina dehiscens* at the Subzone N4a/N4b boundary.

Based on the collected data, a zonal scheme is proposed for the Paleogene sequence of the study area. This scheme correlates easily with other standard schemes, based on a general correspondence between the zonal boundaries.

Introduction

Regional studies concerning the Epiligurian succession in the Northern Apennines date back to the 1960s (Pieri 1961; Pirini 1961; Ghelardoni et al. 1965; Sestini 1970). Other papers and especially the more recent ones deal with restricted areas and their biostratigraphical data are difficult to correlate. Among these are Braga (1962, 1963, 1965; Piacenza area); Andreoni et al. (1981) and Cavanna et al. (1989) for the eastern sector of the Tertiary Piedmont Basin; Fregni (1986) and Fregni & Panini (1987) for the Reggio Emilia-Modena area; Papani (1971), Papani et al. (1987), Cerrina Feroni et al. (1991) and De Nardo et al. (1991) for the Parma area, and Bettelli et al. (1991) for the Bologna area.

Biostratigraphy of the Epiligurian sequence is still poorly constrained owing to several factors, such as structural deformation, difficult correlation and poor preservation of microfossils. The most important factor, however, consists of the peculiar characteristics of foraminiferal assemblages; some of the tropical and Mediterranean zonal markers are, in fact, very rare to absent throughout the succession, or have a different chronostratigraphical range.

Therefore, there was a need to identify additional bioevents, thereby to propose an up-to-date planktonic foraminiferal biostratigraphy that could be correlated with the standard zonations.

This has been the primary aim of a study carried out on 15 sections spanning the Middle Eocene-Early Miocene interval; these sections are located in four areas over a distance of 250 km, between the southeastern Piedmont and the Bologna area (Fig. 1).

Geological framework

Epiligurian sediments crop out in several isolated

*Dipartimento di Scienze della Terra, Università degli Studi di Pavia, via Ferrata 1, 27100 Pavia; e-mail nmancin@manhattan.unipv.it
**Dipartimento per lo Studio del Territorio e delle sue Risorse, Università degli Studi di Genova, corso Europa 26, 16232 Genova.

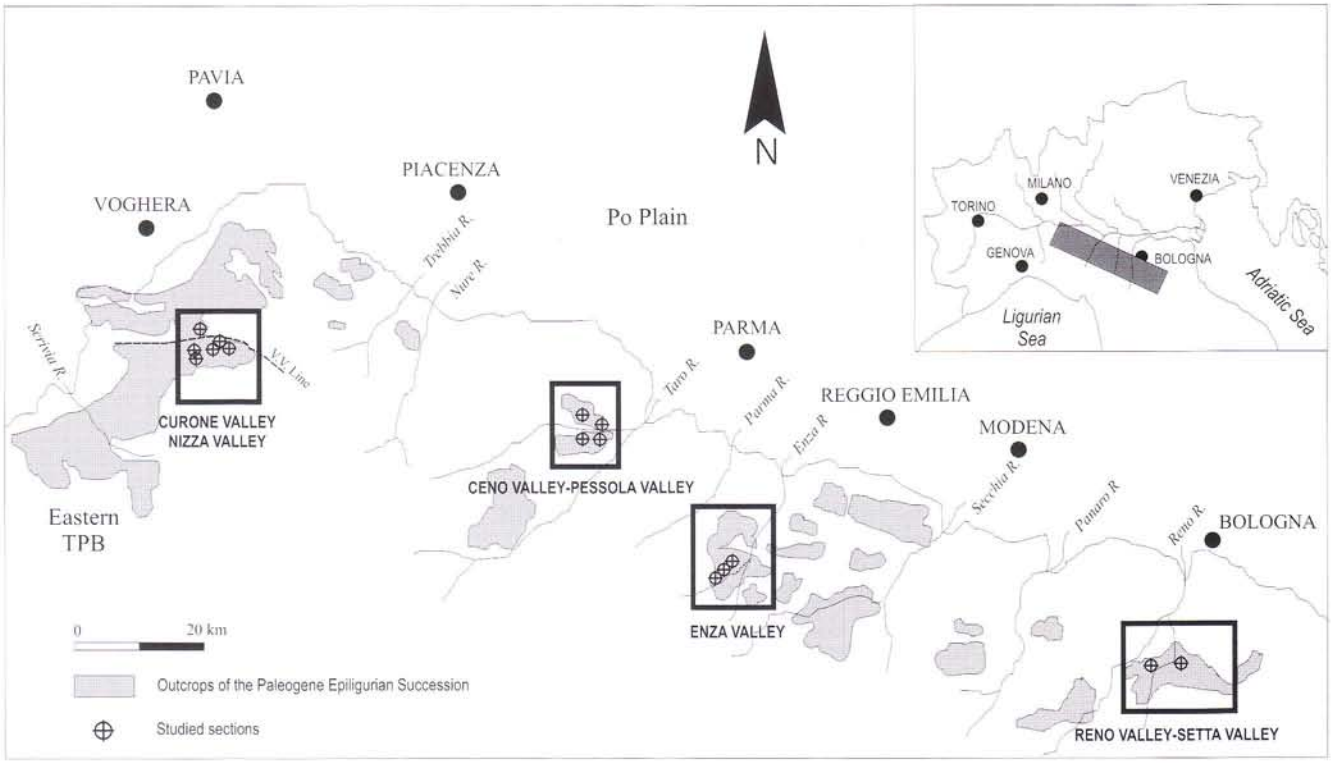


Fig. 1 - Location of the investigated areas of the Paleogene Epiligurian Succession in the Northern Apennines and in the eastern sector of the Tertiary Piedmont Basin (TPB).

bodies along the Northern Apennine chain (Fig. 1). They were deposited from the Middle Eocene in "piggy-back" basins on an accretionary wedge, in a relatively backward position with respect to the deforming front (Ori & Friend 1984; Ricci Lucchi & Ori 1985; Ricci Lucchi 1990). These deposits unconformably overlie the Ligurid Units, deformed during the Early Paleogene orogenic phases. Later, they were translated northeastwards together with the substratum, following the Apennine orogenesis.

The succession of the Tertiary Piedmont Basin (TPB), to the west, is similar to the Epiligurian succession. It differs mainly in the presence of a Ligurid substratum at its eastern margin, and the smaller translational movement (Gelati & Gnaccolini 1982, 1987, 1998; Biella et al. 1987).

Epiligurian sediments are composed of hemipelagic marls and turbiditic sandstones and conglomerates, mainly deposited in deep-water basins showing a complex internal topography. They were fed by erosion of the mountain chain and are characterised by sharp lateral variations in the depositional geometry (Ricci Lucchi 1987, 1990; Bettelli et al. 1987; Boccaletti et al. 1990; Martelli et al. 1993,1998; Mutti et al. 1995).

The studied succession includes the Monte Piano Marl Formation (unconformably overlying the so-called "Sedimentary Mélanges"), the Ranzano Sandstone Formation and the Antognola Marl Formation (Fig. 2). The 15 surveyed sections crop out in four geographical areas over a distance of about 250 km covering, in each area, the various portions of the entire stratigraphic succession, often discontinuos. These are: the Curone Valley-Nizza Valley area (Fontanelle, Ca' Bella N, San Michele, Nivione, Valle di Nivione and Monteacuto sections; AL and PV provinces, Fig. 3-8); the Ceno Valley-Pessola Valley area (Rio delle Lubbie, Rio Molinetto, Fosio and Rio Boccolo sections, PR province; Fig. 9-12); the Enza Valley area (Campora, Mussatico and Antognola sections, PR province; Fig. 13-15), and finally the Reno Valley-Setta Valley area (Cava dell'Albergana and Torrazza sections, BO province; Fig. 16-17). The westernmost area includes two different tectonostratigraphic units: the Curone Valley, belonging to the eastern sector of the TPB and the Nizza Valley to the Northern Apennines domain, as the other areas. They are separated by the Villalvernia-Varzi Line (VV line) often considered the Alps-Apennines boundary (Mutti et al. 1995 and ref. therein).

Geological cartography is reported in references as Geological Maps (GM).

- The Monte Piano Marl Fm. is composed, in its lower part, of varicoloured marly clays passing gradually upward to grey silty marls, through transitional grey-hazel silty marls; these sediments are homogeneous all over the area. The total thickness is about 70 m in the Fosio and Campora sections, but the maximum and minimum values, of 116 m and 40 m respectively, have been recognised in the Monteacuto and Cava dell'Alber-

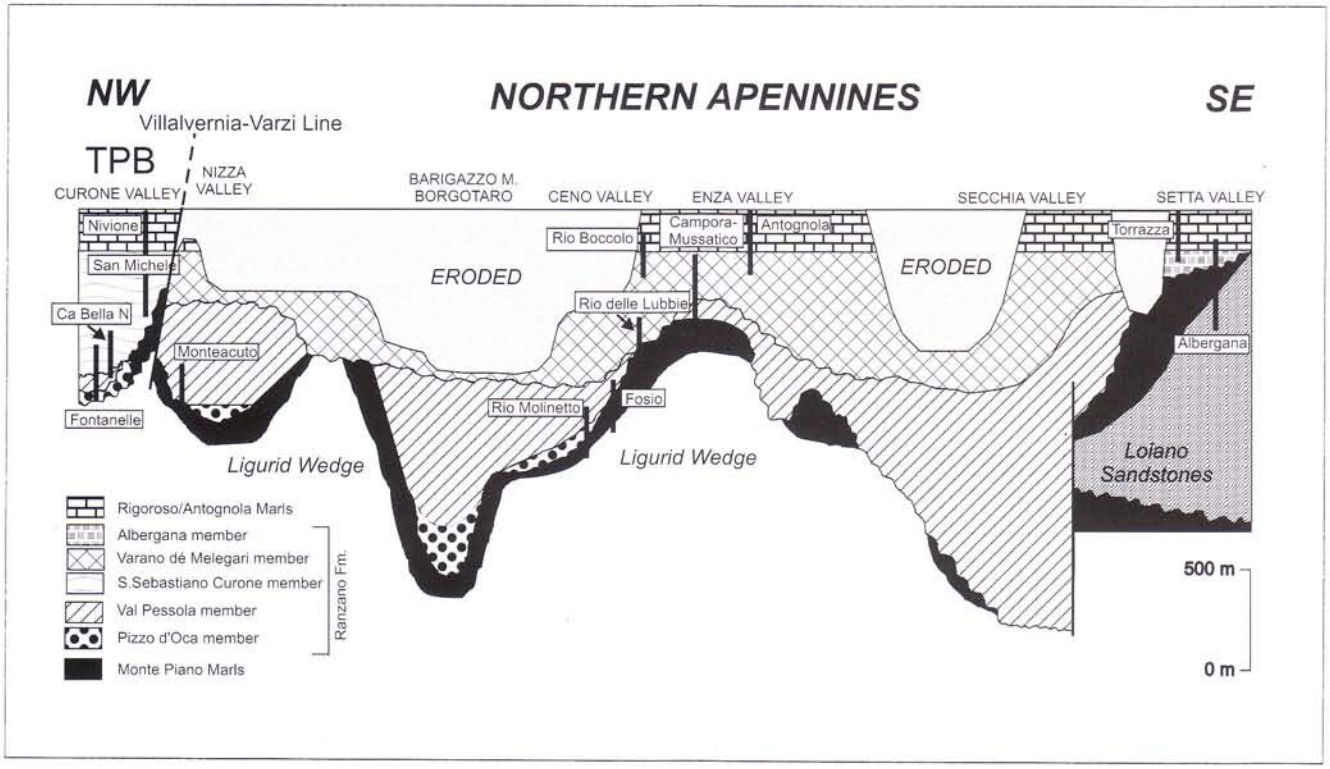


Fig. 2 - Scheme showing the stratigraphic and geometric relations of the studied lithostratigraphic units (from NW to SE) and location of the investigated sections (modified from Martelli et al. 1993).

gana sections. A Bartonian-Priabonian age is assigned to these sediments in the central-western sector and a Bartonian-early Rupelian age to the eastern outcrops (Vescovi & Rio 1981; Fregni 1986; Bettelli et al. 1987, 1991).

- The Bosmenso marls is a local informal unit, present in the eastern sector of the TPB only, with a lithology very similar to that of the Monte Piano Marl "grey facies". In the studied sections, it is interbedded within the middle part of the Ranzano Sandstones but, in the westernmost adjacent areas, it can replace heteropically the Montepiano Marls and/or the Ranzano Sandstones.

- The Ranzano Sandstones is a very thick turbiditic unit (over 700 m thick), recently subdivided into five informal members (Pizzo d'Oca, Val Pessola and the upper heteropic members of San Sebastiano Curone, Varano de' Melegari and Albergana) mostly on the basis of the sandstone composition (Di Giulio 1991; Cibin 1993; Martelli et al. 1993, 1998). In the study areas this formation (Priabonian/early Rupelian to the late Rupelian; Catanzariti et al. 1997) was studied in its lower and upper portions only, that consist of pelitic or pelitic-arenaceous sediments, more suited for planktonic foraminiferal preservation. Moreover, a peculiar sand body, about 20-150 m thick (Lagrimone Sandstones-Upper Rupelian), is intercalated between the top of the Ranzano Sandstones and the overlying Antognola Marls in the Enza Valley (PR province).

- The Antognola Fm. (Rupelian-Burdigalian) is lithologically homogeneous over the whole studied area and is composed of grey silty marls, with local sand bodies (Iatica and Anconella Sandstones) interbedded at different levels. Its upper part consists of cherty marls (Contignaco Formation auct.). In the eastern sector of the TPB, the Antognola Fm. is laterally replaced by hemipelagic and turbiditic sediments of the Rigoroso and Castagnola Formations (Andreoni et al. 1981; Cavanna et al. 1989).

Materials and methods

About 500 samples from 15 sections were analysed for their foraminiferal content. Laboratory techniques, as well as field collection, were based on standard methods.

A quantitative analysis was performed on all the samples. In each fraction (>425, >180 and >125 micron) 300 specimens were counted; a qualitative visual estimate was carried out on the >75 and >38 μm fractions. The best observations have been made on the larger and medium fractions (>125 μm), while the finest one (> 38 μm), consisting mostly of juvenile specimens not recognizable and small taxa as tenuitellids, globorotalids and very rare chiloguembelinids, is usually poorly preserved. Abundance curves of the marker species were plotted using the counting of the >180 μm fraction,

Age	Reference Sections	Main events	Secondary events	Lithostratigraphic units	Other sections
EARLY MIOCENE (Aquitanian - Early Burdigalian)	Valle di Nivione (Fig. 7)	- FO of *P. kugleri* (sample NC7) - FO of *G. dehiscens* (NC10) - LO of *P. kugleri* (NC12)	- LO of *G. sellii* (NC10) - LO of *G. rohri* (NC11) - LO of *P. pseudokugleri* (NC11) - FO of *G. trilobus* gr. (NC12)	All the bioevents have been found in the lower portion of the Castagnola Fm.	- Nivione (Fig. 5; samples m"R45- C53) - Torrazza (Fig. 17; samples TANT15-TANT18)
	Antognola (Fig. 15)	- FO of *P. kugleri* (AANT37) - FO of *G. dehiscens* (AANT39) - LO of *P. kugleri* (AANT47)	- LO of *G. sellii* (AANT42) - LO of *P. pseudokugleri* (AANT45) - FO of *G. trilobus* gr. (AANT48) - LO of *G. rohri* (AANT52)	All the bioevents have been found in the Antognola Fm.	
LATE OLIGOCENE (Chattian)		- LO of *P. opima opima* (AANT20)	- FO of *P. pseudokugleri* (AANT24) - FO of *G. primordius* (AANT28) - LO of *G. angulisuturalis* (AANT36)		- San Michele (Fig. 5; samples Mm'R22- Mm'R30) - Valle di Nivione (Fig. 7, samples NR1-NC6) - Rio delle Lubbie (Fig. 9; samples ANT7- ANT21) - Torrazza (Fig. 17; samples TANT1-TANT14)
	Nivione (Fig. 6)	- LO of *P. opima opima* (m"R30)	- FO of *P. pseudokugleri* (m"R31) - FO of *G. primordius* (m"R38) - LO of *G. angulisuturalis* (m"R44)	All the bioevents have been found in the upper member of the Rigoroso Marls.	
EARLY OLIGOCENE (Rupelian)	San Michele (Fig. 5)	- LO of *G. ampliapertura* (Mm'R9) - LO of *C. cubensis* (Mm'R21)	- LO of *T. pseudoampliapertura* (Mm'R3) - FO of *G. sellii* (Mm'R6) - FO of *G. rohri* (Mm'R9) - FO of *G. ciperoensis* (Mm'R11) - FCO of *P. opima opima* (Mm'R13)	All the bioevents have been found in the lower member of the Rigoroso Marls.	- Fontanelle (Fig. 3; samples FAR15 - FAR20) - Ca' Bella N (Fig. 4; samples CBN1 - CBN16) - Monteacuto (Fig. 8; samples MMP43 - MMP59) - Rio delle Lubbie * (Fig. 9; samples ANT1-ANT6) - Mussatico (Fig. 14; samples MAR1- MAR17) - Antognola (Fig. 15; samples AAR2- AANT15)
	Rio Boccolo (Fig. 12)	- LO of *G. ampliapertura* (Ba24) - *C. cubensis* is continously present throught the section.	- FO of *G. sellii* (Br4)) - FO of *G. ciperoensis* (Br8) - LO of *T. pseudoampliapertura* (Br9) - FO of *G. rohri* (Ba22) - FCO of *P. opima opima* (Ba30)	In the upper portion of the Ranzano Fm. (Varano de' Melegari member; Br) and in the lower part of the Antognola Fm. (Ba)	
	Cava dell'Albergana (Fig. 16)	- LO of *P. naguewichiensis* (AMP27) - LO of *G. ampliapertura* (AMP27) They occur together, probably because this section is condensed.	- FO of *P. opima opima* (AMP26)	All the bioevents have been found in the Albergana mbr. of the Ranzano Fm.	
EOCENE (Late Bartonian - Priabonian)	Campora (Fig. 13)	- LO of muricate species (CMP11) - LO of *G. semiinvoluta* (CAR32)	- FO of *G. semiinvoluta* (CMP8) - LO of *G. subconglobata luterbacheri* (CAR32)	In the Monte Piano Fm. (CMP) and in the Val Pessola member (CAR)	- Fontanelle (Fig. 3; samples FAR1 - FAR14) - Rio delle Lubbie * (Fig. 9; samples MMP0-MMP10) - Rio Molinetto (Fig. 10; samples RMMP1-RMMP19) - Fosio (Fig. 11; samples FMP12b - FMP42) *A hiatus, corresponding to the Upper Bartonian- Rupelian p.p. interval, is present; the Antognola Fm., in fact, directly overlie the varicoloured Monte Piano Marls.
	Monteacuto (Fig. 8)	- LO of muricate species (MMP5) - LO of *G. semiinvoluta* (MMP31) - LO of *T. cerroazulensis* lineage (MMP42)	- LO of *P. pseudoscitulus* (MMP3) - FO of *G. semiinvoluta* (MMP3) - LO of *G. subconglobata luterbacheri* (MMP9) - LO of *T. cerroazulensis pomeroli* (MMP15) - FO of *G. ampliapertura* (MMP25) - FO of *T. pseudoampliapertura* (MMP32) - FO of *P. naguewichiensis* (MMP40) - LO of *P. micra* (MMP42)	All the bioevents have been found in the Monte Piano Fm.	

Tab. 1 - Summary of middle Eocene to early Miocene planktonic foraminiferal bioevents in the studied sections. Main and secondary bioevents have been reported separately for the most rapresentative sections.

only for some smaller species (e.g *Globigerina ciperoensis, Pseudohastigerina* spp., *Paragloborotalia kugleri* and *P. pseudokugleri*) of the >125 μm fraction (Fig. 3 to 17).

Generic and specific planktonic foraminiferal attributions are based on Toumarkine & Luterbacher (1985) for the Eocene taxa, and on Bolli & Saunders (1985), Spezzaferri (1994) and Haggag & Luterbacher (1995) for the Oligocene and Early Miocene taxa.

Biostratigraphical data

The studied sections are grouped on the basis of their chronostratigraphical range: Eocene (Late Bartonian-Priabonian), Early Oligocene (Rupelian), Late Oligocene (Chattian) and Early Miocene (Aquitanian-Early Burdigalian). The chronostratigraphical boundaries and the relevant bioevents are discussed later.

Main and secondary planktonic foraminiferal bioevents have been reported separately for the most representative sections (Tab. 1). The range chart of planktonic foraminifera for each section may be obtained by N. Mancin or on the web site http: www.gp.terra.unimi.it/107N3.html.

Nannofossils analyses

The Eocene/Oligocene boundary, well exposed only in the Fontanelle (AL) and Monteacuto (PV) sections, was better defined by integrating the foraminiferal data with the nannofossil data. Martini's (1971) and Catanzariti & Rio's (in Catanzariti et al. 1997) nannofossil biozonations are applied.

Calcareous nannofossil analyses (Mancin & Cobianchi, 2000; Cobianchi, personal communication) have been carried out on seventy samples from the Monteacuto (Fig. 8) and Fontanelle (Fig.3) sections. Five biozones have been recognised (from bottom to top):

The NP18 p.p. Zone of Martini (1971), characterised by the co-occurrence of *Chiasmolithus grandis, Discoaster bisectus, Discoaster barbadiensis, Discoaster saipanensis* and *Cribrocentrum reticulatum*.

The NP19 p.p. Zone, characterised by the co-occurrence of *Isthmolithus recurvus* and *C. reticulatum*. Other taxa are *D. barbadiensis, D. saipanensis* and *D. bisectus*.

The *Cribrocentrum reticulatum* Zone (MNP19 Zone of Catanzariti & Rio, in Catanzariti et al. 1997), characterised by the FCO (First Common Occurrence) of *I. recurvus*.

The *Discoaster saipanensis* Zone (MNP20), characterised by the LOs of *C. reticulatum* and *C.* aff. *reticulatum* together with the co-occurrence of *D. barbadiensis* and *D. saipanensis*.

Finally, the *Discoaster saipanensis/Ericsonia obruta* Subzone (MNP21a), characterised by the LO of *D. barbadiensis* and *D. saipanensis*.

At the top, the FCO of *E. obruta identifies* the base of the subsequent *E. obruta* Subzone (MNP21b).

Planktonic foraminiferal bioevents

The bioevents, described in table 1 and summarized in Fig. 18, are listed below in stratigraphical order (from bottom to top):

1) LO of the muricate species (*Acarinina* spp., *Morozovella* spp., *Truncorotaloides* spp.)
2) LO of *Globigerinatheka semiinvoluta*
3) LO of *Turborotalia cerroazulensis* group
4) LO of *pseudohastigerinids*
5) LO of *Globigerina ampliapertura*
6) LO of *Chiloguembelina cubensis*
7) LO of *Paragloboroatalia opima opima*
8) FO of *Paragloborotalia kugleri*
9) FO of *Globoquadrina dehiscens*
10) LO of *P. kugleri*

Seventeen secondary bioevents have been also recognised (from bottom to top):

- FO of *Globigerinatheka semiinvoluta*
- LO of *Planorotalites pseudoscitulus*
- LO of *Turborotalia cerroazulensis pomeroli*
- LO of *Globigerinatheka subconglobata luterbacheri*
- FOs of *Pseudohastigerina naguewichiensis* and pseudohastigerinids with sizes > 125 μm.
- FO of *Globoquadrina sellii*
- LO of *Turborotalia pseudoampliapertura*
- FO of *Globoquadrina rohri*
- FO of *Globigerina ciperoensis*
- FCO of *Paragloborotalia opima opima*
- FO of *Paragloborotalia pseudokugleri*
- FO of *Globigerinoides primordius*
- LO of *Globigerina angulisuturalis*
- LO of *Globoquadrina sellii*
- LO of *Globoquadrina rohri*
- LO of *Paragloborotalia pseudokugleri*
- FO of *Globigerinoides trilobus* gr.

Biostratigraphical zonal scheme

Based on the all bioevents, mentioned above (Fig. 18 and 19), a number of planktonic foraminiferal biozones are here proposed and discussed. An informal numerical notation codifies each zone in figures and for simplifying discussions and correlations. MFP and MFN indicate the Mediterranean Foraminifera Paleogene and Mediterranean Foraminifera Neogene, respectively.

- *Acarinina* spp., *Globigerinatheka* spp., *Turborotalia cerroazulensis* Assemblage Zone (MFP16 p.p.).
- *Globigerinatheka semiinvoluta* Interval Zone (MFP17).
- *Turborotalia cerroazulensis* s.l. Interval Zone (MFP18).
- *Pseudohastigerina* spp. Interval Zone (MFP19).
- *Globigerina ampliapertura* Interval Zone

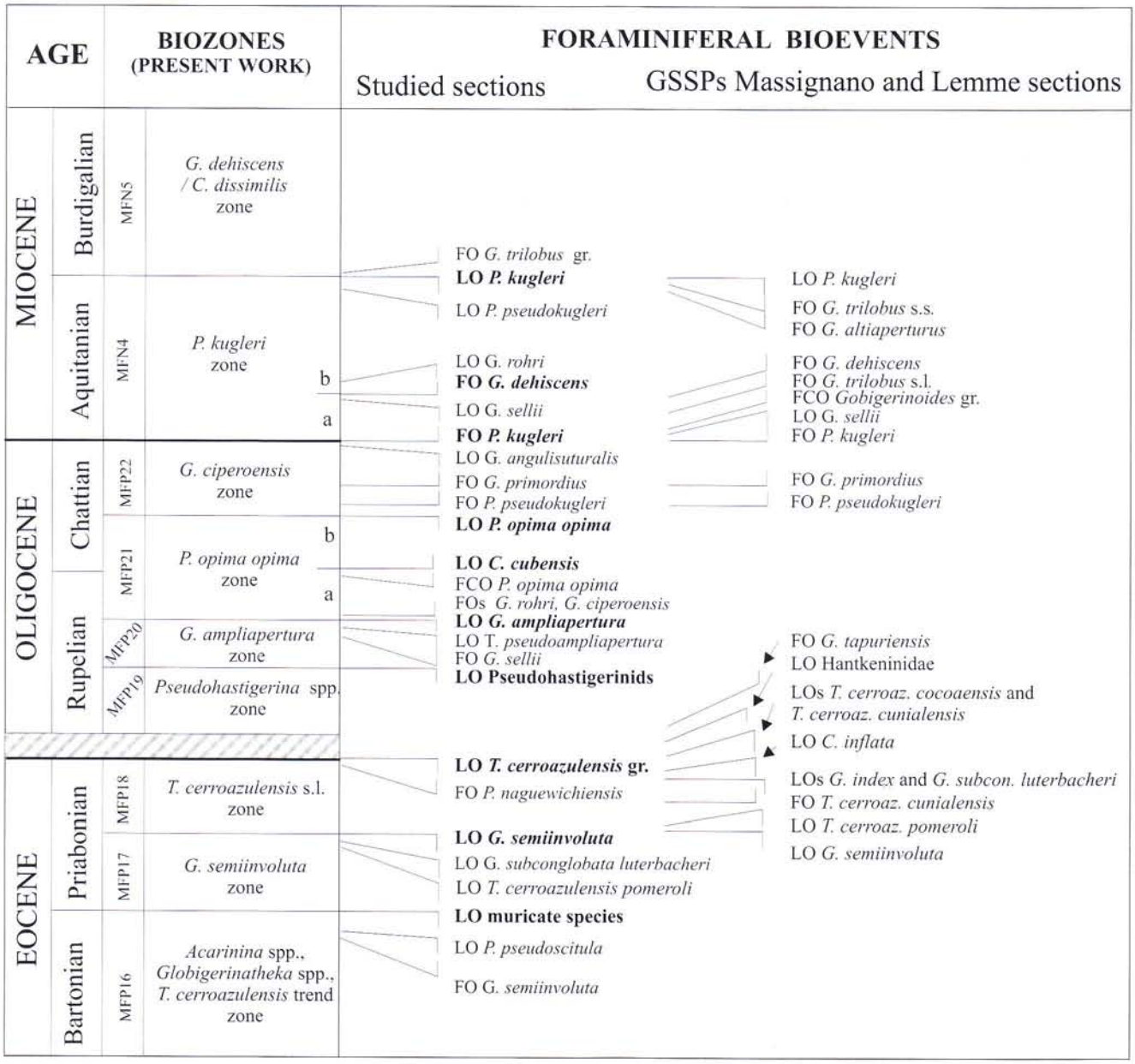


Fig. 18 - Proposed biostratigraphic zonal scheme: main and secondary foraminiferal bioevents in the studied Epiligurian succession and in the GSSPs Massignano and Lemme sections. Main events in bold line. The striped area indicates the discrepancies in the E/O boundary position from the Massiniano and the studied sections.

(MFP20).

- *Paragloborotalia opima opima* Interval Zone (MFP21).
- *Globigerina ciperoensis* Interval Zone (MFP22).
- *Paragloborotalia kugleri* Total Range Zone (MFN 4).
- *Globoquadrina dehiscens/Catapsydrax dissimilis* Co-occurence Range Zone (MFN5).

Acarinina spp., *Globigerinatheka* spp., *Turborotalia cerroazulensis* Assemblage Zone (MFP16 p.p.)

Authors: Mancin & Pirini, in Mancin & Cobianchi (2000).

Definition: interval from the LO of *Orbulinoides beckmanni* (Bolli, 1957a) to the abrupt massive extinction of the muricate species. The base of the zone is not exposed in the studied sections.

Age: Late Bartonian (Middle Eocene).

Description: the planktonic foraminiferal assemblage consists of abundant muricate species (Pl. 1, fig. 1-5), such as *Acarinina bullbrooki* and *A. spinuloinflata*, rare *Truncorotaloides pseudotopilensis*, *Morozovella lehneri* and *M. spinulosa*. *Truncorotaloides rohri* is usually absent to very rare (1-3 specimens out of 300); the genus *Globigerinatheka* (*G. index index, G. subconglobata luterbacheri*, Pl. 2, fig. 1-2) and representatives of the *Turborotalia cerroazulensis* lineage (*T. cerroazulensis pomeroli, T. cerroazulensis cerroazulensis* and subordi-

AGE		PRESENT WORK	Blow (1969)	Toumarkine & Luterbacher (1985)	Bolli & Saunders (1985)	Berggren & Miller (1988)	Spezzaferri (1994)	Iaccarino (1985)	Iaccarino et al. (1996)
MIOCENE	Burdigalian	?	N6	(shaded)	*C. staiforthi* Zone	(shaded)	*G.insueta/ C. dissimilis* Zone (N6)	*G. altiaperturus / C. dissimilis* Subzone	*G. altiaperturus / C. dissimilis* Zone
	Burdigalian	*G. dehiscens / C. dissimilis* (MFN5)	N5	(shaded)	*C. dissimilis* Zone	(shaded)	*G. praedehiscens /G. dehiscens* Zone (N5)		
	Aquitanian	*P. kugleri* (MFN4) b	N4	(shaded)	*G. primordius* Zone	N4 b	*P. kugleri* Zone (N4) b	*G. dehiscens dehiscens* Subzone	*G. dehiscens* Zone
	Aquitanian	a		(shaded)	*G. kugleri* Zone	a	a	(shaded)	*P. kugleri* Zone
OLIGOCENE	Chattian	*G. ciperoensis* (MFP22)	P22	(shaded)	*G. ciperoensis* Zone	P22	*G. ciperoensis* Zone (P22)	(shaded)	*G. ciperoensis ciperoensis* Zone
	Chattian / Rupelian	*P. opima opima* (MFP21) b / a	P21	(shaded)	*G. opima opima* Zone	P21 b / a	*P. opima opima* Zone (P21) b / a	(shaded)	(shaded)
	Rupelian	*G. ampliapertura* (MFP20)	P20	(shaded)	*G. ampliapertura* Zone	P20 / P19	*Z. ampliapertura* Zone (P20)	(shaded)	(shaded)
	Rupelian	*Pseudohastigerina* spp. (MFP19)	P19 / P18	(shaded)	*C. chipolensis/ P. micra* Zone	P18	(shaded)	(shaded)	(shaded)
EOCENE	Priabonian	*T. cerroazulensis* s.l. (MFP18)	P17	*T. cerroazulensis* s.l. Zone	(shaded)	P17	(shaded)	(shaded)	(shaded)
	Priabonian	*G. semiinvoluta* (MFP17)	P16 / P15	*G. semiinvoluta* Zone	(shaded)	P16 / P15	(shaded)	(shaded)	(shaded)
	Bartonian	*Acarinina* spp., *Globigerinatheka* spp., *T. cerroazulensis* (MFP16)	P14	*T. rohri* Zone	(shaded)	P14	(shaded)	(shaded)	(shaded)

Fig. 19 - Summary of middle Eocene to early Miocene planktonic foraminiferal zonal schemes. In bold line the Eocene/Oligocene and the Oligocene/Miocene boundaries according to the various authors.

nately *T. cerroazulensis frontosa*; Pl. 2, fig. 8-10) are common throughout the zone. Other planktonic taxa are: catapsydracids and large "globigerinids" (*Globigerina venezuelana, "Globigerina" senni, Subbotina eocaena, S. eocaenica,* and *S. utilisindex*), *Planorotalites pseudoscitulus, Globorotaloides carcoselleensis* and rare *Pseudohastigerina micra. Globigerinatheka semiinvoluta* and *Planorotalites pseudoscitulus* first and last occur, respectively, in the upper part of the biozone.

The benthic foraminiferal assemblage contains abundant *Nuttallides trümpyi, Anomalinoides alazanensis, Bulimina socialis, B. curtissima, Globocassidulina subglobosa,* and agglutinated taxa, such as *Abyssammina* spp., *Glomospira charoides, G. gordialis, Psammosphaera fusca* and *Rhabdammina* spp. (Mancin 1999).

Remarks: the LO of the muricate species, used to define the upper boundary of the biozone, corresponds to the LO of *T. rohri*, as, these two events are coeval in the oceanic record (Bolli 1957a; Toumarkine & Luterbacher 1985). Nocchi et al. (1986) used the LO of acarininids to define the upper boundary of Zone P14 and the Bartonian/Priabonian boundary in the Umbrian pelagic sequences, because *T. rohri* was missing. The LO of some small muricate species (e.g. *Acarinina medizzai, A. rugosoaculeata, A. rotundimarginata*), however, occurs later in the overlying zone, just above the LO of *T. cerroazulensis pomeroli* and near the FO of *T. cerroazulensis cunialensis* (at 7,2 m), in the Massignano section (Coccioni et al. 1988; Spezzaferri et al. in press).

The LO of muricate species, in the studied sections, is always preceded by a marked reduction in size (<125 μm) and abundance, but no muricate taxa have been observed above the Bartonian/Priabonian boundary.

This interval corresponds to the *T. rohri* Zone (Bolli, 1957a) and is correlated to Zone P14 and the lower part of Zone P15 of Berggren & Miller (1988); the upper boundary of Zone P14, defined by the FO of *G. semiinvoluta*, in the studied sections occurs slightly before the LO of muricate species and is used to correlate Bolli (1957a) and Berggren & Miller (1988) biozonations.

Globigerinatheka semiinvoluta Interval Zone (MFP17)

Author: Bolli (1957a), modified by Proto Decima & Bolli (1970).

Definition: interval from the LO of the muricate species to the LO of *Globigerinatheka semiinvoluta*.

Age: Early Priabonian (Late Eocene).

Description: the zonal marker (Pl. 2, fig. 3) is usually present throughout the interval, sometimes commonly (Fontanelle section). It decreases abruptly in abundance and becomes discontinuously present just before its LO. The planktonic assemblage is characterised by rapresentatives of the *Turborotalia cerroazulensis* lineage (*T. cerroazulensis cerroazulensis, T. cerroazulensis cocoaensis* and *T. cerroazulensis cunialensis*; Pl. 2, fig. 6-7), *Globigerinatheka* (*G. subconglobata luterbacheri* and in suborder *G. index index*), *Globigerina venezuelana, Subbottina utilisindex, Subbottina eocaena, catapsydracids* and *Pseudohastigerina micra. Hantkenina* and *Cribrohantkenina* are usually absent to very rare (Fontanelle section). *T. cerroazulensis pomeroli* and *G. subconglobata luterbacheri* disappear in the middle-upper part of the zone.

Nuttallides trümpyi becomes very rare and last occurs near the middle part of the zone. In the Massignano section, its LO is recorded near the top of Zone P15 (Coccioni et al., 1988). *Heterolepa grimsdalei, Eponides abatissae* and the agglutinated species with calcite cement and a coarse-grained texture (*Hyperammina elongata, Bathysiphon* spp.) are common, as well as *Stilostomella nuttalli* and *Vulvulina spinosa* (Mancin 1999).

Remarks: the LOs of *T. cerroazulensis pomeroli* and *G. subconglobata luterbacheri* occur later in the overlying zone, just above the LO of *G. semiinvoluta*, and near the LO of *Cribrohantkenina inflata*, respectively, in the Massignano section (Coccioni et al. 1988).

This interval corresponds to Zone P15 p.p. and to the lower part of Zone P16 of Berggren & Miller (1988).

Turborotalia cerroazulensis s.l. Interval Zone (MFP18)

Author: Bolli (1957a), modified by the same author in 1972.

PLATE 1

Fig. 1 - *Acarinina bullbrooki* (Bolli, 1957); sample MMP8, Rio delle Lubbie section, Monte Piano Marls, Bartonian. a) Umbilical view. b) Lateral view.

Fig. 2 - *Acarinina* sp.; sample MMP8, Rio delle Lubbie section, Monte Piano Marls, Bartonian. a) Umbilical view. b) Lateral view.

Fig. 3 - *Truncorotaloides testarugosa* (Bandy, 1949); sample MMP10, Rio delle Lubbie section, Monte Piano Marls, Bartonian. a) Umbilical view. b) Lateral view. c) Detail of the muricate structure.

Fig. 4 - *Truncorotaloiedes pseudotopilensis* (Cushman, 1925); sample MMP10, Rio delle Lubbie section, Monte Piano Marls, Bartonian. a) Umbilical view. b) Lateral view.

Fig. 5 - *Morozovella lehneri* (Cushman & Jarvis, 1929); sample MMP10, Rio delle Lubbie section, Monte Piano Marls, Bartonian. a) Umbilical view. b) Lateral view. c) Spiral view.

Fig. 6 - *"Globigerina" senni* (Beckmann, 1953); sample FMP12 base, Fosio section, Monte Piano Marls, Bartonian. a) Umbilical view. b) Later al view. c) Detail of the structure.

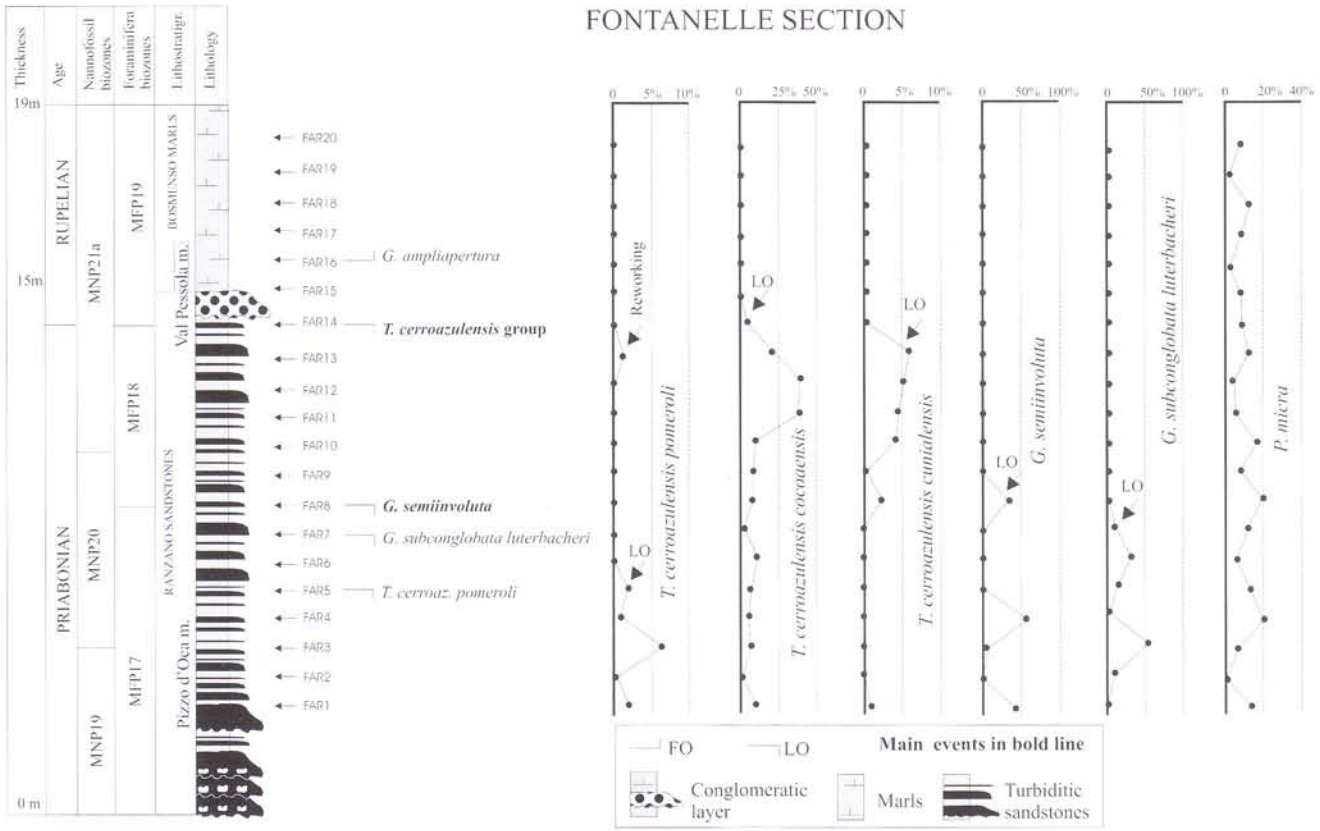


Fig. 3 - Fontanelle section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, integrated biostratigraphy and chronostratigraphy.

Fig. 4 - C

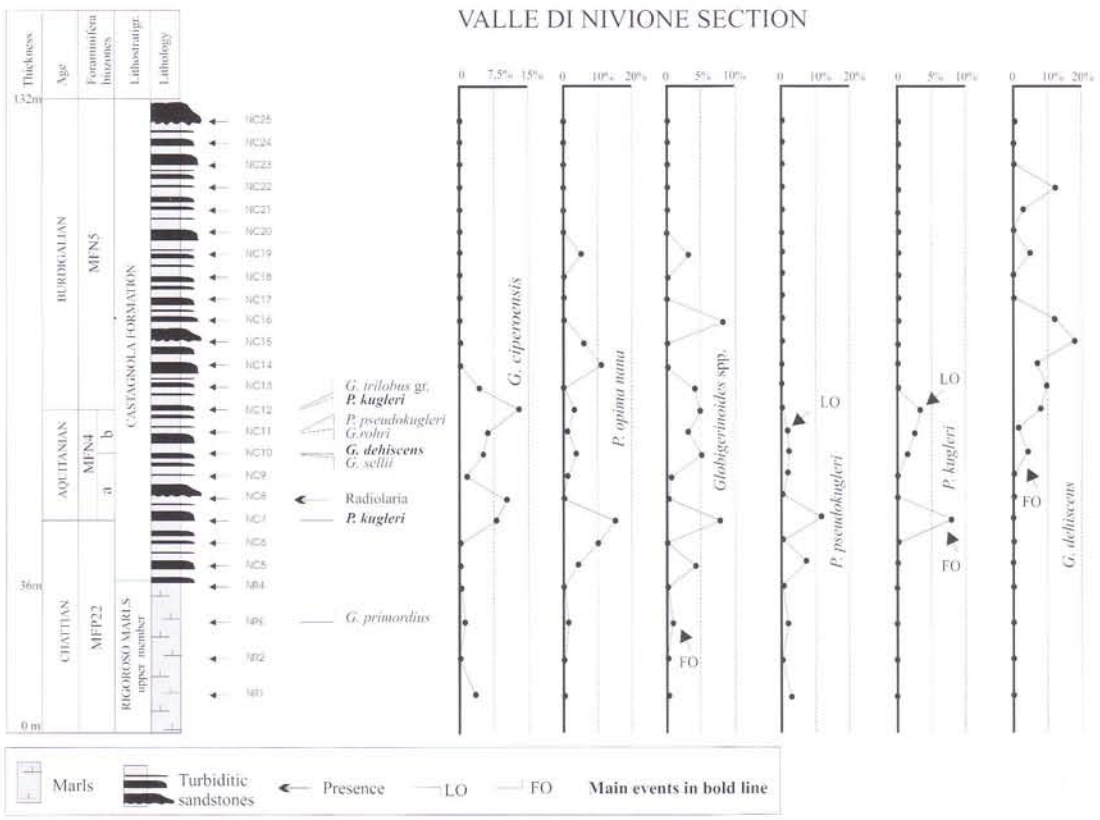


Fig. 7 - Valle di Nivione section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

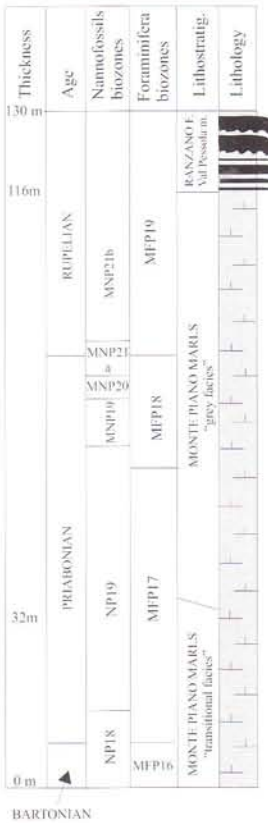
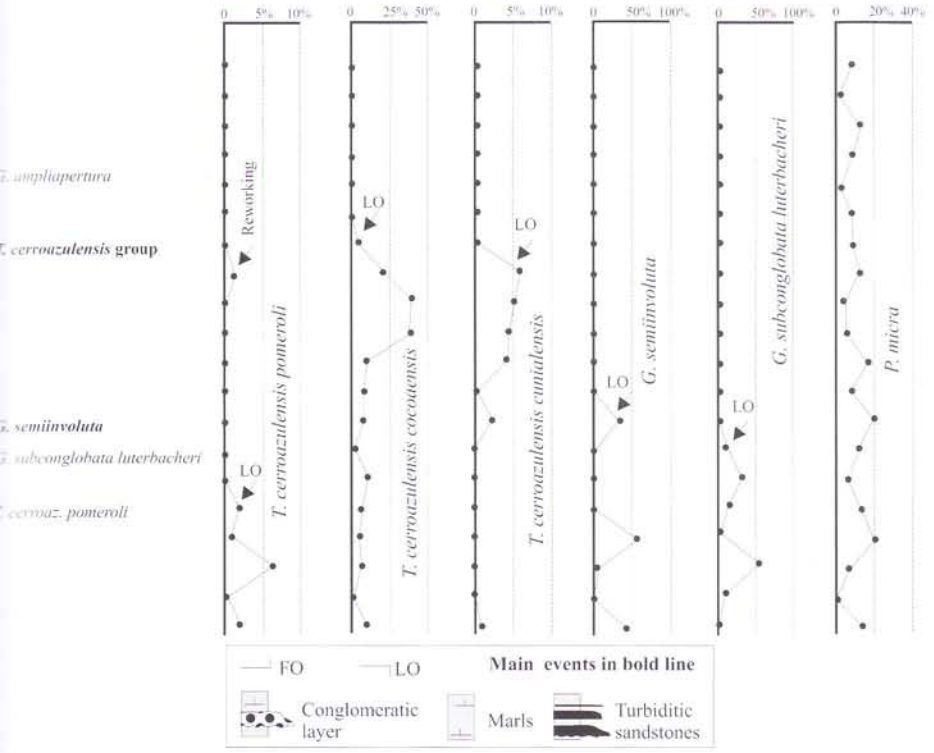


Fig. 8 - Monteacuto section: l



raphy, abundance patterns of selected planktonic foraminiferal species, integrated biostratigraphy and

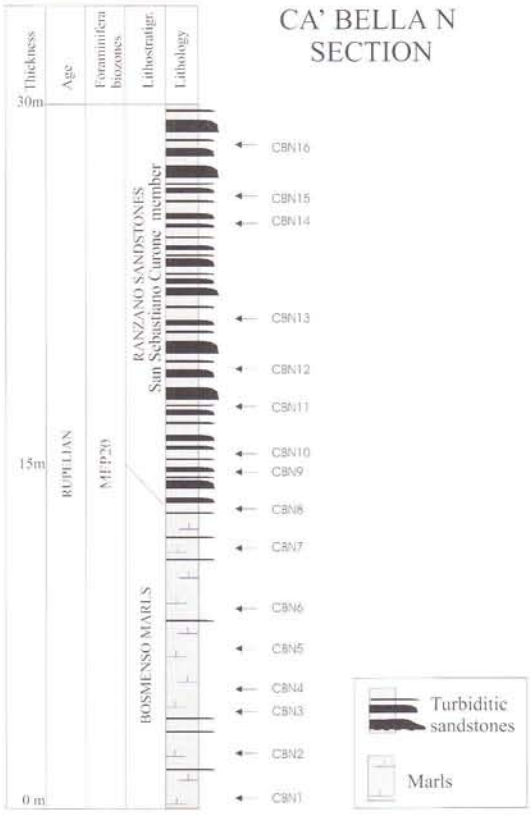


Fig. 4 - Ca Bella N section: lithostratigraphy, foraminiferal biostratigraphy and chronostratigraphy.

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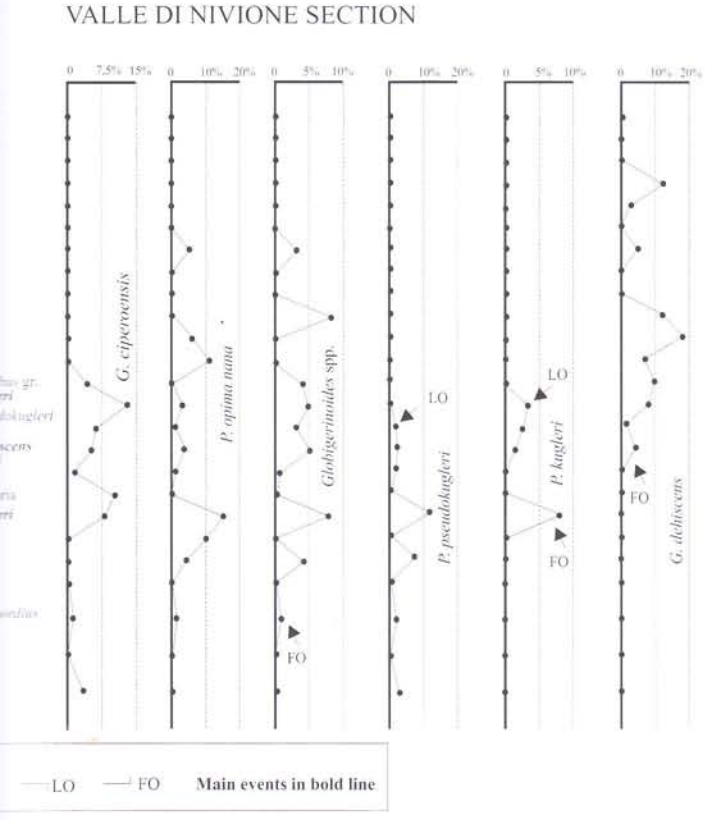


tratigraphy, abundance patterns of selected planktonic foraminiferal species, d chronostratigraphy.

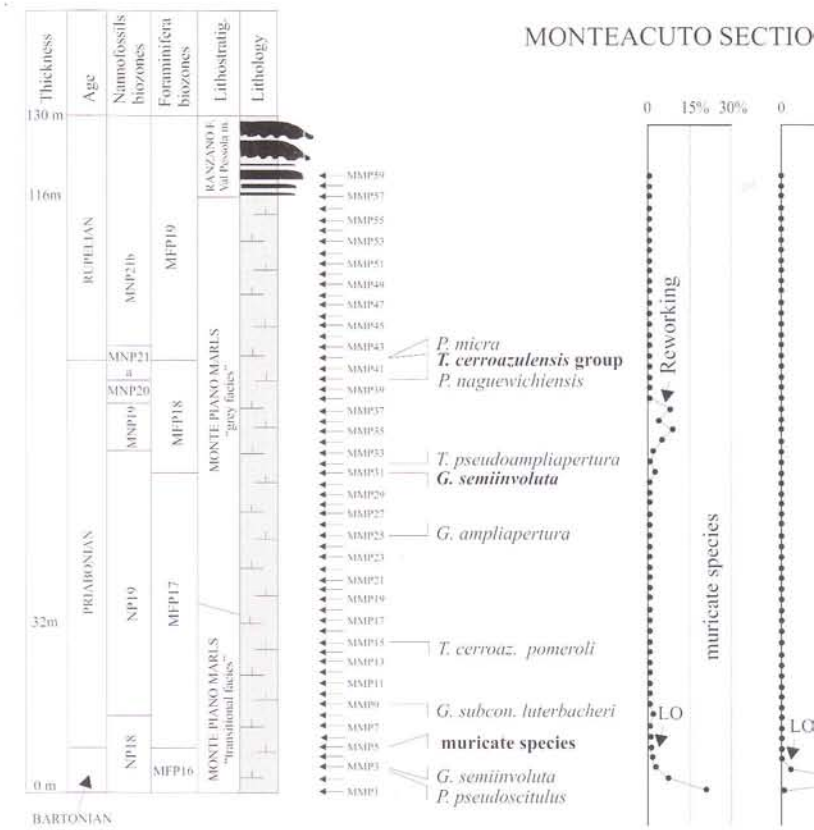
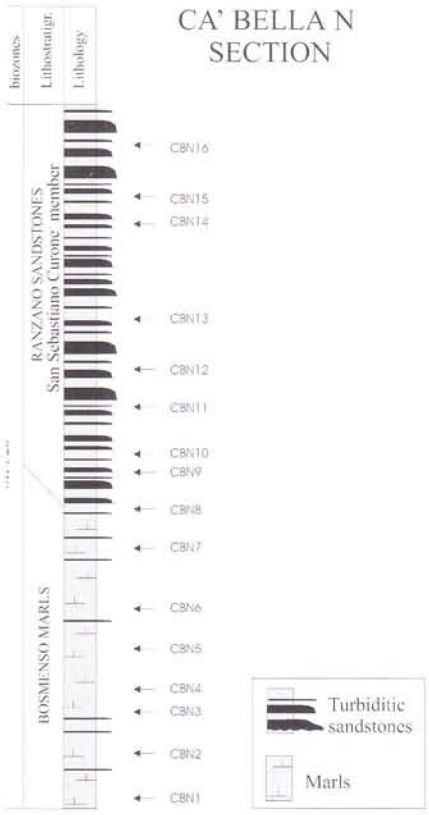


Fig. 8 - Monteacuto section: lithostratigraphy, abundance patterns of selected plankton



Ca Bella N section: lithostratigraphy, foraminiferal biostratigraphy and chronostratigraphy.

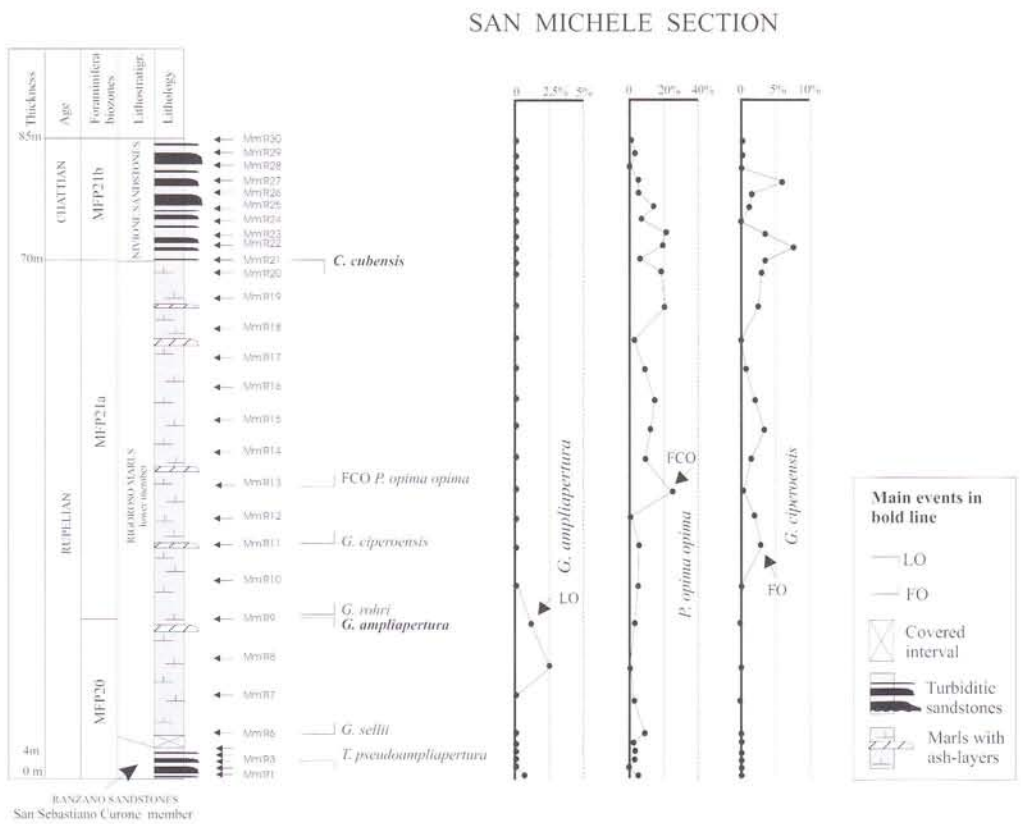
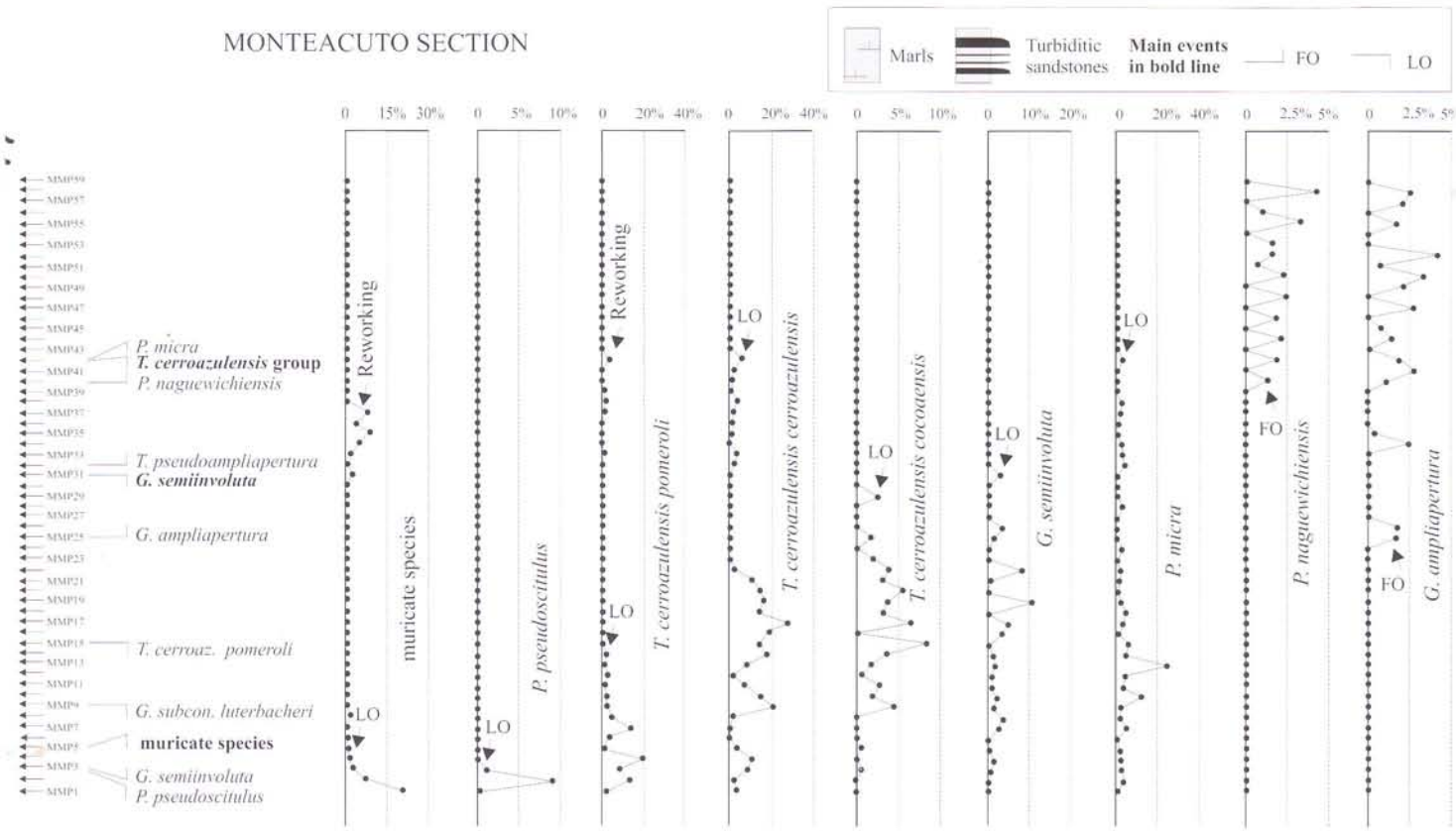


Fig. 5 - San Michele section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.



lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, integrated biostratigraphy and chronostratigraphy.

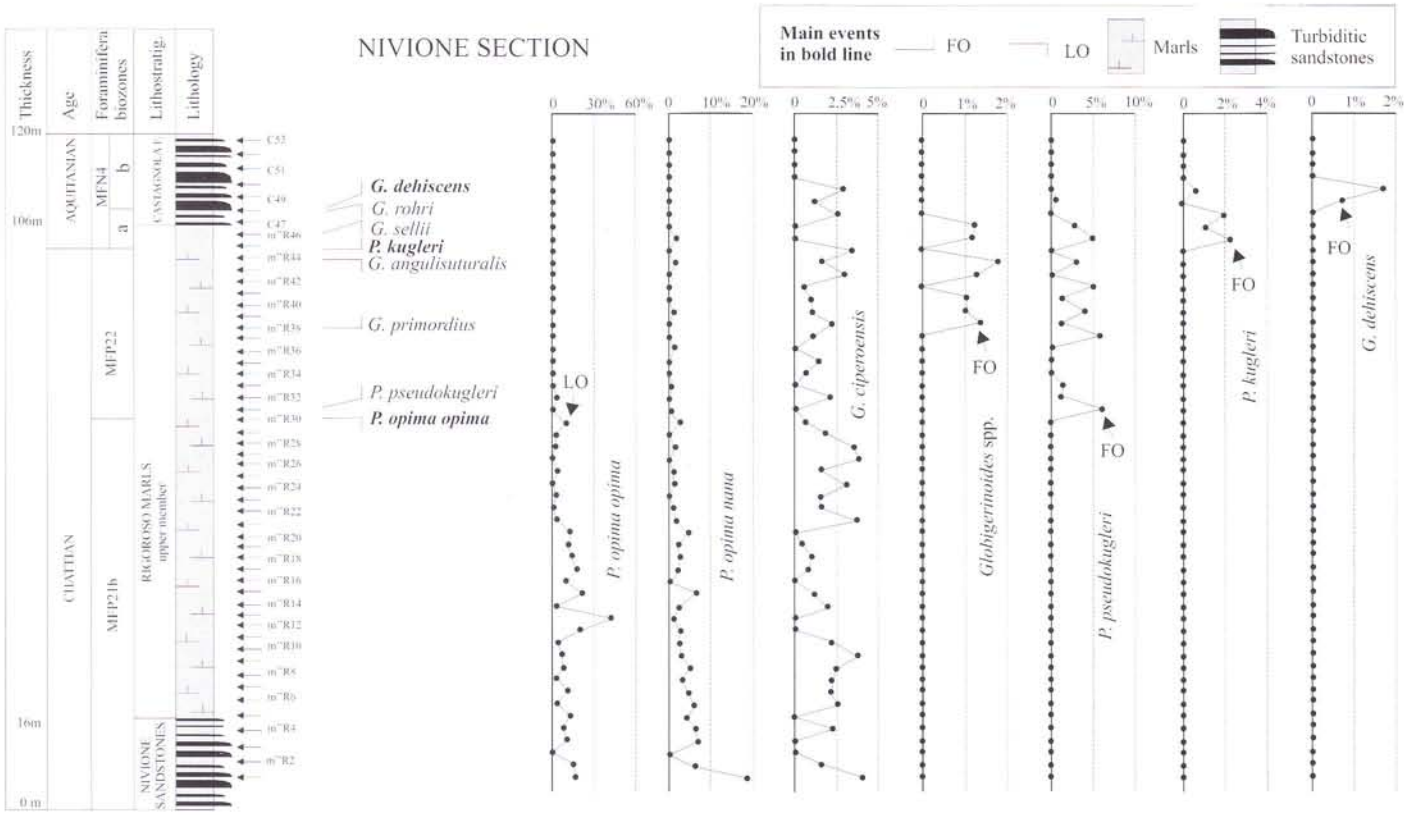


Fig. 6 - Nivione section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

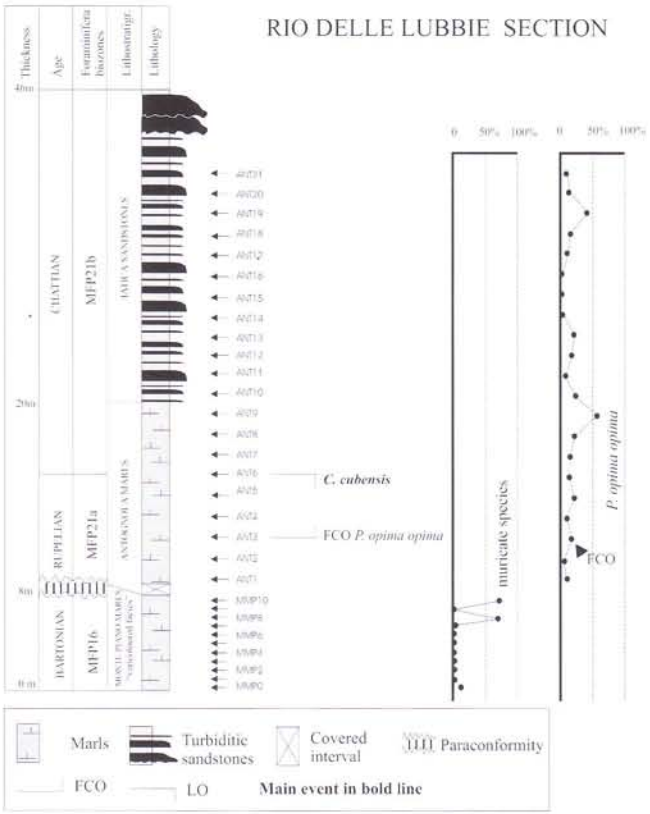


Fig. 9 - Rio delle Lubbie section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

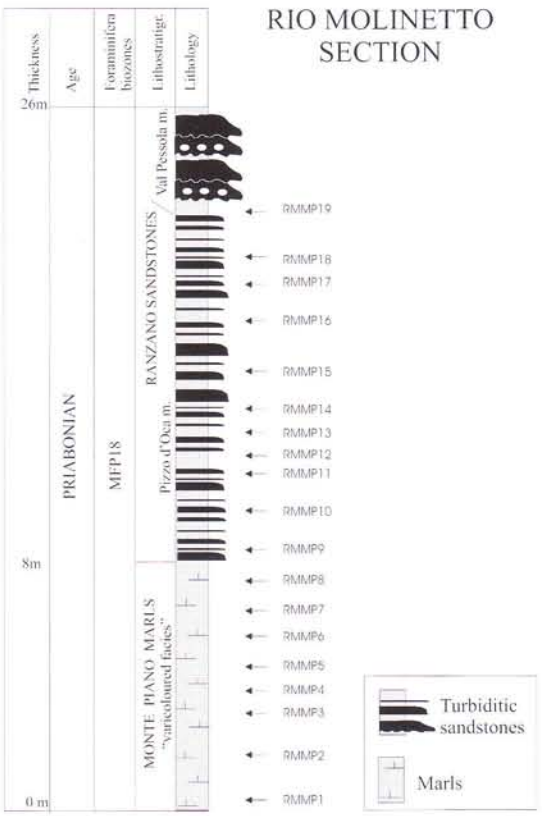


Fig. 10 - Rio Molinetto section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

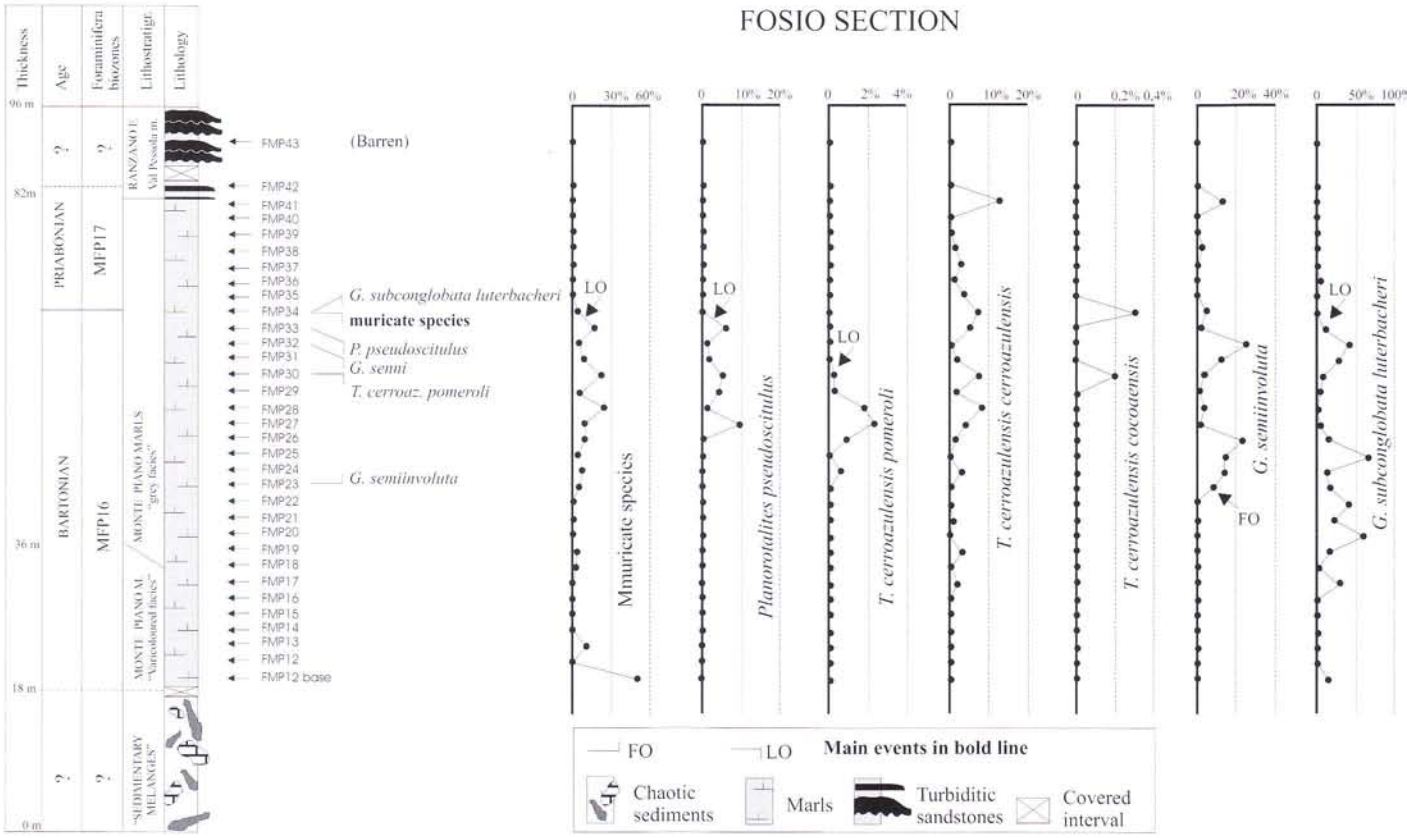


Fig. 11 - Fosio section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraph

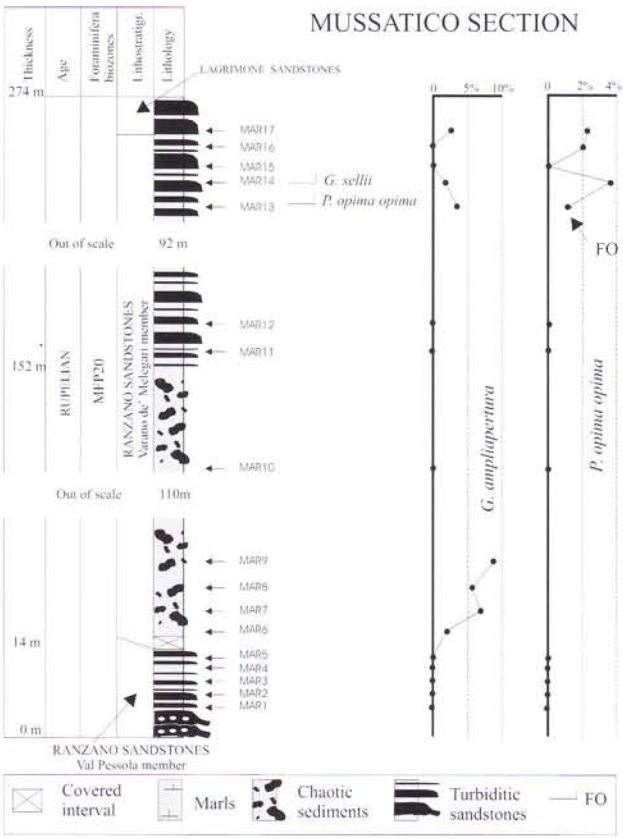


Fig. 14 - Mussatico section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

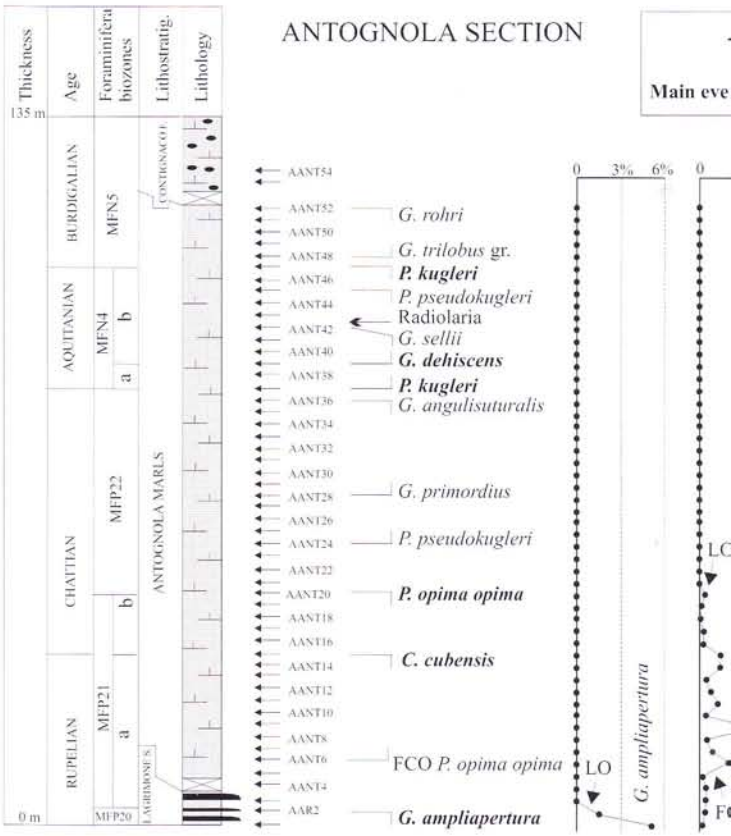


Fig. 15 - Antognola section: lithostratigraphy, abundance patterns of selected pla

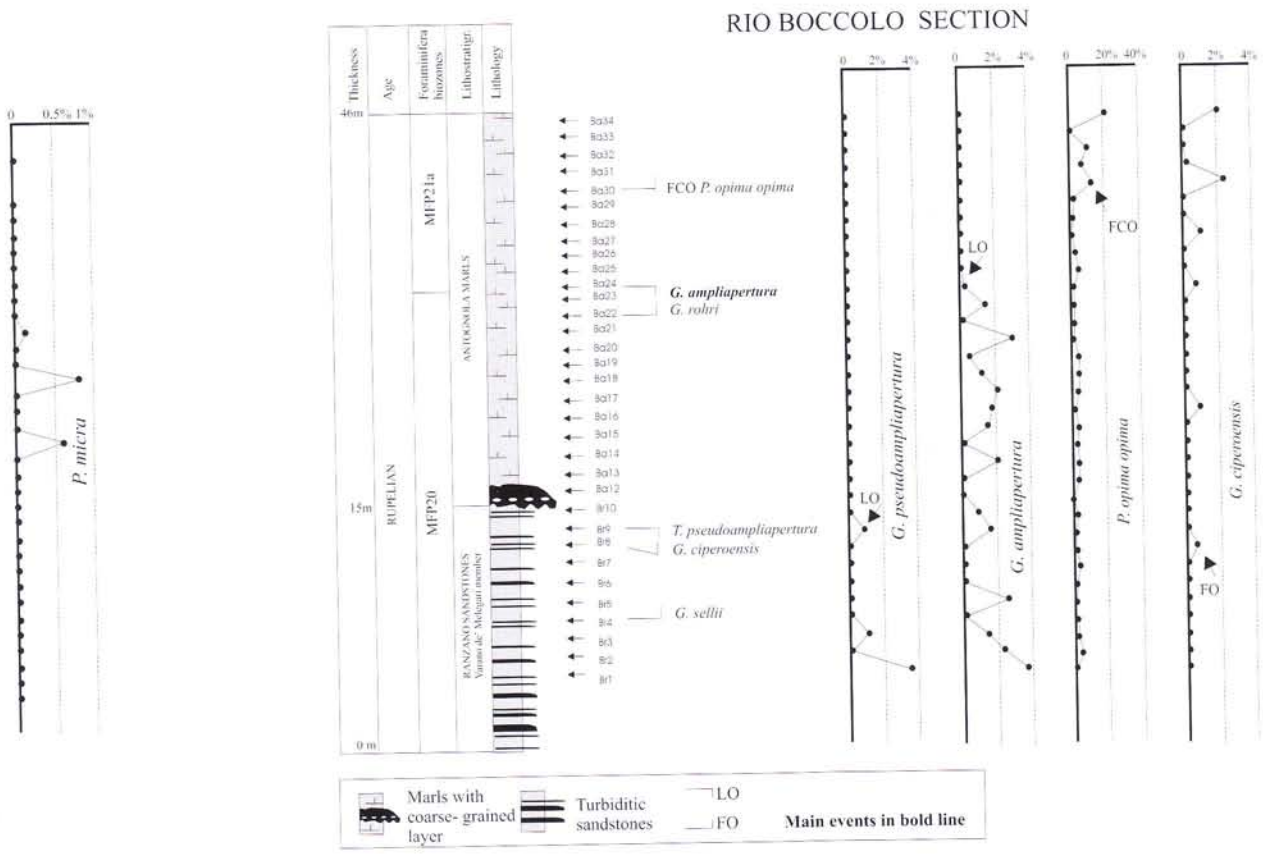
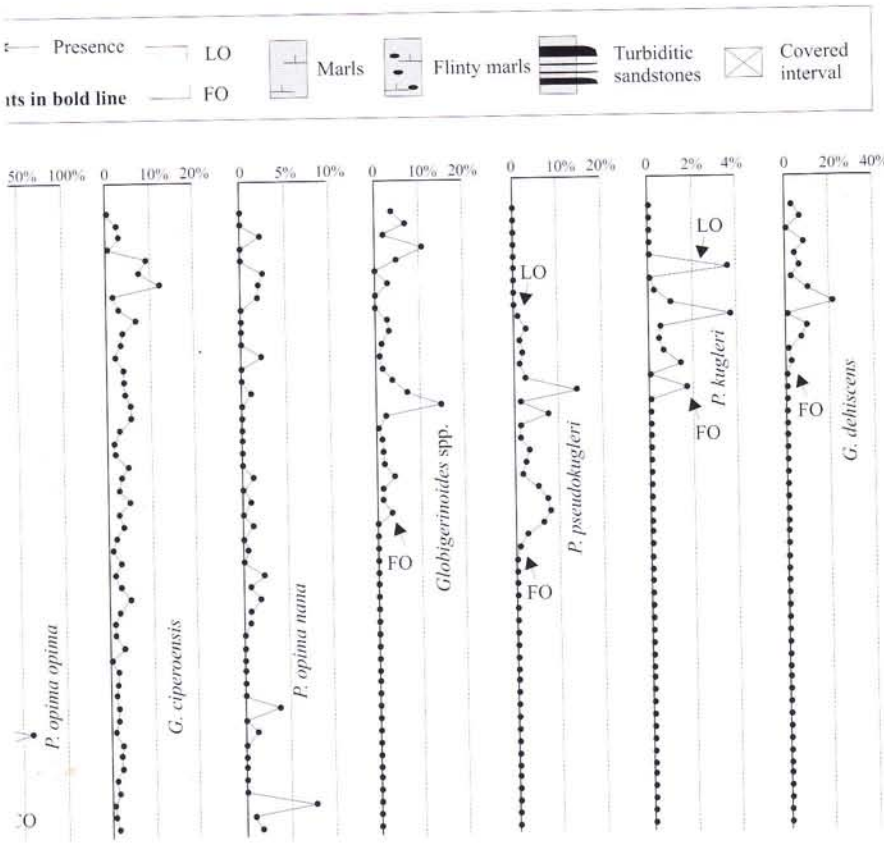


Fig. 12 - Rio Boccolo section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.



ıktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

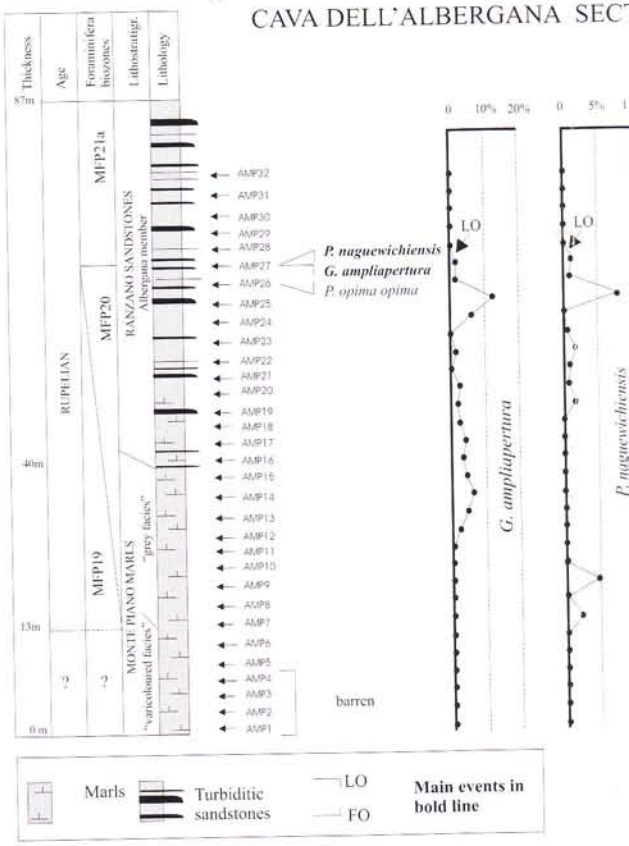
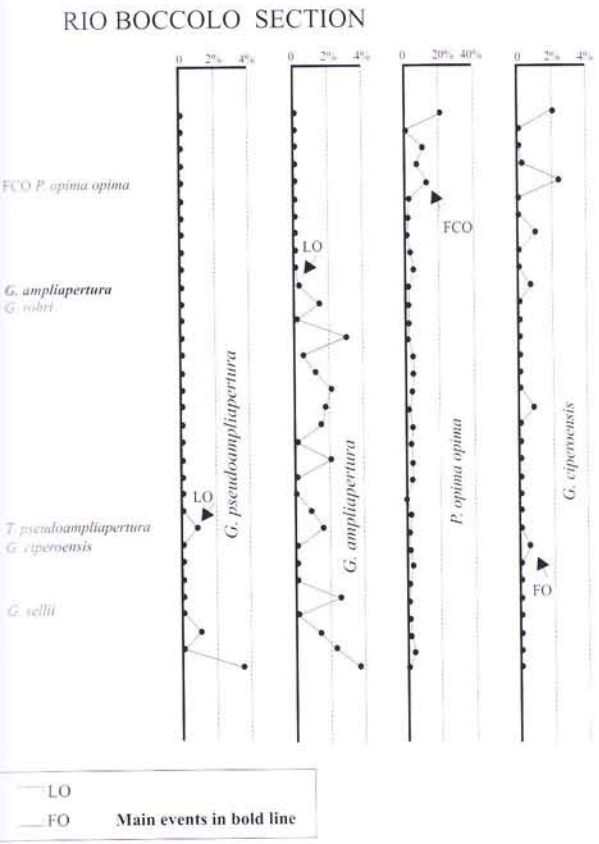
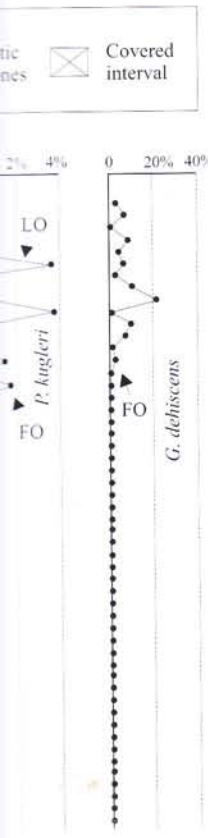


Fig. 16 - Cava dell'Albergana section: lithostratigraphy, abundanc selected planktonic foraminiferal species, foraminiferal b and chronostratigraphy.



lithostratigraphy, abundance patterns of selected planktonic aminiferal biostratigraphy and chronostratigraphy.



igraphy.

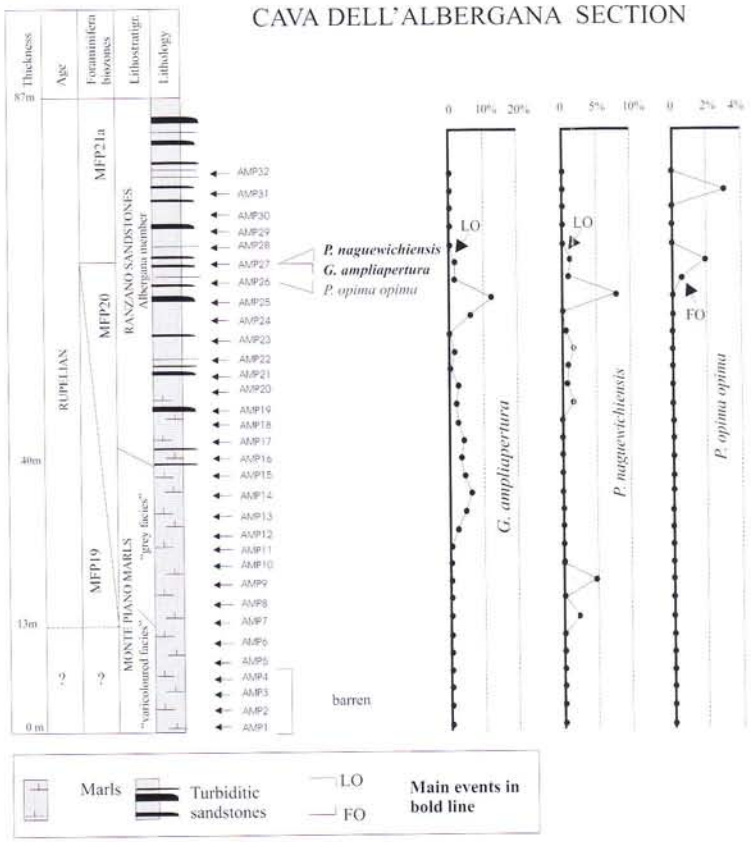


Fig. 16 - Cava dell'Albergana section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

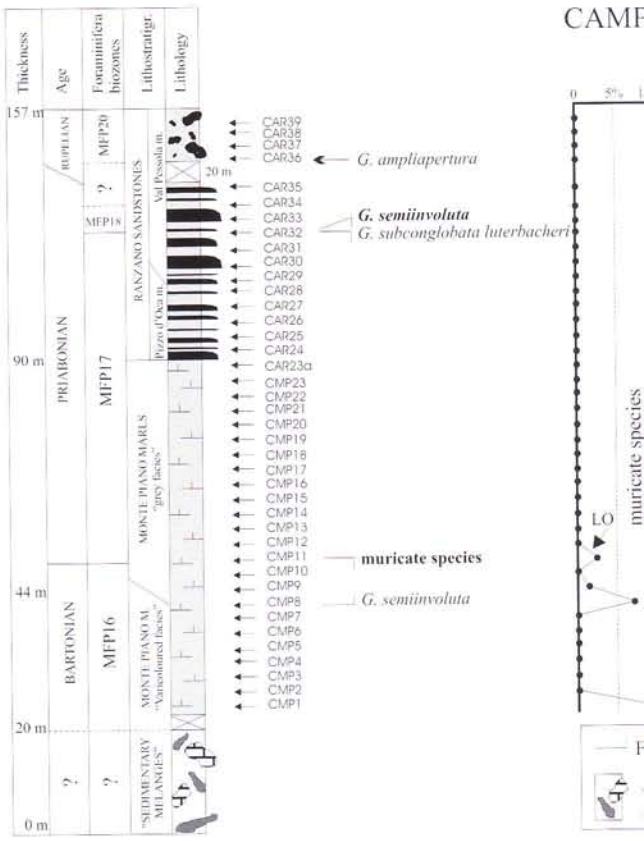


Fig. 13 - Campora section: lithostratigraphy, abundance patterns of se chronostratigraphy.

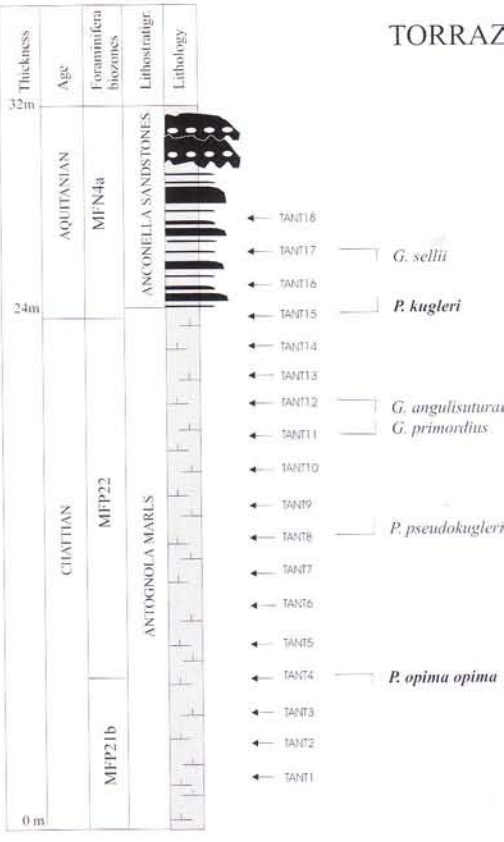


Fig. 17 - Torrazza section: lithostratigraphy, abun biostratigraphy and chronostratigraphy.

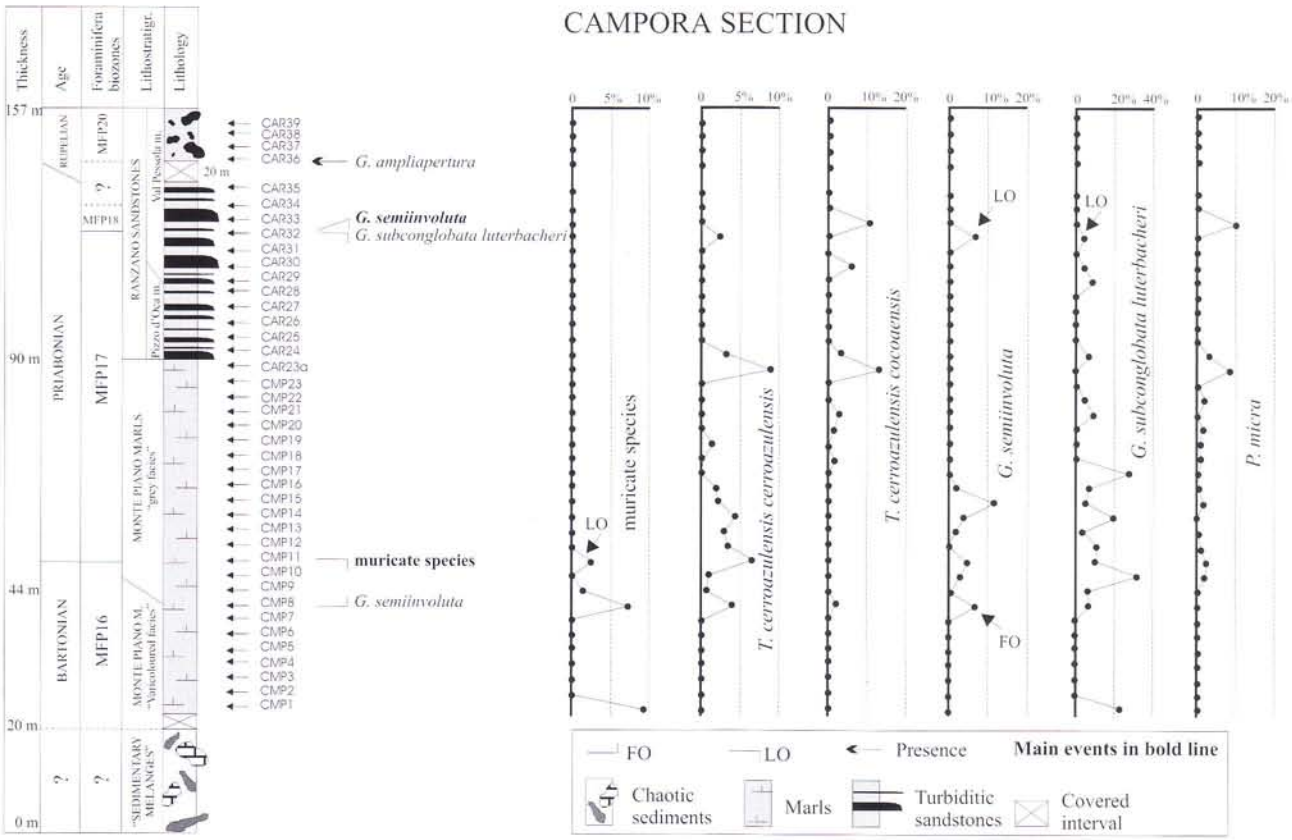
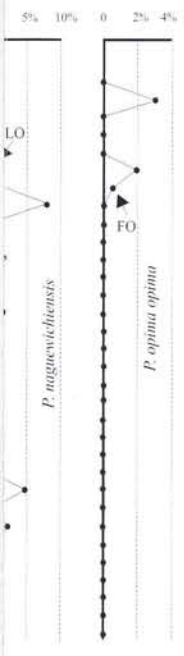


Fig. 13 - Campora section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.

SECTION



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ral biostratigraphy

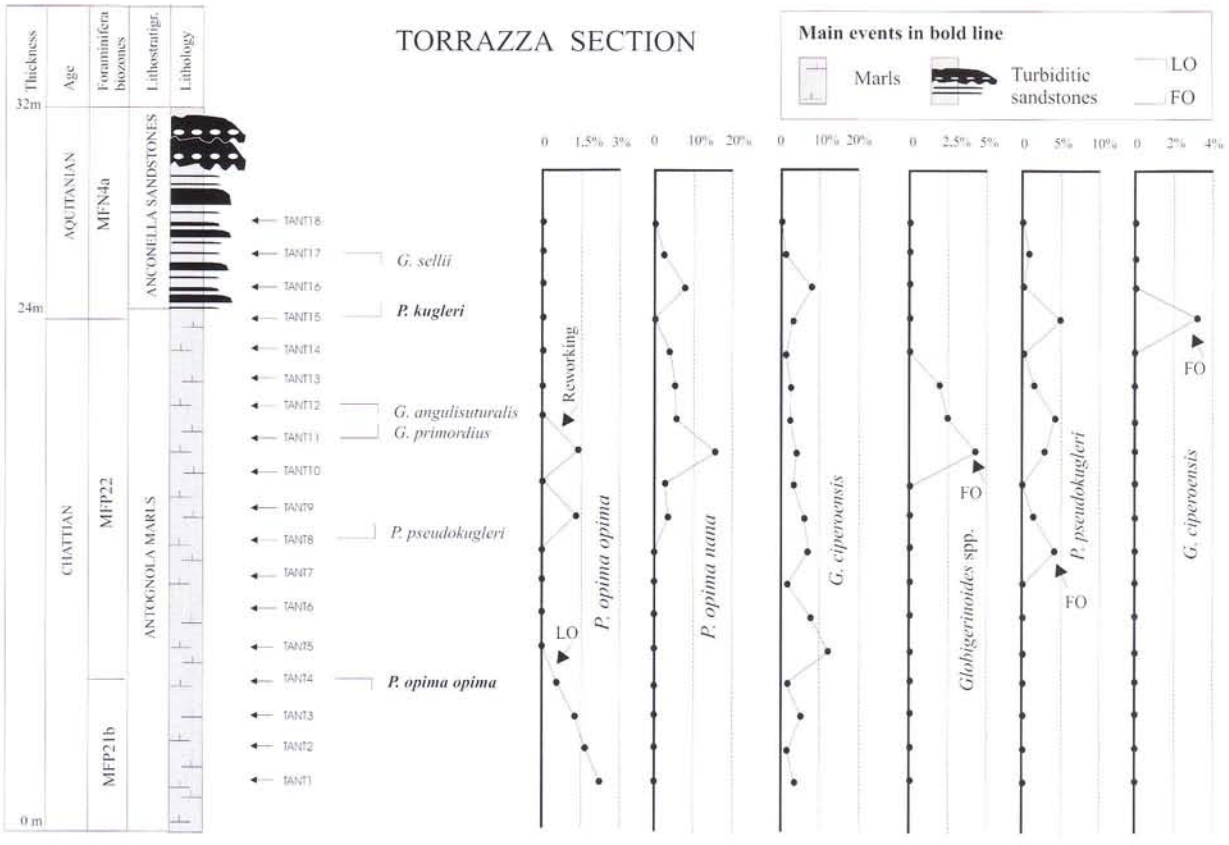
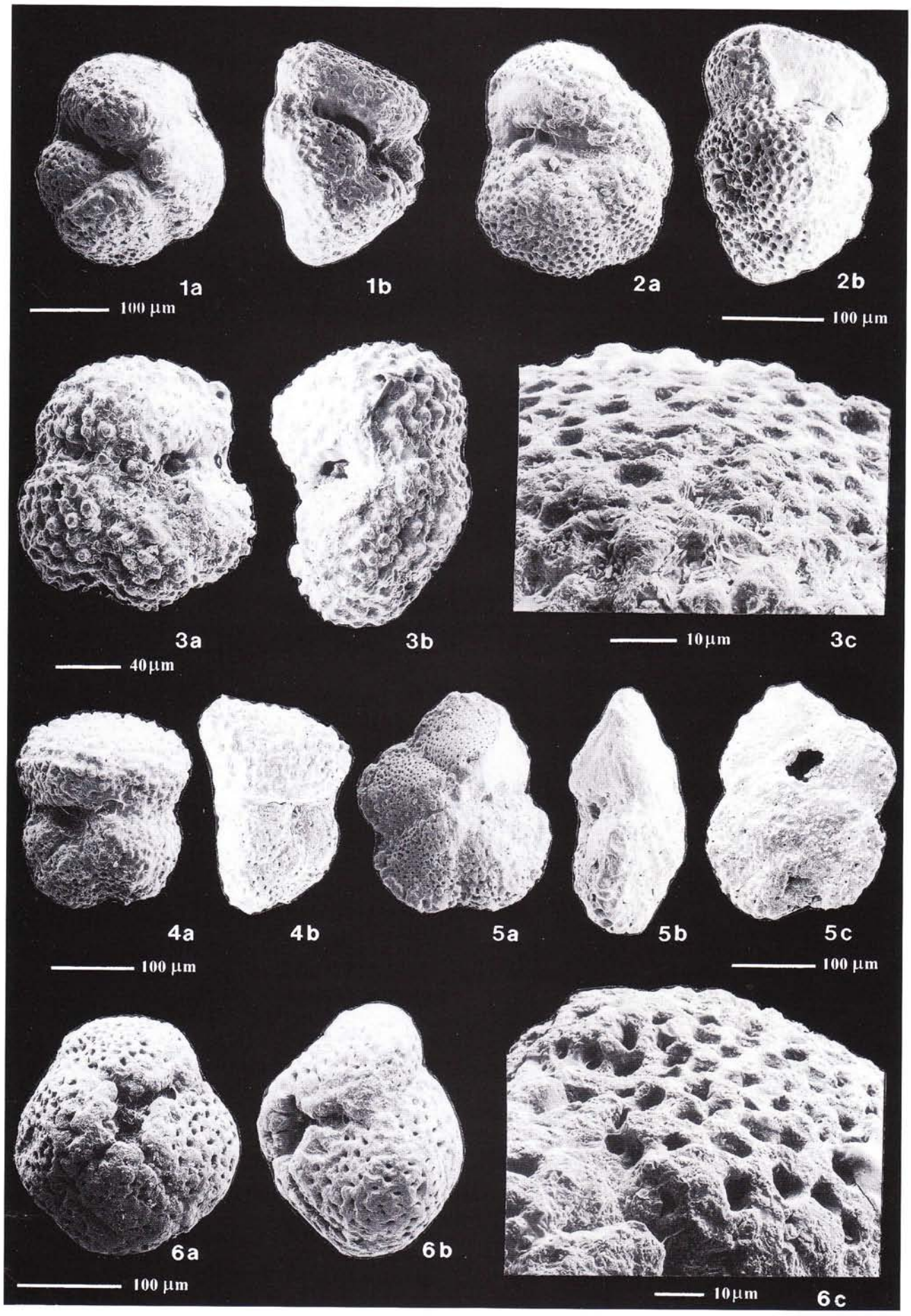


Fig. 17 - Torrazza section: lithostratigraphy, abundance patterns of selected planktonic foraminiferal species, foraminiferal biostratigraphy and chronostratigraphy.


1a
1b
2a
2b
100 µm
100 µm
3a
3b
3c
40µm
10µm
4a
4b
5a
5b
5c
100 µm
100 µm
6a
6b
6c
100 µm
10µm

Definition: interval from the LO of *Globigerinatheka semiinvoluta* to the LO of *Turborotalia cerroazulensis* group.

Age: Late Priabonian (Late Eocene).

Description: *T. cerroazulensis* evolutionary lineage is here usually less diverse than in the tropical areas. *T. cerroazulensis cunialensis* (Pl. 2, fig. 6), is present and abundant in the Fontanelle section only. In the other sections specimens of *T. cerroazulensis cerroazulensis* and *T. cerroazulensis cocoaensis* are rare and discontinuously present. The planktonic foraminiferal assemblage also yields frequent catapsydracids, *Globigerinina venezuelana, Subbotina eocaena* and *Pseudohastigerina micra* (>125 μm, Pl. 2, fig. 4).

The benthic assemblage is identical to that of the previous zone.

Remarks: the extinction of the *T. cerroazulensis* group is preceded by the FO of *Pseudohastigerina naguewichiensis*, always of small size (<125 μm) (Monteacuto section; Pl.2, fig. 5).

The genera *Hantkenina, Cribrohantkenina* and *Chiloguembelina*, which characterise this zone in the oceans and in the "Scaglia umbro-marchigiana", are absent or very rare.

This interval corresponds to Zones P16 p.p. and P17 of Berggren & Miller (1988).

Pseudohastigerina spp. Interval Zone (MFP19)

Author: Mancin & Pirini, in Mancin & Cobianchi (2000).

Definition: interval from the LO of *Turborotalia cerroazulensis* group to the LO of the pseudohastigerinids.

Age: Early Rupelian (Early Oligocene).

Description: *Pseudohastigerina micra* and *P. naguewichiensis* are rare but continuously present. They occur mainly in the small-sized fraction (<125 μm). The planktonic assemblage is characterised by abundant *Catapsydrax, Globigerina (G. venezuelana* and rare *G. ampliapertura), Turborotalia pseudoampliapertura*, sporadic *Subbotina eocaena, Globoquadrina (G. tripartita* and in suborder *G. tapuriensis)* and rare specimens of *"Globorotalia" increbescens*. Tenuitellids are frequent in the small-sized fractions (<125 μm).

The benthic assemblage is characterised by abundant infaunal *(Globocassidulina subglobosa, Stilostomella nuttalli, Uvigerina mexicana)* and epifaunal species *(Planulina renzi, Heterolepa perlucida, Cyclammina apenninica)*. The agglutinated species with calcite cement and fine-grained textures (*Vulvulina* spp., *Gaudryina* spp.) are frequent (Mancin 1999).

Remarks: *Pseudohastigerina micra* is markedly smaller (<125 μm) than the Eocene specimens. This feature has also been reported by some authors from oceanic and Mediterranean areas (Keller 1983; Boersma & Premoli Silva 1986; Nocchi et al. 1986). In the studied sections the LO of *P. micra* predates the LO of pseudohastigerinids (*P. naguewichiensis*).

The genus *Chiloguembelina* and the species *Cassigerinella chipolensis* are absent in the studied sections. *C. chipolensis* characterises this zone in tropical oceanic areas but, in the Northern Apennines, its presence is documented only from the base of the *Paragloborotalia opima opima* Total Range Zone (Beckmann et al. 1981; Mancin 1999).

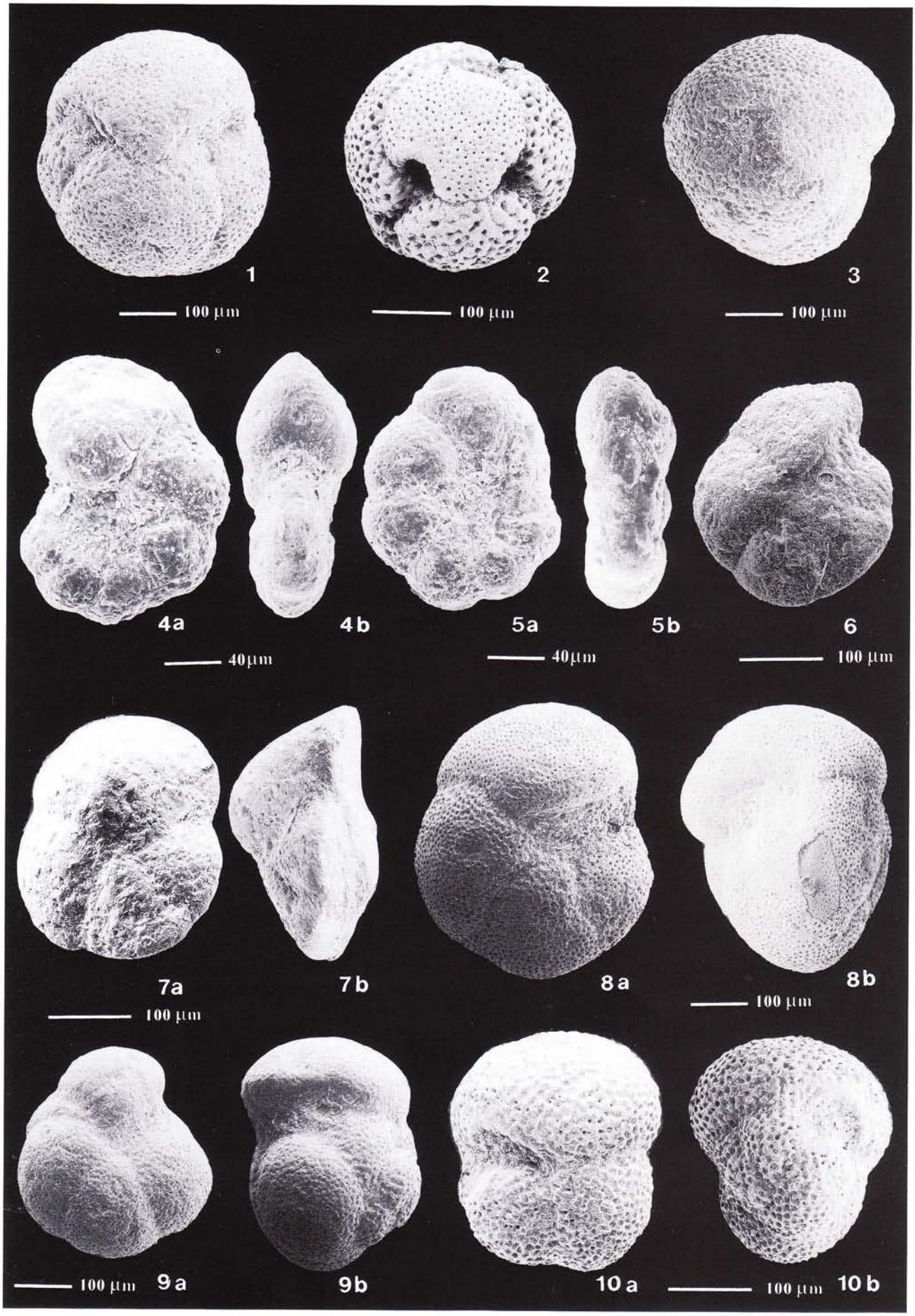
The zonal boundaries correspond to those of Zone P18 of Berggren & Miller (1988; LOs of *T. cerroazulensis* group and pseudohastigerinids), but one of the zonal markers (*C. cubensis*) is absent; for this reason we have proposed a new zone.

This interval corresponds to the *C. chipolensis/P. micra* Zone and to the lower part of the *Globigerina ampliapertura* Zone in the scheme of Bolli & Saunders (1985).

Globigerina ampliapertura Interval Zone (MFP20)

PLATE 2

Fig. 1 - *Globigerinatheka mexicana mexicana* gr. (Cushman, 1925); sample MMP3, Monteacuto section, Monte Piano Marls, Bartonian.
Fig. 2 - *Globigerinatheka subconglobata luterbacheri* Bolli, 1972; sample MMP8, Rio delle Lubbie section, Monte Piano Marls, Bartonian.
Fig. 3 - *Globigerinatheka semiinvoluta* (Keijzer, 1945); sample FAR4, Fontanelle section, Ranzano Sandstones, Priabonian.
Fig. 4 - *Pseudohastigerina micra* (Cole, 1927); sample FAR4, Fontanelle section, Ranzano Sandstones, Priabonian. a) Spiral view. b) Side view.
Fig. 5 - *Pseudohastigerina naguewichiensis* (Myatliuk, 1950); sample MMP42, Monteacuto section, Monte Piano Marls, Priabonian. a) Spiral view. b) Side view.
Fig. 6 - *Turborotalia cerroazulensis cunialensis* (Toumarkine & Bolli), 1970; sample FAR1, Fontanelle section, Ranzano Sandstones, Priabonian. Umbilical view.
Fig. 7 - *Turborotalia cerroazulensis cocoaensis* (Cushman, 1928); sample FAR1, Fontanelle section, Ranzano Sandstones, Priabonian. a) umbilical view. b) Lateral view.
Fig. 8 - *Turborotalia cerroazulensis cerroazulensis* (Cole, 1928); sample FMP30, Fosio section, Monte Piano Marls, Bartonian. a) umbilical view. b) Lateral view.
Fig. 9 - *Turborotalia cerroazulensis pomeroli* (Toumarkine & Bolli), 1970; sample FMP27, Fosio section, Monte Piano Marls, Bartonian. a) umbilical view. b) Lateral view.
Fig. 10 - *Turborotalia cerroazulensis frontosa* (Subbotina, 1953); sample MMP8, Rio delle Lubbie section, Monte Piano Marls, Bartonian. a) umbilical view. b) Lateral view.o Marls, Bartonian. Magnification X200. a) Umbilical view. b) Lateral view. c) Detail of the structure, magnification X1300.


1
100 µm
2
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3
100 µm
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4b
5a
40µm
5b
6
100 µm
7a
100 µm
7b
8a
8b
100 µm
100 µm
9a
9b
10a
100 µm
10b

Author: Bolli (1957b), amended by Spezzaferri (1994).

Definition: interval from the LO of pseudohastigerinids to the LO of *Globigerina ampliapertura*.

Age: Late Rupelian (Early Oligocene).

Description: the zonal marker (rare to very rare) is continuously present throughout the interval and exhibits a wide intraspecific variability (Pl. 3, fig. 3). It usually occurs together with *Turborotalia pseudoampliapertura*, which disappears towards the top of the zone. The latter is identified by its aperture position, from umbilical to extra-umbilical, and by its wall texture, very smooth and similar to that of the *Turborotalia cerroazulensis* lineage (Pl. 3, fig. 1-2). The planktonic assemblage is characterised by abundant *Catapsydrax* and *Globigerina (G. venezuelana, G. euapertura, G. ouachitaensis)* and *Globoquadrina tripartita*; rare specimens of *Paragloborotalia opima opima* appear in the middle-upper portion of this zone. Abundant are also tenuitellids (*T. angustiumbilicata, T. clemenciae*), *Globorotaloides* (*G. permicrus* and *G. exagonus* gr.), rare are *Chiloguembelina* spp. and *Cassigerinella chipolensis* in the small-sized fraction (<125 μm). *Globoquadrina sellii* (Pl. 4, fig. 11) and *T. pseudoampliapertura* first and last occur, respectively, in the upper part of the zone.

The benthic assemblage is identical to that of the previous zone.

Remarks: the FO of *P. opima opima* (Mussatico and Cava dell'Albergana sections) occurs before the LO of *G. ampliapertura* as in Premoli Silva & Spezzaferri (1991) and in Spezzaferri (1994), while in Bolli (1957b) this event is recorded at the base of the overlying zone.

This interval corresponds to the *Globigerina ampliapertura* p.p. Zone and the lower part of the *Globorotalia opima opima* Zone in the scheme of Bolli & Saunders (1985), and to Zone P19 of Berggren & Miller (1988).

Paragloborotalia opima opima Interval Zone (MFP21)

Author: Bolli (1957b), amended by Spezzaferri (1994)

Definition: interval from the LO of *Globigerina ampliapertura* to the LO of *Paragloborotalia opima opima.*

Remarks: as in Spezzaferri (1994) two subzones are recognised.

Subzone a (MFP21a)

Author: Spezzaferri (1994).

Definition: interval from the LO of *Globigerina ampliapertura* to the LO of *Chiloguembelina cubensis.*

Age: Late Rupelian (Early Oligocene).

Description: *P. opima opima* (Pl. 3, fig. 6) is usually rare (<5% of the planktonic assemblage) but continuously present. The planktonic assemblage is characterised by *Catapsydrax* (above all *C. dissimilis*), *Globigerina (G. venezuelana, G. euapertura, G. ouachitaensis, G. praebulloides, G. ciperoensis* and *G. angulisuturalis*; Pl. 3, fig. 4-5), *Globoquadrina* (*G. sellii, G. rohri* and *G. tripartita;* Pl. 4, fig. 10-11) and rare *Paragloborotalia opima nana.* Frequent Tenuitellids, *Globorotaloides*, rare *Paragloborotalia semivera*, *Cassigerinella chipolensis* (Pl. 4, fig. 8) and *Chiloguembelina* spp. are mainly present in the small-sized fractions (<125 mm). Just below the upper boundary of the subzone, the FCO of *Paragloborotalia opima opima* (>5% of the planktonic assemblage) occurs as a secondary event. This event is also reported for the Monte Cagnero and Pieve d'Accinelli sections (Coccioni, pers. comm.) both located in the Umbria-Marche Apennines and proposed as possible GSSPs for the Rupelian/Chattian boundary (Coccioni et al. 1999). Other secondary events, near the lower-middle part of the subzone, are the FOs of *Globoquadrina rohri* and *Globigerina ciperoensis.*

The benthic assemblage is dominated by epifaunal taxa, such as *Heterolepa perlucida, H. mexicana, Gyroidinoides girardanus, Planulina renzi,* and *Hanzawaya ammophila.* Other benthic species are *Pullenia bulloides, Uvigerina havanensis, Globocassidulina subglobosa* and common agglutinated foraminifera, such as *Recurvoides* spp., *Arenobulimina ovoidea* and *Vulvulina* spp. (Mancin 1999).

Remarks: the upper boundary of the subzone is identified by the LO of *C. cubensis.* This species is rare to frequent but poorly preserved in the studied sections (Pl. 4, fig. 1-7).

This interval corresponds to Zones P20 and P21a p.p. of Berggren & Miller (1988).

Subzone b (MFP21b)

PLATE 3

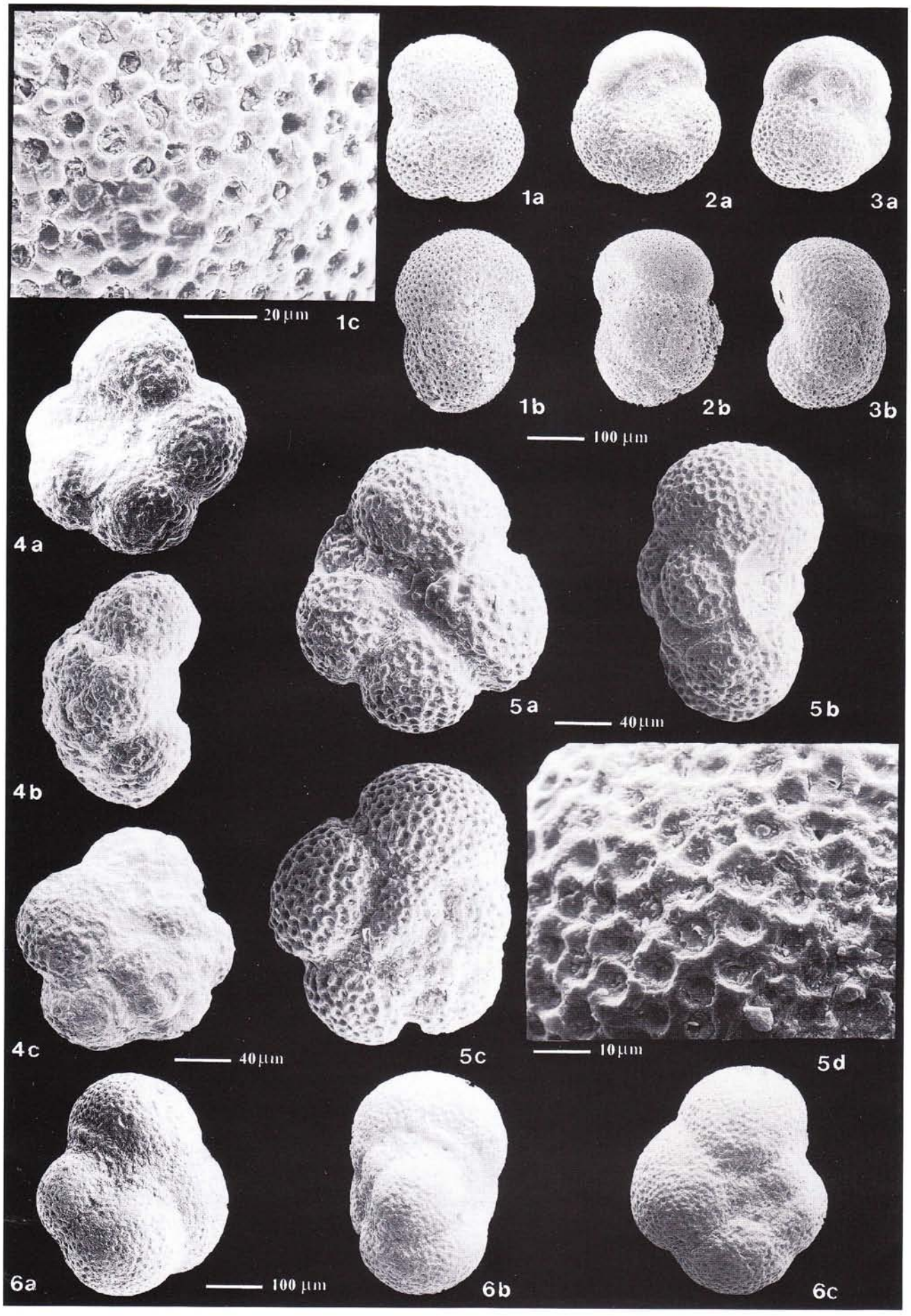
Fig. 1, 2 - *Turborotalia pseudoampliapertura* (Blow & Banner, 1962); sample MAR6, Mussatico section, Ranzano Sandstones, Rupelian. a) Umbilical view. b) Lateral view. c) Detail of the wall.

Fig. 3 - *Globigerina ampliapertura* Bolli, 1957; sample AMP15, Cava dell'Albergana section, Monte Piano Marls, Rupelian. a) Umbilical view. b) Lateral view.

Fig. 4 - *Globigerina ciperoensis* Bolli, 1957; sample Mm'R29, San Michele section, Rigoroso Marls, Chattian. a) Umbilical view. b) Lateral view. c) Spiral view.

Fig. 5 - *Globigerina angulisuturalis* Bolli, 1957; sample m"R1, Nivione section, Nivione Sandstones, Chattian. a) Umbilical view. b) Lateral view. c) Spiral view. d) Detail of the cancellate wall.

Fig. 6 - *Paragloborotalia opima opima* (Bolli, 1957); sample m"R1, Nivione section, Nivione Sandstones, Chattian. a) Umbilical view. b) Lateral view. c) Spiral view.


1a
2a
3a
20 µm
1c
1b
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3b
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4a
5a
40 µm
5b
4b
4c
40 µm
5c
10 µm
5d
6a
100 µm
6b
6c

Author: Spezzaferri (1994).

Definition: interval from the LO of *Chiloguembelina cubensis* to the LO of *Paragloborotalia opima opima*.

Age: Early Chattian (Late Oligocene).

Description: *P. opima opima* is frequent to common (>5%) and continuously present, however, it usually becomes less frequent and discontinuous towards the top. Planktonic and benthic assemblages are similar to that of the previous zone, except for the absence of the chiloguembelinids and for the FOs of *Sphaeroidina bulloides* and *Uvigerina auberiana* var. *attenuata* (Mancin 1999), in the planktonic and benthic assemblages, respectively.

Remarks: this interval corresponds to Zone P21b p.p. of Berggren & Miller (1988).

Globigerina ciperoensis Interval Zone (MFP22)

Author: Cushman & Stainforth (1945), amended by Bolli (1957b).

Definition: interval from the LO of *Paragloborotalia opima opima* to the FO of *Paragloborotalia kugleri*.

Age: Late Chattian (Late Oligocene).

Description: *G. ciperoensis* is usually rare to very rare, but with typical specimens and continuously present throughout the interval. In the upper part of the biozone the zonal marker increases in size (it is found also in the >180 μm fraction) and abundance. The planktonic assemblage is characterised by abundant *Catapsydrax* (above all *C. dissimilis*), *Globigerina* (*G. venezuelana*, *G. euapertura*, *G. ouachitaensis*, *G. praebulloides* and sporadic *G. angulisuturalis*), *Globoquadrina* (*G. tripartita*, *G. sellii* and sporadic *G. rohri*), rare *Globigerinoides primordius* (Pl. 5, fig. 5) and *Paragloborotalia* (*P. pseudokugleri*, Pl. 5, fig. 1; *P. semivera*, *P. pseudocontinuosa*, *P. opima nana*). Rare tenuitellids and *Globorotaloides* are observed in the small-sized fractions. It is worth of note in the middle-upper part of the zone, the FOs of *P. pseudokugleri* and *G. primordius* and the LO of *Globigerina angulisuturalis*. The latter event was used by Baldi Becke et al. (1978) to identify the upper boundary of the zone in absence of *Paragloborotalia kugleri*.

The benthic assemblage is similar to that of the previous zone.

Remarks: This interval corresponds to Zone P22 of Berggren & Miller (1988) and Spezzaferri (1994).

Paragloborotalia kugleri Total Range Zone (MFN4)

Author: Bolli (1957b).

Definition: interval defined by the total range of *Paragloborotalia kugleri*. This biozone is subdivided into two subzones as in Srinivasan & Kennett (1983).

Subzone a (MFN4a)

Authors: Srinivasan & Kennett (1983)

Definition: interval from the FO of *P. kugleri* to the FO of *G. debiscens*.

Age: Early Aquitanian (Early Miocene).

Description: *P. kugleri* is always rare to very rare, but continuously present throughout the interval. The specimens differ from the oceanic forms (Spezzaferri 1991) in some characteristics: smaller size, fewer chambers in the last whorl (6 rarely 7), peripheral margin moderately subacute and the dorsal side less prominent with gently curved sutures (Pl. 5, fig. 3). The planktonic assemblage is also characterised by *Globigerinoides primordius*, *Globigerina ciperoensis*, *Paragloborotalia* (*P. pseudokugleri*, *P. opima nana*, *P. semivera*), together with common *Catapsydrax* and large globigerinids. Rare *Globorotaloides* are present in the small-sized fractions. It is worthy mentioning in this subzone, the LO of *Globoquadrina sellii* and the occurrence of radiolaria (Valle di Nivione section), at first in the small-sized fractions, then in the coarser ones.

The benthic assemblage shows a moderate increase of the infaunal taxa, such as *Sphaeroidina bulloides*, *Praeglobobulimina* spp., *Globocassidulina subglobosa* and *Uvigerina* spp. (Mancin 1999).

Remarks: the genus *Globigerinoides* is always rare to very rare with one species only (*G. primordius*) in the studied sections, whereas in the oceanic record and in the Lemme section a marked diversification level (FCO), is documented (Spezzaferri 1994; Iaccarino et al. 1996). The *Globigerinoides* diversification level, however, is poorly detectable in mid latitude sediments, as in the coeval Monferrato and Torino Hill sediments, where, however, *G. primordius* appears only after the FO of *P. kugleri* (Bicchi et al. 1994).

PLATE 4

Figs.1-2 - *Chiloguembelina cubensis* (Palmer, 1934); sample Mm'R1, San Michele section, Rigoroso Marls, Rupelian.

Figs. 3-4 - *Chiloguembelina cubensis* (Palmer, 1934); sample Mm'R20, San Michele section, Rigoroso Marls, Rupelian. a) Frontal view. b) Side view.

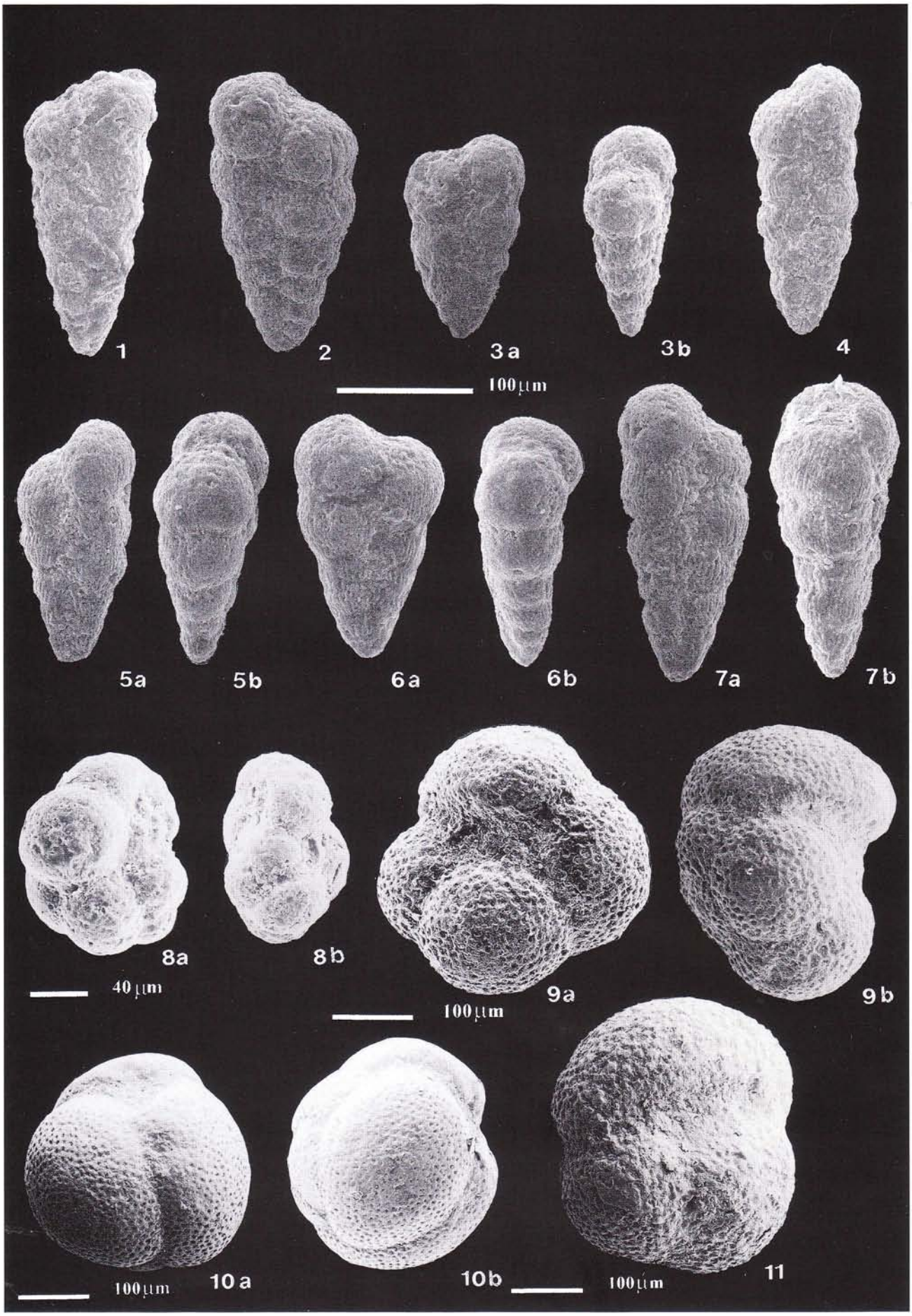
Figs. 5-7 - *Chiloguembelina cubensis* (Palmer, 1934); sample Mm'R15, San Michele section, Rigoroso Marls, Rupelian. a) Frontal view. b) Side view.

Fig. 8 - *Cassigerinella chipolensis* (Cushman & Ponton, 1932), sample Br8, Rio Boccolo section, Ranzano Sandstones, Rupelian. a) Spiral view. b) Side view.

Fig. 9 - *Globigerina venezuelana* Hedberg, 1937; sample m"R12, Nivione section, Rigoroso Marls, Chattian. a) Umbilical view. b) Lateral view.

Fig. 10 - *Globoquadrina rorbi* (Bolli, 1957); sample ANT12, Rio delle Lubbie section, Antognola Marls, Chattian. a) Umbilical view. b) Lateral view.

Fig. 11 - *Globoquadrina sellii* Borsetti, 1959; sample ANT3, Rio delle Lubbie section, Antognola Marls, Rupelian. Umbilical view.


1
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7b
8a
8b
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100 µm
9b
100 µm
10a
10b
100 µm
11

This interval corresponds to the *G. kugleri* Zone and the lower part of the *G. primordius* Zone in the scheme of Bolli & Saunders (1985), to Subzone N4a of Berggren & Miller (1988) and to Subzones N4a and N4b p.p. of Spezzaferri (1994).

Subzone b (MFN4b)

Authors: Srinivasan & Kennett (1983).

Definition: interval from the FO of *G. dehiscens* to the LO of *P. kugleri.*

Age: Middle-Late Aquitanian (Early Miocene).

Description: *P. kugleri* is always rare and becomes discontinuous before its last occurrence. *G. dehiscens* (Pl. 5, fig. 6) is rare and discontinuous at the beginning, but rapidly becomes frequent to common. The planktonic foraminiferal assemblage is characterised by *Paragloborotalia (P. pseudokugleri, P. semivera, P. opima nana), Globigerinoides primordius, Globigerina (G. ciperoensis, G. venezuelana, G. euapertura)* and *Catapsydrax dissimilis. Globoquadrina rohri* and *Paragloborotalia pseudokugleri* last occurr in the upper part of the zone.

Remarks: the upper zone boundary (LO of *P. kugleri*) is difficult to recognize because of the rare presence of the marker species. Even at the GSSP Lemme section this bioevent is not well constrained because in its final range *P. kugleri* becomes rare and discontinuous, making its extinction difficult to locate precisely. *Globoquadrina praedehiscens* and *Globigerinoides altiaperturus* are absent in the studied sections as in the coeval Monferrato sediments (Bicchi et al., 1994). The latter species appears near the top of the subzone, before the LO of *P. kugleri*, in the Mediterranean area and in the GSSP Lemme section (Iaccarino & Salvatorini 1982; Iaccarino 1985; Steininger & the Working Group on the Paleogene/Neogene boundary 1994), but the FO of *G. altiaperturus* is not easly recognizable, because it is generally rare (Iaccarino et al. 1996).

This interval corresponds to the *G. primordius* Zone p.p. in the scheme of Bolli & Saunders (1985), to Subzone N4b of Berggren & Miller (1988), to Subzone N4b of Spezzaferri (1994), and to the *G. dehiscens dehiscens* Subzone and the lower part of the *G. altiaperturus/C. dissimilis* Subzone of Iaccarino (1985).

Globoquadrina dehiscens/Catapsydrax dissimilis Co-occurrent Range Zone (MFN5)

Authors: Mancin & Pirini, this paper.

Definition: interval identified by the co-occurrence of the zonal markers, after the LO of *Paragloborotalia kugleri*. This definition is provisional since, in the studied sections, the upper boundary of the zone could not be defined.

Age: Early Burdigalian (Early Miocene).

Description: the zonal markers are continuously present throughout the interval, usually frequent and with typical specimens. The planktonic assemblage is characterised by abundant *Globigerina venezuelana, G. euapertura*, rare *Globigerinoides (G. primordius, G. immaturus* and *G. trilobus* gr.), *Paragloborotalia semivera, P. siakensis, Zeaglobigerina woodi* and common radiolaria. The FO of *Globigerinoides trilobus* gr. usually occurs at the base of this interval.

Remarks: *G. altiaperturus, G. praedehiscens* and *Globigerinatella insueta* are absent from the studied sections and therefore the biozones of Iaccarino (1985), Bolli & Saunders (1985) and Spezzaferri (1994) respectively, are not applicable. Furthermore, some additional markers have not been found, preventing better resolution of this interval. For this reason this interval is also difficult to correlate with the standard zonations (Fig. 19).

Chronostratigraphy

The chronostratigraphical scheme (Fig. 20) shows the main planktonic foraminiferal bioevents recognised in the Northern Apennines and the vertical and horizontal relationships among the numerous lithostratigraphical units of the study areas.

Bartonian/Priabonian Boundary (Middle Eocene/Late Eocene): the abrupt extinction of the muricate species belonging to *Acarinina, Truncorotaloides* and *Morozovella (*Monteacuto, Fosio and Campora sections, in the Monte Piano Marls) is the only foraminiferal bioevent that marked the boundary, as already proposed by Proto Decima et al. (1975) and Berggren et al. (1985, 1995). The secondary events recorded just below the boundary are the FO of *Globigerinatheka semiinvoluta* and the LO

PLATE 5

Fig. 1 - *Paragloborotalia pseudokugleri* (Blow, 1969); sample m"R39, Nivione section, Rigoroso Marls, Chattian. a) Umbilical view. b) Lateral view. c) Spiral view. d) Detail of the cancellate wall.

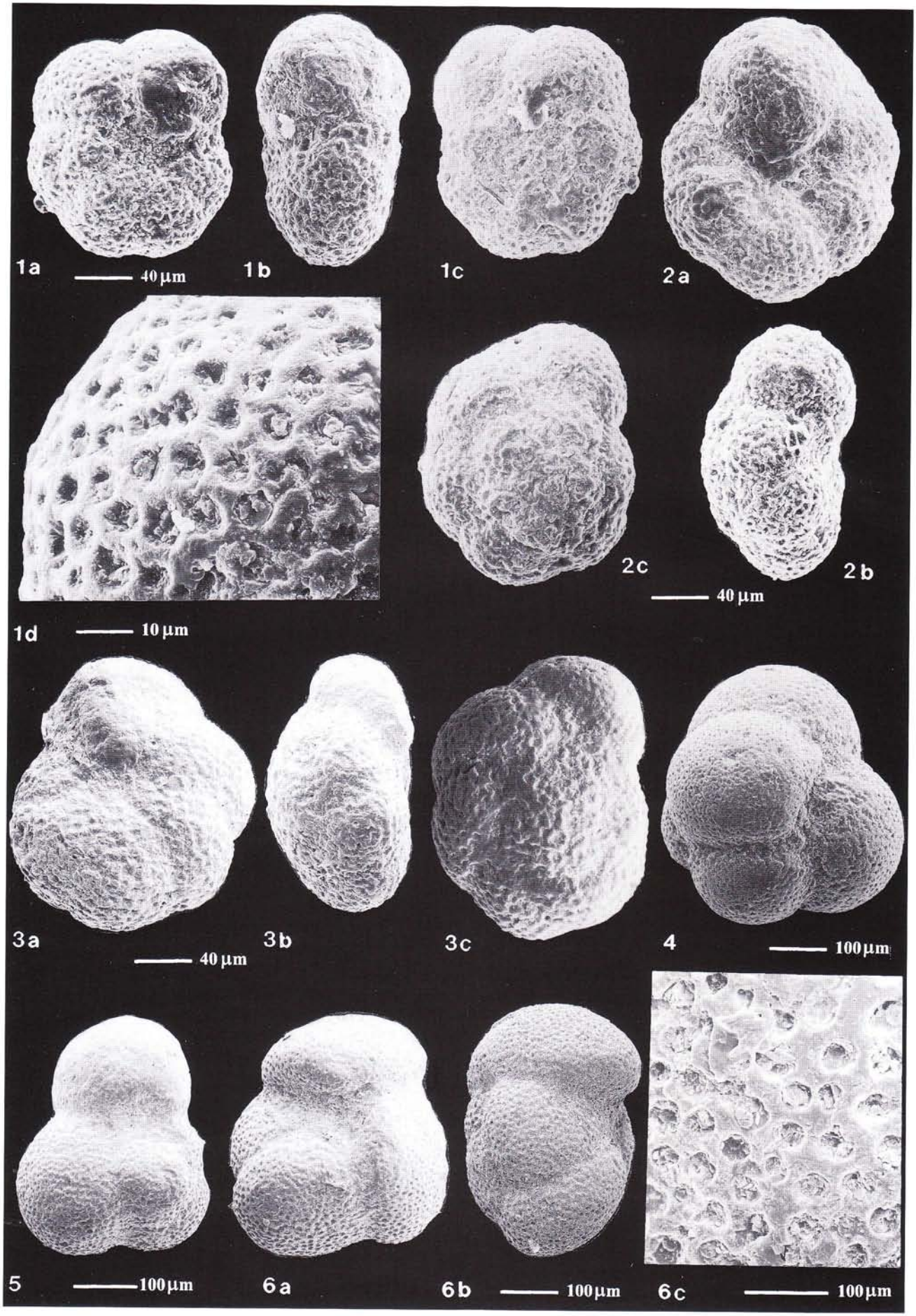
Fig. 2 - *Paragloborotalia pseudokugleri/ Paragloborotalia kugleri* transitional form; sample m"R39, Nivione section, Rigoroso Marls, Chattian. a) Umbilical view. b) Lateral view. c) Spiral view.

Fig. 3 - *Paragloborotalia kugleri* (Bolli, 1957); sample NC9, Valle di Nivione section, Castagnola Formation, Aquitania. a) Umbilical view. b) Lateral view. c) Spiral view.

Fig. 4 - *Catapsydrax dissimilis* (Cushman & Bermudez, 1937); sample AANT30, Antognola section, Antognola Marls, Chattian. Umbilical view.

Fig. 5 - *Globigerinoides primordius* Blow & Banner, 1962; sample AANT30, Antognola section, Antognola Marls, Chattian. Umbilical view.

Fig. 6 - *Globoquadrina dehiscens* (Chapman, Parr & Collins, 1934); sample AANT41, Antognola section, Antognola Marls, Aquitanian. a) Umbilical view. b) Lateral view. c) Detail of the wall.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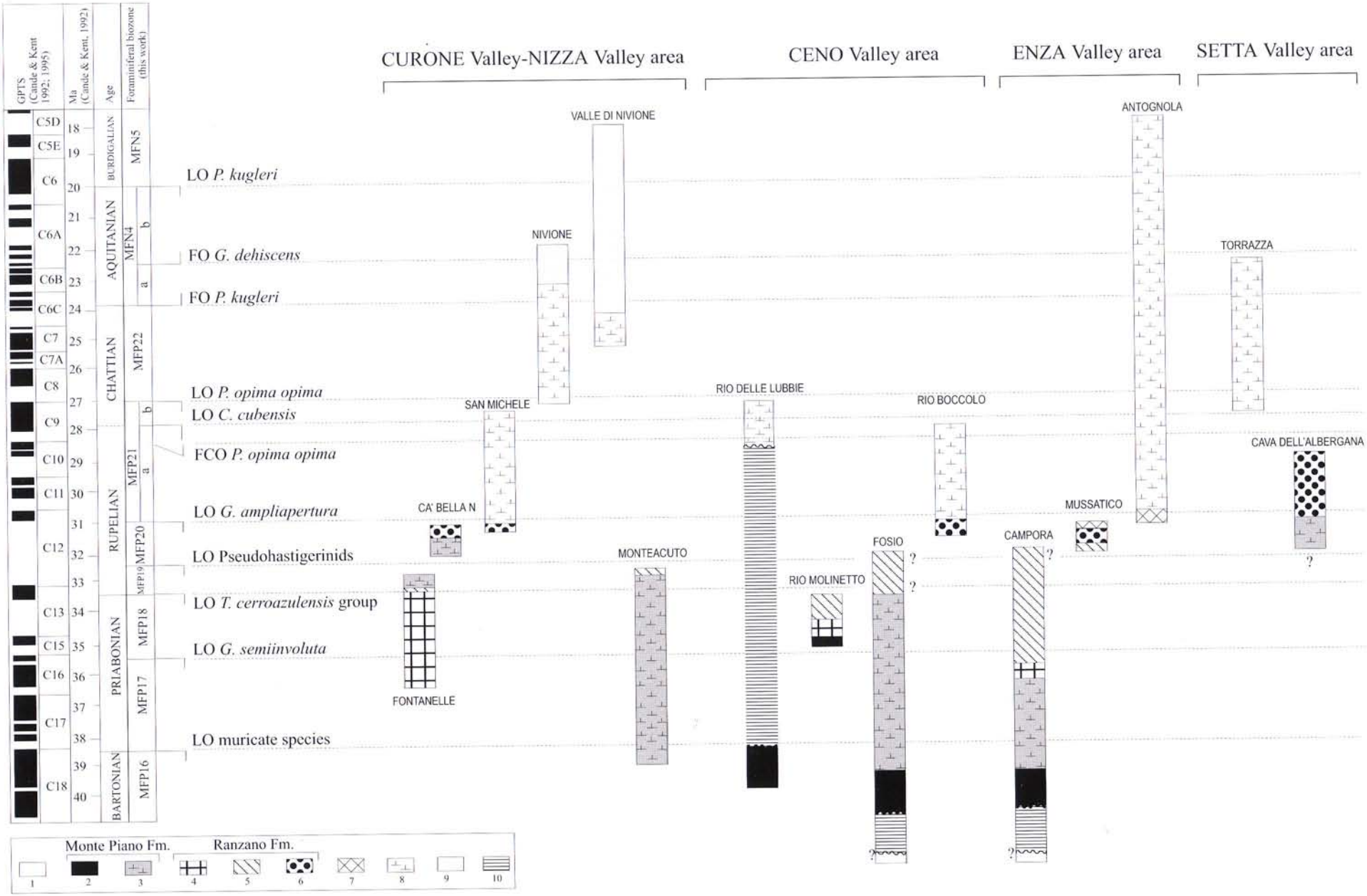

Fig. 20 - Chronostratigraphic scheme of the 15 sections considered in this paper. Symbols: 1: Sedimentary Mélanges; 2: "varicoloured facies" (Monte Piano Marls); 3: "grey facies" (Monte Piano and Bosmenso Marls); 4: Pizzo d'Oca member; 5: Val Pessola member; 6: Heteropics members; 7: Lagrimone Sandstones; 8: Antognola and Rigoroso Marls; 9: Catagnola Formation; 10: Unconformity or depositional hiatus. Thicknesses not on scale.

of *Planorotalites pseudoscitulus*.

The LO of muricate species lies at the top of Chron C18n in the pelagic sediments of the "Umbria-Marche" Basin (Nocchi et al. 1986; Premoli Silva & Boersma 1988).

Priabonian/Rupelian Boundary (Eocene/Oligocene): the LO of the *Turborotalia cerroazulensis* group is the only foraminiferal bioevent that closely approximates this boundary. It has been recognised in the well exposed Fontanelle (lower part of the Ranzano Fm.) and Monteacuto (upper part of the Monte Piano Marls) sections. The secondary events recorded near the boundary are the FO of *Pseudohastigerina naguewichiensis* just below and the LO of *Pseudohastigerina micra* just above (Monteacuto section). The *Pseudohastigerina* group shows a decrease in size (< 125 μm) in both the Fontanelle and Monteacuto sections from the boundary up.

In the GSSPs Massignano section the E/O boundary falls in the lowermost part of Chron 13R1, just above the short normal interval 13N1 (Bice & Montanari 1988) and about 40 cm above the LOs of *T. cerroazulensis cunialensis* and *T. cerroazulensis cocoaensis*. The LOs of *T. cerroazulensis cunialensis* and *T. cerroazulensis cocoaensis* are present only in the Fontanelle section, while the LO of hantkeninids is not recorded in the studied sections.

The boundary falls also in the Calcareous Nannofossil MNP21a Subzone, after the LOs of *Discoaster saipanensis* and *D. barbadiensis*, as also reported by Coccioni et al. (1988) for the GSSPs Massignano section, and by Catanzariti et al. (1997) for contiguous Northern Apennines sections.

Rupelian/Chattian Boundary (Early Oligocene/Late Oligocene): it is marked by the LO of *Chiloguembelina cubensis* (San Michele, Rio delle Lubbie and Antognola sections, in the lower portion of the Rigoroso and Antognola Marls, respectively), postdating the FCO of *Paragloborotalia opima opima*.

In the Cagnero and Pieve d'Accinelli sections, proposed as possible GSSPs sections (Coccioni et al. 1999), the boundary falls in the lower portion of Chron 9n.

Chattian/Aquitanian Boundary (Oligocene/Miocene): the FO of *Paragloborotalia kugleri* is the only foraminiferal bioevent that closely approximates this boundary. It has been recognised in the well exposed Nivione (at the top of the Rigoroso Marls), Valle di Nivione (at the base of the Castagnola Fm.), Antognola (in the upper portion of the Antognola Marls) and Torrazza (at the top of the Antognola Marls) sections. The secondary events recorded near the boundary are the FO of *Globigerinoides primordius* and the LO of *Globigerina angulisuturalis* just below the boundary and the LO of *Globoquadrina sellii* and the FO of *Globoquadrina dehiscens* just above. Abundant radiolaria occur near the boundary in both the Valle di Nivione and the Antognola sections.

This boundary, in the GSSPs Lemme section (the "meter 35.00"), is equated to the base of Chron C6Cn2n (Steininger et al. 1994, Iaccarino et al. 1996), the FO of *P. kugleri* lying about 2 m above.

Aquitanian/Burdigalian Boundary: it is marked by the LO of *Paragloborotalia kugleri* (Valle di Nivione and Antognola sections, in the Castagnola and Antognola Fm., respectively). The secondary events recorded near the boundary are the LO of *Paragloborotalia pseudokugleri* just below the boundary and the FO of *Globigerinoides trilobus* gr. just above.

The FO of *Globigerinoides altiaperturus*, used by Iaccarino (1985) and Iaccarino et al. (1996) to define this boundary in the Mediterranean area and in the GSSPs Lemme section, is absent in the studied sections. In the Lemme section the LO of *P. kugleri* falls in the Chron C6AAr.1r.

Age of the studied Epiligurian succession

According to the data obtained, the ages of the surveyed lithostratigraphical units are as follows (Fig.20):

- Monte Piano Marls (late Bartonian-late Rupelian; MFP16 p.p.-MFP20 Zones): the oldest collected samples are late Bartonian in age (MFP16 p.p. Zone). The top of this unit is diachronous; in the Enza Valley it is dated to the early Priabonian (MFP17 p.p. Zone); in the Ceno and Pessola Valleys to the late Priabonian (MFP18 p.p. Zone); in the Nizza Valley to the early Rupelian (MFP19 p.p. Zone); and finally in the Setta Valley to the late Rupelian (MFP19-MFP20 Zones). As a consequence the unit is clearly older in the depocentral areas and younger near the basin margins (Fig. 2).

- Ranzano Sandstones (early Priabonian-latest Rupelian, MFP17-MFP21a Zones): the Monte Piano Marls/Ranzano Sandstones boundary is confirmed to be regionally time-transgressive (Catanzariti et al. 1997). This is also marked by its member distribution; the Pizzo d'Oca and Val Pessola members are present in the depocentres only, where the units span the greater chronostratigraphical range, whereas they becomes heteropic with the Monte Piano Marl "grey facies" near the basin margins. The base of the overlying heteropic members (San Sebastiano Curone, Varano de' Melegari and Albergana member) is instead synchronous (MFP20 Zone, late Rupelian) in the studied sections. The top is also generally synchronous (upper part of the MFP20 Zone), with the exception of the Albergana member in the Setta Valley (BO) where it ranges up to the latest Rupelian (MFP21a Subzone). Moreover, in the Enza Valley the Lagrimone Sandstones, intercalated between the Ranzano and Antognola Formations, make the arenaceous/marly facies boundary mainly diachronous.

- Antognola Marls (late Rupelian-early Burdigalian; MFP20-MFN5 Zones): the base of this formation is diachronous and becomes younger from west to east. In particular in the Ceno Valley it is dated to the late Rupelian (MFP20 Zone), in the Enza Valley to the latest Rupelian (lower portion of the MFP21a Subzone) and finally in the Reno Valley to the early Chattian (MFP21b Subzone). The boundary between the Antognola Marls and the overlying Bismantova Group has not been studied.

- Rigoroso Marls (TPB; late Rupelian-early Aquitanian; MFP20-MFN4 Zones): the age of the base of this formation corresponds to that of the Antognola Marls in the Ceno Valley (late Rupelian). The top is strongly diachronous (latest Rupelian to earliest Aquitanian) as the turbiditic Castagnola Formation clearly onlaps the marls; the boundary falls in the upper part of the MFP22 Zone in the Valle di Nivione section and within the NFN4 Zone in the nearby Nivione section.

Concluding remarks

Four key points summarise the present paper:

1) the standard tropical and Mediterranean planktonic foraminiferal schemes do not totally apply to the studied Epiligurian succession. Some markers are, in fact, absent or show different chronostratigraphical ranges. The most important bias is the absence of *Truncorotaloides rohri, Globoquadrina praedehiscens, Globigerinatella insueta* and *Globigerinoides altiaperturus.* Moreover *Cassigerinella chipolensis* and *Pseudohastigerina micra* do not co-occurr, the former appears later, in the *Globigerina ampliapertura* Zone, while the latter often disappears near the Eocene/Oligocene boundary.

2) Some additional bioevents are used to propose a new biostratigraphical scheme. They are: the abrupt extinction of the muricate species at the Bartonian/Priabonian boundary; the increasing abundance of *Paraglloborotalia opima opima* near the Subzone P21a/P21b boundary (= Rupelian/Chattian boundary) and the FO of *Globoquadrina dehiscens* at the Subzone N4a/N4b boundary.

3) The proposed scheme applies to the four areas of the Northern Apennines Epiligurian succession, over a distance of about 250 km eaesly correlated with the standard schemes.

4) Finally, this study could help in better defining the stratigraphical and evolutionary history of the Epiligurian succession and could represent a basis for biostratigraphical schemes applaied to even larger areas.

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Geological Maps (GM)

1. Carta Geologica dell'Appennino Emiliano-Romagnolo, 1:10000. Archivio Cart. Regione Emilia-Romagna, Bologna.
   1a Foglio Scurano, sez. 217080 (1985).
   1b Foglio Ranzano, sez. 217120 (1986).
   1c Foglio Lagrimone, sez. 217110 (1988).
   1d Foglio Pellegrino Parmense, sez. 198080 (1992).
   1e Foglio Tizzano Val Parma, sez. 217070 (1993).
   1f Foglio Castel d'Aiano, sez. 237090 (1993).
   1g Foglio Rioveggio, sez. 237110 (1994).
2. Carta Geologica d'Italia, 1:50000. Ufficio Geologico Regione Emilia-Romagna, Bologna.
   2a Foglio Bardi, n°158 (in print).
   2b Foglio Parma SW, n° 199 (in prep.).
   2c Foglio Castel Nuovo Ne' Monti, n°218 (in print).
   2d FoglioSasso Marconi, n°237, (in print).
3. Carta Geologica d'Italia, 1:100000. Archivio Cart. Regione Emilia-Romagna, Bologna.
   3a Foglio Pontremoli, n°84 (1951).
   3b Foglio Castel Nuovo Ne' Monti, n°85 (1951).
   3c Foglio Voghera, n°71 (1959).
   3d Foglio Parma, n°73 (1961).
4. Carta Geologica dell'estremità orientale del Bacino Terziario Ligure Piemontese, 1:25000. In Cavanna et al. (1989).