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PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALAEOCLIMATIC MODELING OF THE PELAGIC OLIGOCENE-BASAL MIOCENE FROM THE PIOBBICO AREA (MARCHE BASIN, CENTRAL ITALY)

MARCO MENICHINI

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Key-words: Central Apennine, Inner Marchean Basin, Oligocene-Miocene, Biostratigraphy, Planktonic foraminifers, Dinoflagellate cysts.

Riassunto. Nell'area di Piobbico (Pesaro, Italia Centrale, Bacino Marchigiano Interno) i sedimenti pelagici paleogenici-miocenici affioranti sono largamente estesi e principalmente costituiti da marne e calcari marnosi.

In questo lavoro sono state considerate due sezioni nell'area di Pieve d'Accinelli (PDA e PDA bis), per le quali è stato eseguito un dettagliato studio biostratigrafico sull'associazione a foraminiferi planctonici adottando le biozonazioni standard.

La sezione PDA bis si estende tra l'Oligocene inferiore e l'Aquitaniano basale (dalla Zona P20 alla Sottozona N4a), mentre la sezione PDA è inclusa nella Zona N4 (porzione inferiore dell'Aquitaniano).

Sono stati identificati i bioeventi "standard" come la LO (Last Occurrence) di "*Globigerina*" *ampliapertura*, *Chiloguembelina* spp., *Paragloborotalia opima opima* e la FO (First Occurrence) di *Paragloborotalia kugleri* e di *Globoquadrina dehiscens*, unitamente ad altri bioeventi "ausiliari". Inoltre, nell'intervallo analizzato, si verificano numerosi picchi di abbondanza come quello di *Dentoglobigerina* nella porzione medio-superiore della Sottozona P21b, un forte incremento dei generi *Tenuitella* e *Catapsydrax* nella Sottozona P21b, ed un incremento di *Dentoglobigerina* al tetto della Zona P22, di *Globoquadrina* nella Sottozona N4a, di *Globigerinoides* spp. al tetto della Sottozona N4a e di *Globoquadrina dehiscens* nella Sottozona N4b.

È stata successivamente eseguita un'analisi preliminare dell'associazione a cisti di dinoflagellati intorno al limite Oligocene inferiore/Oligocene superiore. Sono stati quindi individuati due bioeventi quali un picco di abbondanza di *Svalbardella cooksonae* alla base della Sottozona P21b e la FO di *Impaginodinium minor* alla base della Zona P22.

Sulla base dell'analisi semiquantitativa delle associazioni a foraminiferi planctonici, è stato infine ipotizzato un modello paleoclimatico. Tale analisi suggerisce condizioni temperato-fredde al tetto della Zona P20. Nella parte bassa dell'Oligocene superiore l'associazione evidenzia condizioni molto fredde, mentre l'intervallo compreso tra la Zona P22 e la Sottozona N4b mostra una generale instabilità paleoclematica.

Abstract. In the Piobbico area (Pesaro, Central Italy, Inner Marchean Basin), outcrops of Paleogene to Early Miocene pelagic sediments are widespread and mainly consist of marls and marly limestones. In this paper two sections have been considered in the near Pieve d'Accinelli (PDA and PDA bis).

A detailed biostratigraphic study was performed on planktonic foraminiferal assemblages using the standard zonations. PDA bis section spans from Early Oligocene to basal Aquitanian (Zone P20 to Subzone N4a), while PDA section is included in Zone N4 (Early Aquitanian).

"Standard" bioevents such as the LO (Last Occurrence) of "*Globigerina*" *ampliapertura*, *Chiloguembelina* spp., *Paragloborotalia opima opima* and the FO (First Occurrence) of *Paragloborotalia kugleri* and of *Globoquadrina dehiscens*, together with other "added" bioevents, have been identified. Moreover, several peaks in abundance occur such as a fair peak of *Dentoglobigerina* in the middle-upper portion of Subzone P21b, a strong increase in abundance of *Tenuitella* and *Catapsydrax* groups in Subzone P21b, an increase in abundance of *Dentoglobigerina* at the top of Zone P22, of *Globoquadrina* in Subzone N4a, of *Globigerinoides* spp. at the top of Subzone N4a and of *Globoquadrina dehiscens* in Subzone N4b.

A preliminary study of dinoflagellate cyst assemblages was carried out around Early Oligocene/Late Oligocene boundary. Two bioevents such as a peak in abundance of *Svalbardella cooksonae* at the base of Subzone P21b and the FO of *Impaginodinium minor* at the base of Zone P22 have been identified.

On the ground of a semiquantitative analysis of the planktonic foraminiferal assemblages, a paleoclimatic pattern has been tentatively inferred. This analysis suggests cool-temperate conditions at the top of Zone P20. In the lower part of the Late Oligocene the assemblages indicate the outset of very cool conditions, while the interval that spans Zone P22 to Subzone N4b is characterized by a generalized paleoclimatic instability.

Introduction.

Oligocene is an Epoch characterized by important global eustatic level fluctuations. In partcular, "mid" Oligocene records a moderate accumulation of ice on the Antartic continent (Biolzi, 1985) that reflects a substantially cool period which caused glacio-eustatic phenomena.

The interval spanning from the Early Oligocene to the basal Miocene is charcterized by monotonous planktonic flora and fauna assemblages, generally represented by long ranging forms. Only few of them are good markers, even if their range may result diachronous for

- Dipartimento di Scienze della Terra, Università di Perugia, 06100, Perugia (Pg), Italy.

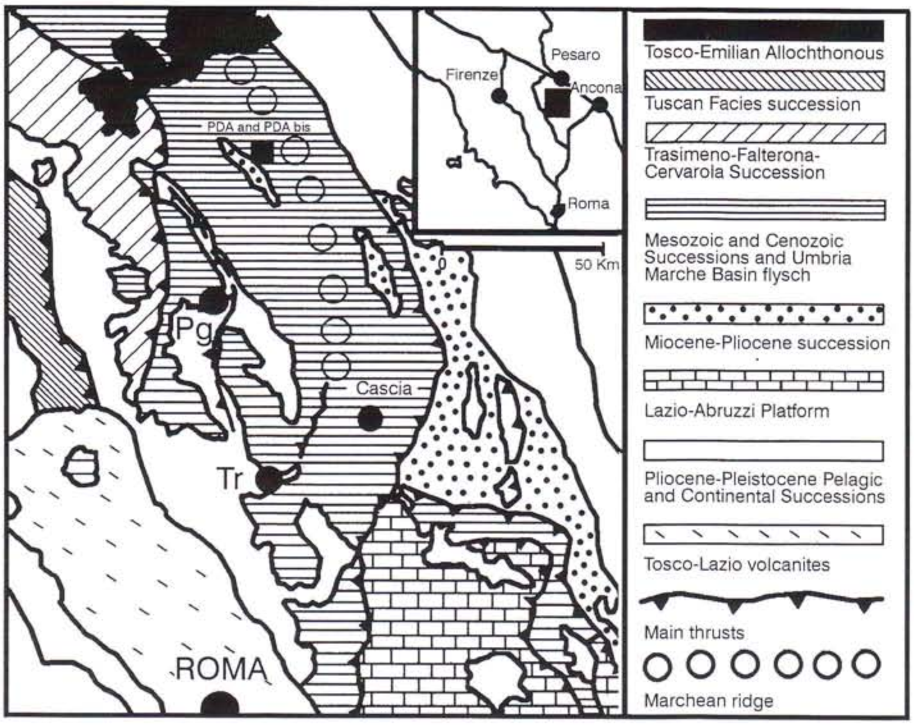


Fig. 1 - Geological map of the Umbria-Marche Domain and location map of the studied sections (after Monaco, 1988).

At "state of art", it is necessary to look for a standard stratotype on basinal facies for the Lower Oligocene/Upper Oligocene (Rupelian-Chattian) boundary. Due to the presence of wide, nearly continuous and complete successions of Tertiary pelagic limestones and marls without evident hiatuses, extraformational supplies and intense tectonic disturbances, the Inner Marchean Basin offers an ideal area for biochronostratigraphic studies of the Oligo-Miocene successions.

The present biostratigraphic analysis concerns planktonic foraminifers of two sections lying to the north of Piobbico (PDA and PDA bis, Marche, Central Italy). These sections include the Oligocene-basal Miocene Scaglia Cinerea Fm. and the basal portion of the Aquitanian Bisciaro Fm.

The lower portion occurring in PDA bis section is scarcely represented. Therefore, this section is not suitable as a standard stratotype for the Rupelian/Chattian boundary. These sections, however, are important for they record both Early Oligocene/Late Oligocene and Oligocene/Miocene boundaries.

Moreover, dinoflagellate cysts assemblages around the Lower Oligocene/Upper Oligocene (Rupelian/Chattian) and Zone P21/Zone P22 boundaries have been investigated.

the control due to palaegeographic and palaeoclimatic variations. Moreover, general unstable conditions affected the cosmopolitan flora and fauna which show low diversity, simply morphology and a low evolutionary rate (Boersma et al., 1987). These factors determine the presence of few significant bioevents and the necessity of a better biostratigraphic resolution of this period.

Oligocene is served by a twofold time-stratigraphic subdivision: Rupelian (Early Oligocene) and Chattian (Late Oligocene). The boundary between these two stages is defined with the LAD (Last Appearance Datum) of *Chiloguembelina* spp. (Berggren & Miller, 1988), while Oligocene-Miocene boundary with the FAD (First Appearance Datum) of *Paragloborotalia kugleri* (Berggren & Miller, 1988).

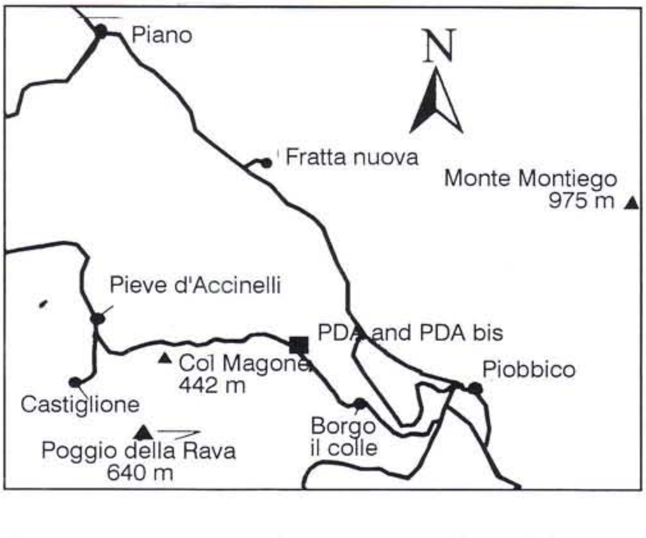


Fig. 2 - Location map (Foglio 116, IV NW, Piobbico) of the studied sections.

Geological setting.

The PDA and PDA bis sections belong to the forelimb of Monte Nerone-Monte Catria anticline, a conical fold almost regular, simmetric and approximately deeping towards NW. The "Scaglia" outcrops continuously along the limbs of this anticline and consists of reddish marls and marly limestones at the base, passing to mainly gray marly facies.

Several faults interested Miocene successions; these faults are related to the tectonic Tortonian phase, when the Marchean ridge emerged, splitting the originally unique Marchean Basin in to a Inner and Outer Basin (Fig. 1).

In the Piobbico area, the Scaglia Cinerea Fm. (Late Eocene-Basal Aquitanian) and Bisciaro Fm. (Aqui-

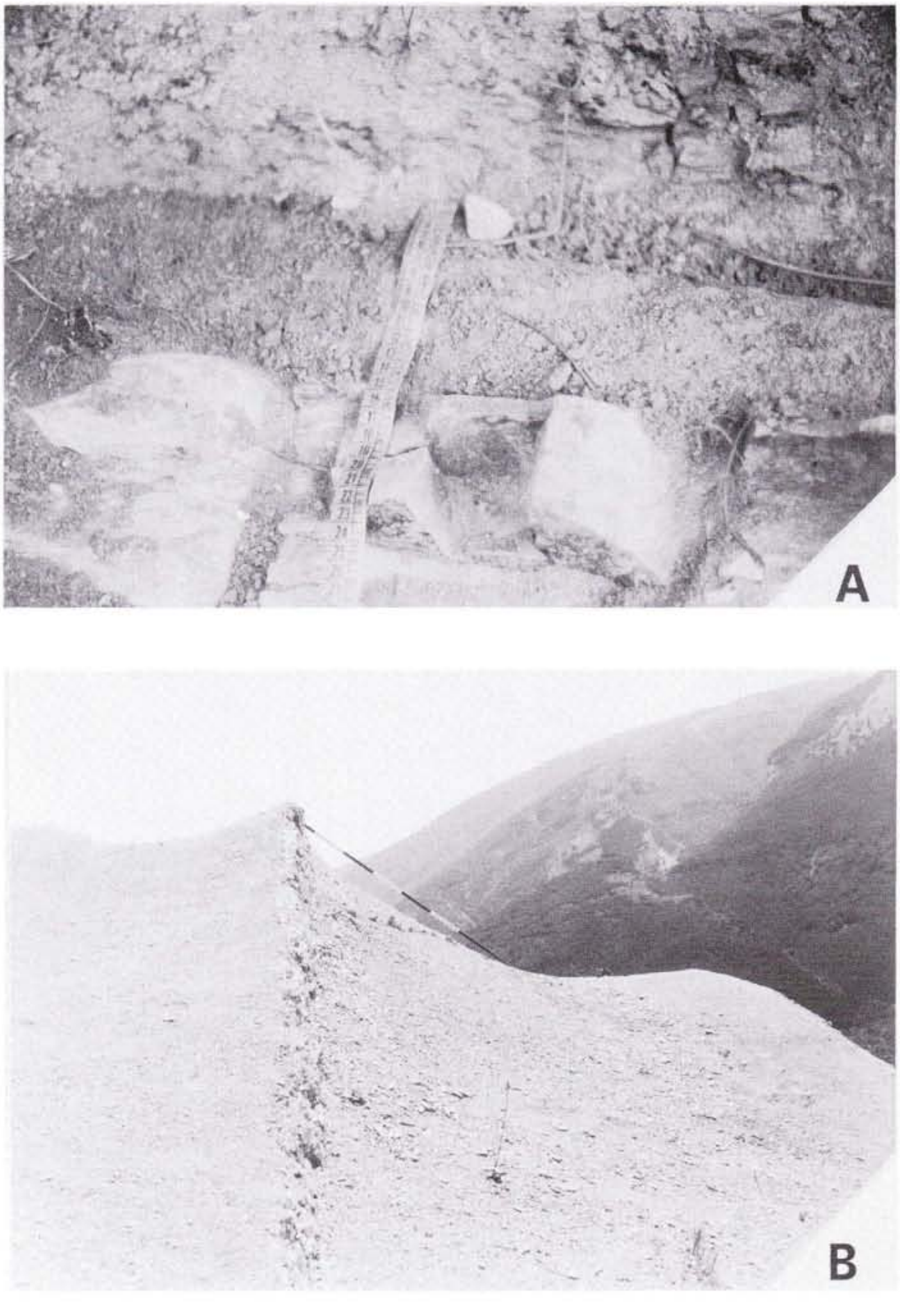


Fig. 3 - A) The "Livello Raffaello"; B) Particular of the PDA bis section (meter 17.00).

tanian p.p.-Burdigalian p.p.) outcrops are wide spread, common and well exposed.

Scaglia Cinerea Fm. has a thickness around 100 meters in the studied area and consists of homogeneous sedimentation of well bedded green-gray calcareous marls and marly limestones, tending to be brown with the increase of the clay content. Often it is characterized by splintery fracturation. The lower part, more calcareous and bioturbated, shows both middle and thin layers, while the upper one shows a most regular stratification.

Concerning the Scaglia Cinerea lower boundary, the last occurrence of reddish marly limestones marks the boundary between Scaglia Variegata Fm. and Scaglia Cinerea Fm. The upper boundary of the Scaglia Cinerea is marked by the so called Livello Raffaello (Coccioni et al., 1989) located at the base of the overlying Bisciaro Fm. The Livello Raffaello represents the first volcanic episode of the Miocene vulcanism in the Umbria-Marchean Basin and biostratigraphic studies provided for this level a Middle Aquitanian age (Coccioni et al., 1994).

The Bisciaro Fm. is made of an alternation of calcareous marls, siliceous marly limestones, volcaniclastic ashes, tuffits and bentonite and has a variable thickness from 15 to 170 meters. It can be subdivided in three lithologic members as follows: 1) lower marly member; 2) middle calcareous siliceous tuffitic member; 3) upper marly member. Only the first member is partially recorded in the PDA section and consists of marly limestones rich of light or dark cherts. The age of the Bisciaro has been estimated on bio-magnetostratigraphic basis as Aquitanian p.p. to Burdigalian p.p. (Guerrera, 1977).

Lithostratigraphy.

The two studied sections are located on the Monte Nerone–Monte Catria anticline forelimb (Lat:43°35' 34"; Long. 12°29'57" E Greenwich).

From the Piobbico's Square, a road leads to the Borgo del Colle locality. After 1.3 km, on the right side of the road, there is a new house behind and beside of which the two sections are located (Fig. 2). These are separated by a small ditch and while PDA section is delimited by the house and a mule-track, PDA bis section is included between the same mule-track and the road Piobbico-Pieve d'Accinelli. Their thickness is 14.20 m and 54.20 m respectively.

In the PDA section the volcaniclastic Livello Raffaello was identified (Fig. 3) and the Bisciaro Fm. outcrops for 6 meters (Fig. 4).

In the investigated interval, 77 samples were collected approximately every meter, 59 of them for the

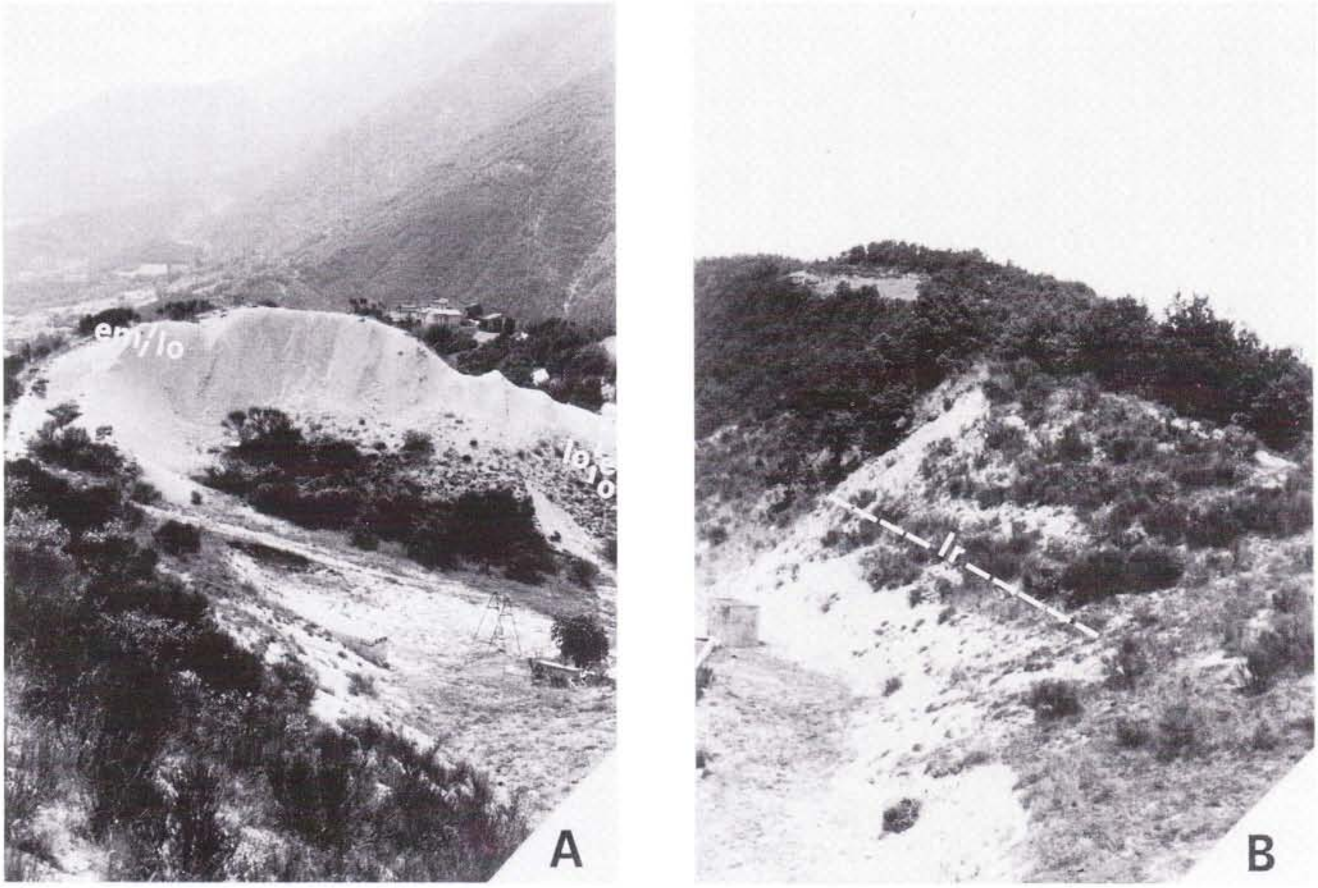


Fig. 4 - A) View of PDA bis section. Location of both the EO/LO (Early Oligocene/Late Oligocene) and LO/EM (Late Oligocene/Early Miocene) boundaries; B) View of PDA section. Location of the "Livello Raffaello" (LR).

PDA bis section. PDA bis section has this abbreviation because it has been sampled later than the PDA section, even if it records older lithology than the latter.

PDA bis section is wholly included within the Scaglia Cinerea Fm. which appears with small and splintery gray elements and is more bioturbated and calcareous in its lower part. A rich biotite level, 4 mm thick, occurs between samples 13.20 and 13.30 and two levels characterized by intense bioturbation in samples PDA bis 16.30 and PDA bis 22.30 were identified. Lithology is made by an alternation of marls and calcareous marls, with few interbedded marly limestone layers about 20 cm thick (Fig. 5); carbonate content varies from 54.17% to 73.01%.

The PDA section spans the top of the Scaglia Cinerea Fm. through the Livello Raffaello (Fig. 4). In this section the Livello Raffaello is 15 cm thick, shows a reddish colour and is barren of foraminifera. Also a cineritic level, 3 cm thick, has been identified at 11.60 m. From the base to the top, the section is affected by a slow but progressive increase of calcareous supply and the lithology changes from marls to calcareous marls (Fig. 6). The last 1.50 meters contain black chert nodules intercalated with marly limestones. This latter part of the section has been investigated both in thin sections and washed residues.

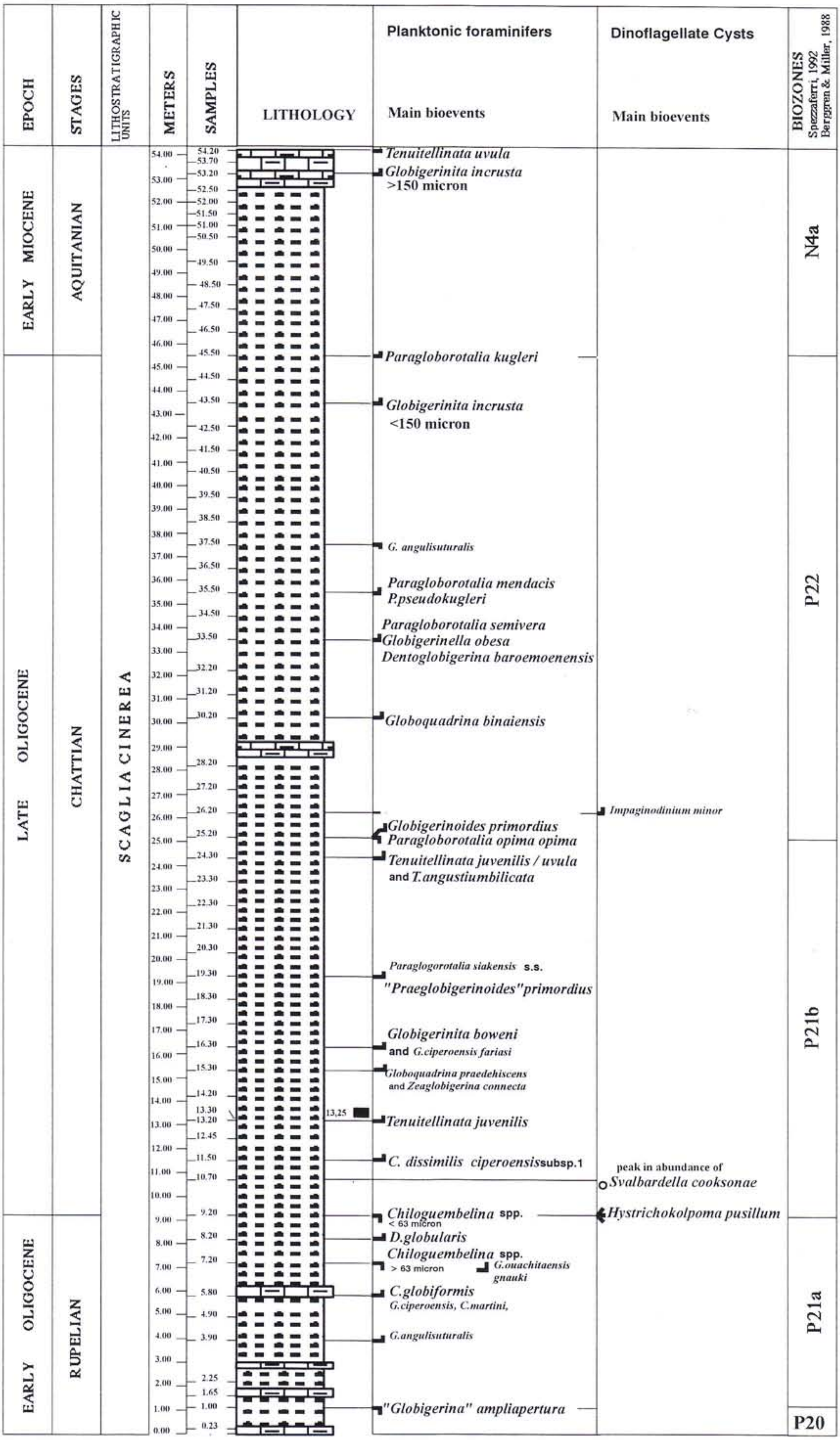
Biostratigraphy.

Planktonic foraminifers.

Material and method. A detailed biostratigraphic study was performed on 77 samples. These samples were soaked in desogene, very rarely in hydrogen peroxide (130 vol.), then washed through 40 μm sieves. The residue was splitted in two fractions, the first >63 μm to 150 μm (fine fraction), and the second > 150 μm (coarse fraction). For the lower part of the PDA bis section (PDA bis 0.23-PDA bis 15.30) a further sieve (40 μm) was used.

The state of preservation of planktonic foraminiferal assemblages varies from poor (lower portion of

Fig. 5 - Litho-biostratigraphic log of the PDA bis section (for legend see Fig. 6). In this figure, the dubious FO and LO are marked with an asterisk (Spezzaferri, 1992 for P20/P21 Zones; Berggren & Miller, 1988 for P22-N4 Zones).


EPOCH
STAGES
LITHOSTRATIGRAPHIC UNITS
METERS
SAMPLES
LITHOLOGY
Planktonic foraminifers
Main bioevents
Dinoflagellate Cysts
Main bioevents
BIOZONES
Spezzaferri, 1992
Berggren & Miller, 1988
EARLY MIOCENE
AQUITANIAN
LATE OLIGOCENE
CHATTIAN
EARLY OLIGOCENE
RUPELIAN
SCAGLIA CINEREA
Tenuitellinata uvula
Globigerinita incrusta >150 micron
Paragloborotalia kugleri
Globigerinita incrusta <150 micron
G. angulisuturalis
Paragloborotalia mendacis
P.pseudokugleri
Paragloborotalia semivera
Globigerinella obesa
Dentoglobigerina baroemoenensis
Globoquadrina binaiensis
Globigerinoides primordius
Paragloborotalia opima opima
Tenuitellinata juvenilis / uvula
and T.angustiumbilicata
Paraglogorotalia siakensis s.s.
"Praeglobigerinoides"primordius
Globigerinita boweni
and G.ciperoensis fariasi
Globoquadrina praedehiscens
and Zeaglobigerina connecta
Tenuitellinata juvenilis
C. dissimilis ciperoensis subsp.1
Chiloguembelina spp.
< 63 micron
D.globularis
Chiloguembelina spp.
> 63 micron
G.ouachitaensis gnauki
C.globiformis
G.ciperoensis, C.martini,
G.angulisuturalis
"Globigerina" ampliapertura
Impaginodinium minor
peak in abundance of
Svalbardella cooksonae
Hystrichokolpoma pusillum
N4a
P22
P21b
P21a
P20
13,25

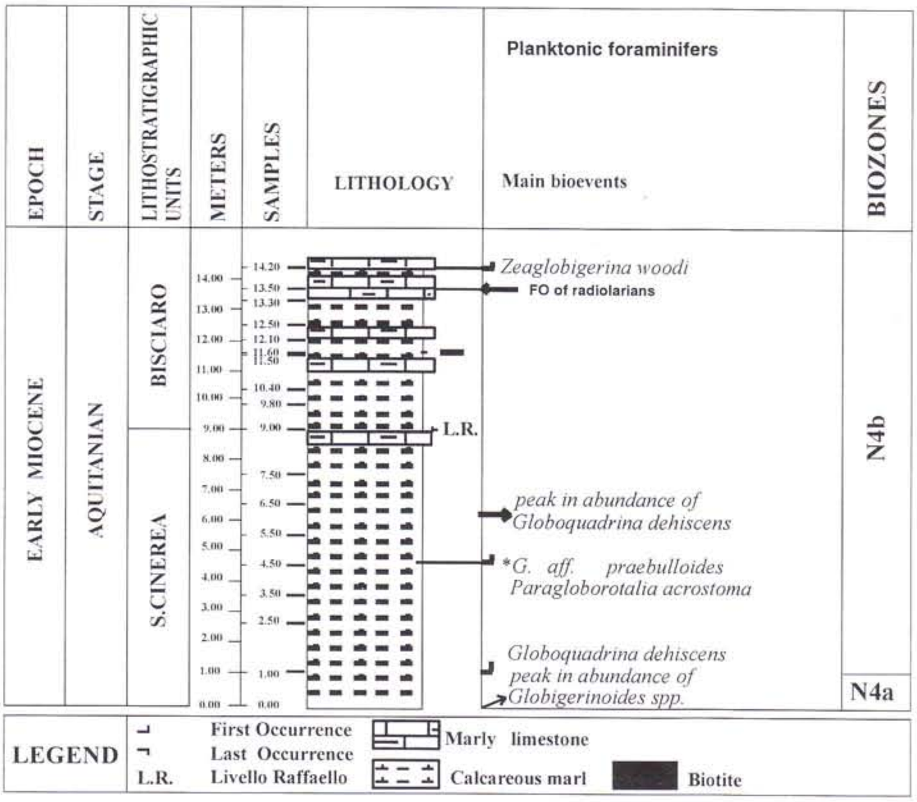


Fig. 6 - Litho-biostratigraphic log of the PDA section.

were used. Particularly Spezzaferri's ones was applied for the interval spanning Zone P20 to Subzone P21a. Infact, the bioevents recorded in the lower portion of the PDA bis section did not allow to follow the biozonal scheme of Berggren & Miller (1988) for this interval because these Authors define the Zone P20-Zone P21 boundary with the FO of *G. angulisuturalis*, just after the extinction of "*Globigerina*" *ampliapertura*.

In the PDA bis section *G. angulisuturalis* is a discontinuous and rare taxon, and it is possible that its real FO may happen in the section's lower part not sampled, therefore before the LO of "*G.*" *ampliapertura*, as it was found by Baumann (1970) in the Monte Cagnero section (Inner Marchean Basin).

About the interval between Subzone P21b and Zone N4, the biozonal scheme of Berggren & Miller (1998) was used. In fact, all the bioevents that mark the zonal boundaries of this interval were recorded in the PDA and PDA bis sections in the same stratigraphical order.

PDA bis section and upper portion of PDA section) to discrete (middle-upper portion of PDA bis section and middle-lower portion of PDA section) although the test is still recrystallized.

The presence and abundance of planktonic foraminiferal components was estimated for each of the two sections. Four categories were distinguished and plotted on the range charts. They are: Rr (Very rare) <3%; 3%<R (Rare)<7%; 7%<C (Common) <20%; A (Abundant) >20%. Semiquantitative analysis of single planktonic foraminiferal species or groups was performed and used to quantify the abundance of the palaeoclimatic indicators according to Spezzaferri & Premoli Silva (1991), Spezzaferri (1992, 1995, 1996), Luciani & Silvestrini (1996) and Novaretti & Bicchi (1996). Such indicators are subdivided in warm, warm-temperate, temperate, cool-temperate and cool indexes.

Moreover, the author remarks that some first occurrences identified in the two analysed sections may be uncertain because the paleoclimatic instability of the Oligocene-Miocene interval causes continuous fluctuations in abundance and presence of some taxa. Therefore, in this paper, the dubious first occurrence are marked with a question mark (Ex: FO(?) of *Paragloborotalia siakensis*) and in Figure 5 are indicated with an asterisk. The photographs of the main taxa among the planktonic foraminifers recorded in the two analysed sections are shown in Plate 1 and Plate 2.

Biozonation. In this work the zonal schemes of Spezzaferri (1992) and of Berggren & Miller (1998)

Main bioevents. PDA bis section. The vertical distribution of the most significant and abundant species is reported in Fig. 7 (coarse fraction) and Fig. 8 (fine fraction). All the so called "standard" bioevents and the Lower Oligocene/Upper Oligocene (Rupelian/Chattian) and Upper Oligocene/Lower Miocene (Chattian/Aquitanian) boundaries, marked by the LO of *Chiloguembelina* spp. (Berggren & Miller, 1988) and by the FO of *Paragloborotalia kugleri* (Berggren & Miller, 1988) respectively, have been identified (see Fig. 5-6).

Particularly, the LO of *Chiloguembelina* spp. occurs in sample PDA bis 9.20 and the FO of *P. kugleri* in sample 45.50.

PDA section. The vertical distribution of the identified species is reported in Fig. 9 (coarse fraction) and in Fig. 10 (fine fraction).

Four bioevents are recorded in PDA section: the FO of *Globoquadrina dehiscens* in PDA 1.00, the FO of *Paragloborotalia acrostoma* and the FO (?) of *Globigerina* aff. *praebulloides* (sensu Spezzaferri, 1994) in PDA 4.50, and the FO of *Zeaglobigerina woodi* in PDA 14.20. Furthermore, "*Praeglobigerinoides*" aff. *trilobus*, *Tenuitellina*-

Fig. 7 - Distribution chart of the species identified in the PDA bis section (fraction > 150 μm) and biozonation based on Spezzaferri, 1992; Berggren & Miller, 1988. A= abundant; C= common; R= rare; Rr= very rare.

ta neoclemencee, *T. praestainforthi*, *Paragloborotalia continuosa* and transitional forms of *T. angustiumbilicata / T. pseusoedita* are present throughout the section.

The absence of *G. dehiscens* and the presence of *P. kugleri* allow to attribute the first meter of the PDA section to Subzone N4a, while the concurrence of the two nominated taxa enables to attribute the interval PDA 1.00-PDA 14.20 to Subzone N4b (sensu Berggren & Miller, 1988).

The Bisciaro Fm., here outcropping for 6 meters, was also analysed in thin section, in which specimens of *G. dehiscens*, glauconite, intense bioturbation and small sized planktonic foraminifers were identified. This data are consistent with the lithologic description of the lower member of the Bisciaro Fm. (Coccioni et al., 1997). It is interesting to point out that in samples PDA 13.50-14.20 (above the Livello Raffaello) radiolarians appear, even if not abundant, and *P. kugleri* (even if rare) is still present in the last sample of the section, 5 m above the Livello Raffaello.

Description of the identified Zones and Subzones.

Zone P20, *"Globigerina" ampliapertura* Partial Range Zone (Spezzaferri, 1992): from PDA bis 0.23 to PDA bis 1.00; only the top of this Zone is recorded:

Definition: partial range of the nominate taxon between the LO of *Pseudohastigerina barbadoensis* (base) and the LO of *"G." ampliapertura* (top).

Thickness: the partial thickness of this Zone, in which the base is not recorded, is around 1 meter.

Coarse fraction: the zonal marker (*"G." ampliapertura*) is generally very rare. In this fraction, planktonic foraminiferal assemblages consist of abundant catapsydracids and paragloborotaliids, represented by *P. opima opima* s.s., *P. opima nana* and *P. pseudocontinuosa*. The assemblage is furthermore characterized by common "large" globigerinids, small *Globigerina senilis* and *G. euapertura*, few and much rare small globigerinids. Scattered forms of *Globorotaloides suteri*, *Subbotina gortanii* and *Globoquadrina tapuriensis* are present. *Globigerina bulloides criptomphala* is very rare in the basal sample, above which this taxon is identified only in few samples (Fig. 7). Benthonic foraminifers and fish tooth are present as well.

Fine fraction: this fraction is dominated by chiloguembelinids, tenuitellids and rare, but constant, *Gumbelitria*.

Zone P21, *Globigerina angulisuturalis/Paragloborotalia opima opima* Concurrent Range Zone (Berggren & Miller, 1988): from PDA bis 1.00 to PDA bis 25.20.

Definition: concurrent range of nominate taxon between the LO of *"G." ampliapertura* (base) and the LO of *P. opima opima* (top).

Thickness: around 24.00 meters.

Remarks: on ground of the LO of *Chiloguembelina* spp. (Berggren & Miller, 1988) two Subzones are identified.

Subzone P21a, *Globigerina angulisuturalis/Chiloguembelina cubensis* Concurrent Range Subzone (Berggren & Miller, 1988; emended by Spezzaferri, 1992): from PDA bis 1.00 to PDA bis 9.20.

Definition: concurrent range of the nominate taxa between the LO of *"G." ampliapertura* (base) and the LO of *Chiloguembelina* spp. (top).

Thickness: around 8.20 meters.

Coarse fraction: the assemblages are still dominated by catapsydracids (mainly *C. dissimilis dissimilis*) and *paragloborotaliids*. Like in Zone P20, "large" globigerinids are common. On the contrary *G. praebulloides*, *G. angulioffıcinalis* and *G. euapertura* are rare and discontinuously present. Within this Subzone *C. dissimilis ciperoensis*, rare in Zone P20, increases in abundance. The genus *Paragloborotalia* is once again represented by *P. opima opima*, *P. opima nana* and *P. pseudocontinuosa*. The first two taxa are common and more frequent than the last one, and show a peak in abundance.

G. angulisuturalis appears in the lower part of this Subzone. In the middle portion of this Subzone, the FO(?) of *C. dissimilis ciperoensis* with 4 apertures, *C. martini* and *C. globiformis*, taxa rare and discontinuously present in this interval, are identified.

Fine fraction: this fraction is similar to the Zone P20's one and still badly preserved. Planktonic foraminiferal assemblages are dominated by chiloguembelinids, tenuitellids, *P. opima nana* and *P. pseudocontinuosa*. *Chiloguembelina* is generally constant but becomes more abundant in the middle-upper portion of the Subzone.

Subzone P21b, *Globigerina angulisuturalis/Paragloborotalia opima opima* Concurrent Range Subzone (Berggren & Miller, 1988): from PDA bis 9.20 to PDA bis 25.20.

Definition: concurrent partial range of the nominate taxa between the LO of *Chiloguembelina* spp. (base) and the LO of *Paragloborotalia opima opima* (top).

Thickness: approximately 16 meters.

Coarse fraction: in the lower part of this Subzone *C. dissimilis* subsp.1 (sensu Molina, 1979) is identified for the first time. This fraction is mainly represented by globigerinids, paragloborotaliids, catapsydracids and dentoglobigerinids. *G. selli* is present only in scattered samples. Very important is the presence of rare *Globigerinoides primordius* in the last sample of the Subzone. This confirms the stratigraphic overlap of this taxon with the zonal marker *P. opima opima* (Shafik & Chaproniere, 1978).

Fine fraction: this fraction is better preserved than in the previous zones. Five centimeters below a rich biotite level identified in the PDA bis section (PDA bis 13.25), the FO of *Tenuitellinata juvenilis* is recorded. In the middle part of this Subzone the FO of *Globigerinita*

Fig. 8 - Distribution chart of the species identified in the PDA bis section (fraction < 150 (m) and biozonation based on Spezzaferri, 1992; Berggren & Miller, 1988. A= abundant; C= common; R= rare; Rr= very rare.

EPOCH	STAGE	BIOZONE	SAMPLES	*Chiloguembelinidae* > 63 micron	*Chiloguembelinidae* < 63 micron	*Paragloborotalia opima opima*	*P. pseudocontinuosa*	*Tenuitella* spp.	*Gumbelitria*	*Paragloborotalia opima nana*	*Globorotaloides suteri*	*Globigerina praebulloides*	*Globigerina ouachitaensis*	*Globigerina angulioffcinalis*	*Globigerina angulisuturalis*	*Paragloborotalia* cf. *siakensis*	*Globigerina ciperoensis*	*Tenuitellinata juvenilis*	*Globigerinita boweni*	*Zeaglobigerina connecta*	*Globigerinita* spp.	*T. angustiumbilicata*	*T. juvenilis / T. uvula*	*G. ciperoensis fariasi*	*Protentella* spp.	*Paragloborotalia mendacis*	*Paragloborotalia pseudokugleri*	*Globigerinella obesa*	*Globigerinita incrusta*	*Paragloborotalia kugleri*	*Tenuitellinata uvula*
EARLY MIOCENE	AQUITANIAN	N4a	PDA bis 54.20				R	C	R	R		Rr				R		R	R	R		R	Rr			R	C	Rr	Rr	R	Rr
			PDA bis 53.70				R	C	R	R		Rr				R		R	R	R			R			R	C	Rr	R	R	
			PDA bis 53.30				R	C	R	R	Rr	Rr				R		R	R	Rr		Rr			Rr	R	C	Rr		R	
			PDA bis 53.20				R	C	R	R		Rr				R		R	R	Rr	Rr					R	C	Rr	Rr	R	
			PDA bis 52.50				R	C	Rr	R		Rr	Rr			Rr	R	Rr	Rr	R	R	R			R	R	C	Rr	Rr	R	
			PDA bis 52.00				R	C	R	R		Rr				Rr		R		R		Rr	Rr		Rr	R	C	Rr	Rr	R	
			PDA bis 51.50				R	C	R	R	Rr	Rr						R	R	R		Rr				R	C	Rr		R	
			PDA bis 51.00				R	C	R	R		R				Rr		R	R	R	R	R				R	C	Rr	Rr	R	
			PDA bis 50.50				R	C	R	R		R						R	Rr	Rr		R				R	C	Rr		R	
			PDA bis 49.50				R	C	R	R	R	R	Rr			Rr		R	R	Rr	Rr	R	Rr		Rr		C	Rr	Rr	R	
			PDA bis 48.50				R	C	R	R	Rr	R	R			Rr		R		Rr	R	R				R	C	Rr	Rr	R	
			PDA bis 47.50				R	C	R	R	R	R				R		R	R			R				R	C	Rr	Rr	R	
			PDA bis 46.50				R	C	R	R	Rr	R	Rr					R	R	Rr	R	R			Rr	R	R		Rr	Rr	
			PDA bis 45.50				R	C	C	R	R	R				Rr		R			R	R			Rr	R	C	Rr	Rr	Rr	
LATE OLIGOCENE	CHATTIAN	P22	PDA bis 44.50				R	C	R	R		Rr	Rr	Rr		R		R	R	Rr	R	R			Rr	Rr	C		Rr		
			PDA bis 43.50				R	C	R	R		R	Rr			Rr		R	R	Rr	R	R	Rr		Rr		C	Rr	R		
			PDA bis 42.50				R	C	R	R	Rr	R						R	R		R	R					C	R			
			PDA bis 41.50				R	C	R	C	Rr	R		R		Rr	Rr	R		Rr	R	C				Rr	C	R			
			PDA bis 40.50				R	C	R	R		R				Rr	R	R	R	Rr	R	R				Rr	R				
			PDA bis 39.50				R	C	R	C		R	Rr	R		Rr	Rr	R	R	Rr	C	R	Rr	Rr	Rr		R				
			PDA bis 38.50				R	C	R	C	Rr	R	Rr					R			R	R					R				
			PDA bis 37.50				R	C	R	C		R		R	Rr	R		R	R	Rr	R	R				Rr	R				
			PDA bis 36.50				R	C	R	C	R	R	Rr	R			Rr	C	R	R	R	R			Rr		R				
			PDA bis 35.50				R	C	R	C	R	R	Rr	R	R	Rr		C		R	R	R	R		Rr	Rr	Rr				
			PDA bis 34.50				R	C	R	C		R	Rr					R	Rr	R	R	C									
			PDA bis 33.50				R	C	Rr	C	R	R						R	R	R	R	R									
			PDA bis 32.20				R	C	R	C	R	C	Rr	R		R		R	R	R	R	C	R	R	Rr						
			PDA bis 31.20				R	C	R	C	R	C	Rr	R		R	R	R	C	R	R	C	R	R							
			PDA bis 30.20				R	C	R	C	R	C	R	R		R	R	C	C	R	R	C									
			PDA bis 28.20				C	C	R	C	R	R	Rr	R			R	C	R		R	C									
			PDA bis 27.20				C	C	R	C	R	R		R		R	R	C	R	R	R	C									
			PDA bis 26.20				R	C	R	R		R	R	R				C	R	R	R	C									
		P21b	PDA bis 25.20				R	C	R	R	R	C	C	R			R	R	R	Rr	R	C									
			PDA bis 24.30			R	C	C	R	C	R	C	R	R		R	R	C	R	Rr	R	C	Rr								
			PDA bis 23.30				C	C	R	C	R	C	R	R		R	Rr	C	R		R										
			PDA bis 22.30			R	C	A	Rr	C	R	C	R	R		R		C	R	R	R										
			PDA bis 21.30			R	R	A	R	R		C	R	R		R	R	C	R	R	R										
			PDA bis 20.30			R	C	C	R	C		R		R				C	R	R	R										
			PDA bis 19.30			R	C	C	R	C	Rr	C	R	C		R		C	R	R	R										
			PDA bis 18.30			R	C	C	R	C		R		C				C	Rr	R											
			PDA bis 17.30			R	C	C	R	C		C		R		R		C	R	R											
			PDA bis 16.30			R	C	C	R	C		R	R	R	R	R	Rr	C	Rr												
			PDA bis 15.30			Rr	C	C	R	C	Rr	R	R	R		R		R													
			PDA bis 14.30			R	C	C	R	C	C	R	R					R													
			PDA bis 13.30			R	C	C	R	C	R	R	R	R		R		R													
			PDA bis 13.20			R	R	R	Rr	R		R						Rr													
			PDA bis 12.45			Rr	R	C	Rr	Rr	R	R	R	R	R		Rr														
			PDA bis 11.50			R	R	C	Rr	C		R		R		R															
			PDA bis 10.70			R	C	C	Rr	C	R	R	R	Rr		R															
EARLY OLIGOCENE	RUPELIAN	P21a	PDA bis 9.20		Rr	R	R	C	C	C	R	R	R																		
			PDA bis 8.20		Rr	R	C	C	R	C	R	R			R	R															
			PDA bis 7.20	A	A	Rr	C	C	C	C	R	R	R	R	R																
			PDA bis 5.80	A	A	R	C	R	C	C			R	R	C																
			PDA bis 4.90	C	C		C	C	R	C	R	R		C	R																
			PDA bis 3.90	C	C	Rr	C	C	R	C	R	R		R																	
			PDA bis 2.25	C	C	R	C	C	C	C	R	R	R	C																	
			PDA bis 1.65	C	C	C	C	C	C	C	R	R																			
		P20	PDA bis 1.00	R	R	R	C	C	R	C	R																				
			PDA bis 0.23	C	C	R	C	C	R	C	R																				

EPOCH	STAGE	BIOZONE	SAMPLES	"Globigerinoides" sp. (sensu Spezzaferri)	Globigerina euapertura	Catapsydrax dissimilis subsp. 1	C. dissimilis ciperoensis 4 apertures	Dentoglobigerina globularis	Paragloborotalia pseudocontinuosa	D. aff. altispira altispira	C. unicavus	"G." praesepis	"G." venezuelana	Globoquadrina tripartita with bulla	Globorotaloides sutera	"Praeglobigerinoides" primordius	G. praebulloides	C. dissimilis dissimilis	Globigerinita incrusta	"P." aff. trilous	Globigerinoides primordius	Globoquadrina dehiscens praedehiscens	Globoquadrina praedehiscens	G. ciperoensis	C. dissimilis ciperoensis	D. haroemoenensis	D. galavisa	Globoquadrina dehiscens	Zeaglobigerina connecta	Globoquadrina tripartita	Globigerinella obesa	Globigerinita glutinata	P. semivera	C. africanus	P. acrostoma	G. aff. praebulloides (sensu Spezzaferri)	Z. woodi
EARLY MIOCENE	AQUITANIAN	N4b	PDA 14.20		Rr			R		Rr		R	R	R	R	R		R	R		R	R		R	R	R	R	R	R	R			Rr		Rr	Rr	Rr
			PDA 13.30		Rr		R	R			Rr		Rr	Rr	R			R			Rr	Rr		R	R		R	R		Rr	R		R				
			PDA 12.50				R				R		R	Rr	R	Rr			Rr			R		R	R	Rr		R	Rr		R		R		Rr		
			PDA 12.10	Rr	Rr		R				R	R	Rr	R	R		R	Rr			R	R		R	Rr	Rr	R	R		Rr	Rr			Rr	Rr	Rr	
			PDA 11.60	R	Rr		R	Rr	R	Rr	Rr	Rr	Rr	Rr	R	Rr		Rr		Rr	R	R	Rr	Rr	R		R	C			Rr	Rr	R		Rr	Rr	
			PDA 11.50	R	Rr		R		R	Rr	Rr	Rr	Rr	Rr	R	Rr	R	Rr	Rr	Rr	R	R	R	Rr	Rr	R	R	C	Rr		Rr	Rr	R		Rr	Rr	
			PDA 10.40	Rr	Rr			R	R	Rr	Rr			Rr	R		Rr	Rr		Rr	R	R	R		Rr	Rr		C		Rr	R		Rr			Rr	
			PDA 9.80	Rr			R	Rr	R	Rr	R	Rr	R	Rr	Rr		Rr	R	Rr		R	R	R	Rr	R	R	R	C	Rr	Rr	Rr						
			PDA 9.00		Rr	Rr		R	Rr		R		R	R	R	R	Rr	R	R		R		R	Rr	R	R	R	R	R	R	Rr		Rr		R	R	
			PDA 7.50		Rr	R		R	R	Rr		R	R	R	Rr			R	R		R		R		R	R	R	R	R	R		R	Rr			R	
			PDA 6.50	Rr	R	Rr	Rr	R		Rr	R	R	R	R	R		R	R	R		R	Rr	Rr		R		R	R	R	R	Rr		Rr		Rr	R	
			PDA 5.50		R		Rr	R	R	R		R	R	R	R	R		R	R	R	C					R	R	C	R	R	Rr	R			R	R	
			PDA 4.50		R	R	R	R	R	Rr	Rr	C	R	R	R		Rr	R	R		R	Rr	Rr			R	R	C	R	R	Rr	R	R		Rr	R	
			PDA 3.50		R	R		R	R		Rr	R	R	R	R	R	R	Rr	R		R	R	R	Rr	R	R	R	R	R	Rr	Rr	R	R	Rr			
			PDA 2.50	R	R	R	R	R	R	C	R	C	C	C	C	R		R	Rr	R	Rr	R	R	R	C	R	R	Rr									
			PDA 1.00	R	R	R	Rr	R	R	Rr	Rr	R	R	R	Rr	R	R	Rr	Rr	R	R	R	R		R	R	R	Rr									
		N4a	PDA 0.00	C	R	Rr	Rr	R	R	Rr	Rr	C	C	C	Rr	C	Rr	Rr	Rr	R	C	R	R	R	Rr	R	R										

Fig. 9 - Distribution chart of the species identified in the PDA section (fraction > 150 µm) and biozonation based on Spezzaferri, 1992; Berggren & Miller, 1988. A= abundant; C= common; R= rare; Rr= very rare.

boweni, rare but continuous throughout the section, has been identified. Furthermore, 1.00 m below the top of this Subzone, the FO of *T. angustiumbilicata* and of transitional forms between *T. juvenilis/T. uvula*, irregularly present in this section, are recorded. *Gumbelitria* and *Tenuitella* spp. are present as well.

Zone P22, *Globigerina ciperoensis* Interval Range Zone (Berggren & Miller, 1988): from PDA bis 25.20 to PDA bis 45.50.

Definition: partial range of nominate taxa between the LO of *Paragloborotalia opima opima* (base) and the FO of *Paragloborotalia kugleri* (top).

Thickness: around 20 meters.

Coarse fraction: this fraction shows substantial changes in the planktonic foraminiferal assemblages. In fact, in this Zone, some FO occur (see Fig. 5).

Globigerinoides primordius is rare or very rare and discontinuously present. This fraction is mainly represented by catapsydracids, paragloborotaliids and, partially, by small and large globigerinids, *Globoquadrina* and *Dentoglobigerina*. Within this Zone the scattered presence of *Zeaglobigerina brazieri* is also identified.

Fine fraction: the preservation of this fraction continues to improve. In the middle part of this Zone, the contemporary FO of *Paragloborotalia mendacis* and *P. pseudokugleri* occur. *P. pseudokugleri* is continuously present and small "*Praeglobigerinoides*" *primordius* show a weak positive peak in the upper portion of this Zone. The FO of *Globigerinita incrusta* 2.00 m below the Oligocene/Miocene boundary is recorded in this Zone as well.

Zone N4, *Paragloborotalia kugleri* Total Range Zone (Berggren & Miller, 1988): from PDA bis 45.50 to PDA 14.20.

Definition: interval defined by the total range of *Paragloborotalia kugleri*.

Thickness: the minimum thickness of this Zone combining the record of both PDA and PDA bis sections is approximately 22.40 meters.

Remarks: the presence of *Paragloborotalia kugleri* and the absence of *Globoquadrina dehiscens* in the last 8.50 m of the PDA bis section and in the first meter of

EPOCH	STAGE	BIOZONE	SAMPLES	*Paragloborotalia opima nana*	*P. continuosa*	*P. siakensis s. s.*	*Tenuitellinata juvenilis / T. uvula*	*P. pseudocontinuosa*	*Globigerinella obesa*	*T. uvula*	*T. angustiumbilicata / T. pseudoedita*	*Globigerinita glutinata*	*T. praestainforthi*	*T. juvenilis*	*Globorotaloides suteri*	*Globigerinita boweni*	*P. pseudokugleri*	*Tenuitella munda*	*T. gemma*	*Globigerina praebulloides*	*T. neoclemeniae*	*Zeaglobigerina connecta*	*Globigerinita incrusta*	*P. kugleri*
EARLY MIOCENE	AQUITANIAN	N4b	PDA 14.20		R	R	R	R	Rr		R	R	Rr	R	Rr	R	R	C	R		R	R	R	R
			PDA 13.30		R	Rr		R	Rr	Rr	Rr	Rr		Rr	R	Rr	Rr	C	Rr	Rr		Rr	Rr	R
			PDA 12.50	Rr		Rr	Rr	R		Rr		R	R	R		R	R	C	R	Rr		Rr	R	R
			PDA 12.10		R			R	R		Rr	R		Rr	R	Rr	R	R	Rr				R	R
			PDA 11.60	Rr		R	R	R	R	Rr		Rr	Rr	R		Rr	R	C	Rr	Rr			Rr	R
			PDA 11.50		R	R		R	Rr		Rr	R		R	Rr	Rr	R	C	R	Rr		R		R
			PDA 10.40	R	R	R		R	R	Rr	Rr	R		R		R	Rr	C		Rr		Rr	R	R
			PDA 9.80		R			R		Rr		R	Rr	R		Rr		R	Rr	R			R	Rr
			PDA 9.00	Rr	R	Rr	R	R	R	Rr	R	R		R	R	R	R	C	R	Rr	R	R	R	R
			PDA 7.50		R	Rr	R	R	R	Rr		R	Rr	R	R	R	R	C	R	Rr	Rr	R	R	R
			PDA 6.50		R	Rr	R	R			R	Rr		R	R	R	R	C	R	Rr	Rr	R	R	R
			PDA 5.50	Rr	R	R	R		Rr	Rr	R	R	Rr	R		R	R	R	R			R	R	R
			PDA 4.50		R	R	R	R	Rr	R	R	R	Rr	R	Rr	Rr	R	C	R		Rr	R	R	R
			PDA 3.50	Rr	R	R	R	R		Rr	R	R	Rr	R	R	R	C	R	R	Rr	R	R	C	R
			PDA 2.50	Rr	Rr	R	R	R	R	Rr	R	R	Rr	R	R	R	C	C	R	Rr	Rr	R	C	R
			PDA 1.00	Rr	R	R	R	R		Rr	R	R	Rr	R	R	R	C	C	R		R	R	C	R
		N4a	PDA 0.00	Rr	Rr	R	R	R	R	Rr	R	R	Rr	R	R	R	C	Rr	R	R	Rr	R	C	R

Fig. 10 - Distribution chart of the species identified in the PDA bis section (fraction < 150 µm) and biozonation based on Spezzaferri, 1992; Berggren & Miller, 1988. A= abundant; C= common; R= rare; Rr= very rare.

the PDA section allow to attribute these two portions of the studied succession to Subzone N4a (Berggren & Miller, 1988). On the contrary, the concurrence of these two taxa from sample PDA 1.00 to the top of the PDA section attributes this interval to Subzone N4b (Berggren & Miller, 1988).

Subzone N4a, *Globigerinoides primordius* Interval Range Subzone (Berggren & Miller, 1988): from PDA bis 45.50 to PDA bis 54.20 for PDA bis section and from PDA 0.00 to PDA 1.00 for PDA section.

Definition: interval range of nominate taxon defined by the FO of *P. kugleri* (base) and the FO of *Globoquadrina dehiscens* (top).

Thickness: at least 9.50 meters.

Coarse fraction: this fraction does not present any substantial variation from the previous zone (P22). It includes only the FO of *Globigerinita incrusta* > 150 µm 8.00 m above the Oligocene/Miocene boundary (FO of *Paragloborotalia kugleri*). Common *Tenuitellinata angustiumbilicata* > 150 µm are identified from sample PDA bis 58.50.

This taxon shows a moderate decrease in abundance at the top of the section. *Globigerinoides* spp. shows a peak in abundance at the top of the Subzone (PDA 0.00) and becomes abundant and dominant in the coarse fraction.

The genus *Globoquadrina* is well represented (*G. sellii*, *G. tripartita* with and without bulla, *G. binaiensis*) and together with "large" globigerinids, becomes common and dominant in the upper portion of the PDA bis section.

Fine fraction: the preservation of the fine fraction continues to improve. No *G. angulisuturalis* and *G.*

ciperoensis fariasi occur. *Globigerinita incrusta* concurs with *Globigerinella obesa* and *P. kugleri* throughout the interval. The zonal marker *P. kugleri* records a weak increase in abundance towards the top of the PDA bis section, while *T. juvenilis* shows in this Subzone a clear decrease in abundance. At the top of the PDA bis section, the FO of *Tenuitellinata uvula* s.s. has been recorded. *Gumbelitria* occurs costantly throughout the upper portion of the PDA bis section, while it is absent in the PDA section. *Paragloborotalia opima nana* is rarer than in the previous Zones.

Subzone N4b, *Paragloborotalia kugleri/Globoquadrina dehiscens* Concurrent Range Subzone (Berggren & Miller, 1988): from PDA 1.00 to PDA 14.20; the top of this Subzone is not recorded.

Definition: concurrent range of nominate taxa between the FO of *Globoquadrina dehiscens* (base) and the LO of *Paragloborotalia kugleri* (top).

Thickness: the base of this Subzone is recorded in the PDA section (PDA 1.00), while its top was not sampled. The thickness of this Subzone is at least 13.00 meters.

Coarse fraction: the FO of *Paragloborotalia acrostoma* in the lower portion of the Subzone, and the FO of *Zeaglobigerina woodi* in the last sample of the section have been identified. Some forms similar to *Globigerinoides trilobus*, but without secondary aperture, have been observed. This taxon has been informally named "*Praeglobigerinoides*" (Spezzaferri, 1994) *trilobus*. Sample PDA 3.50 records a strong decrease in abundance of the dominant assemblage and the contemporary weak gradual increase in abundance of *Globigerinoides primordius* and of *Globoquadrina dehiscens*. This trend has shown its acme 5.50 m above the base of the section, where *G. primordius* becomes common but not abundant and *G. dehiscens* increases in abundance and size. In the sample above, *G. dehiscens* is characterized by a continuous and gradual reduction in size and abundance, while *G. primordius*, after a partial decrease in abundance, is constant throughout the interval. In this Subzone the presence of *P. kugleri* with 7 or more chambers has not been identified in agreement with Biolzi (1985), that points out the absence of these forms in the Mediterranean area.

Fine fraction: in this fraction, the presence of *Globigerinita glutinata*, *Tenuitellinata praestaiforthi*, *T. neoclemenciae*, rare forms of *Paragloborotalia continuosa* and of transitional forms between *T. angustiumbilicata/T. pseudoedita* (Li et al., 1992, plate 1, fig. 11) have been identified. Moreover, *Gumbelitria* and *P. mendacis* are completely absent. *Globigerinita incrusta* turns from common to rare, from the base to the top of the PDA section and the radiolarians, observed in thin section (PDA 13.50 and PDA 14.20), are rare.

Discussion.

The Zones and Subzones identified in the analysed sections, on the ground both of their thickness and absolute age estimated for the main bioevents which mark their boundaries (by Berggren et al., 1995), show the following sedimentation rate: P21a=9.11 m/my; P21b=11.42 m/my; P22=6.11 m/my; N4a= at least 13.80 m/my; N4b= at least 7.14 m/my. Subzones N4a and N4b, in these sections, are much thicker in comparison to the same subzones recorded in both the Contessa (Gubbio, Umbria, Montanari et al., 1997, Subzone N4a=3.5m, Subzone N4b=5.9m) and Santa Croce d'Arcevia (central Marche) sections (Coccioni et al., 1997, Subzone N4a=3.0m, Subzone N4b=11.4m). This may due to the presence of one or more hiutuses above the base of the Livello Raffaello (Montanari et al., 1991; Coccioni et al., 1997).

The main identified bioevents are recorded in both the fine and coarse fractions, even if the most character-

PLATE 1

Fig. 1a-c - *Paragloborotalia kugleri* (Bolli, 1957). Sample PDA 3.00, Subzone N4b, Early Miocene. 1a) spiral view; 1b) side view; 1c) umbilical view.

Fig. 2a-c - *Paragloborotalia kugleri* (Bolli, 1957). Sample PDA bis 45.50, Subzone N4a, Early Miocene. 2a) spiral view; 2b) side view; 2c) umbilical view.

Fig. 3a-c - *Paragloborotalia mendacis* (Blow, 1969). Sample PDA bis 47.50, Subzone N4a, Early Miocene. 3a) spiral view; 3b) side view; 3c) umbilical view.

Fig. 4a-c - *Paragloborotalia opima opima* (Bolli, 1957). Sample PDA bis 25.20, Subzone P21b, Late Oligocene. 4a) spiral view; 4b) side view; 4c) umbilical view.

Fig. 5a-c - *Paragloborotalia pseudokugleri* (Blow, 1969). Sample PDA 14.20, Subzone N4b, Early Miocene. 5a) spiral view; 5b) side view; 5c) umbilical view.

Fig. 6a-b - *Paragloborotalia siakensis* (LeRoy, 1939). Sample PDA bis 19.30, Subzone P21b, Late Oligocene. 6a) spiral view; 6b) umbilical view.

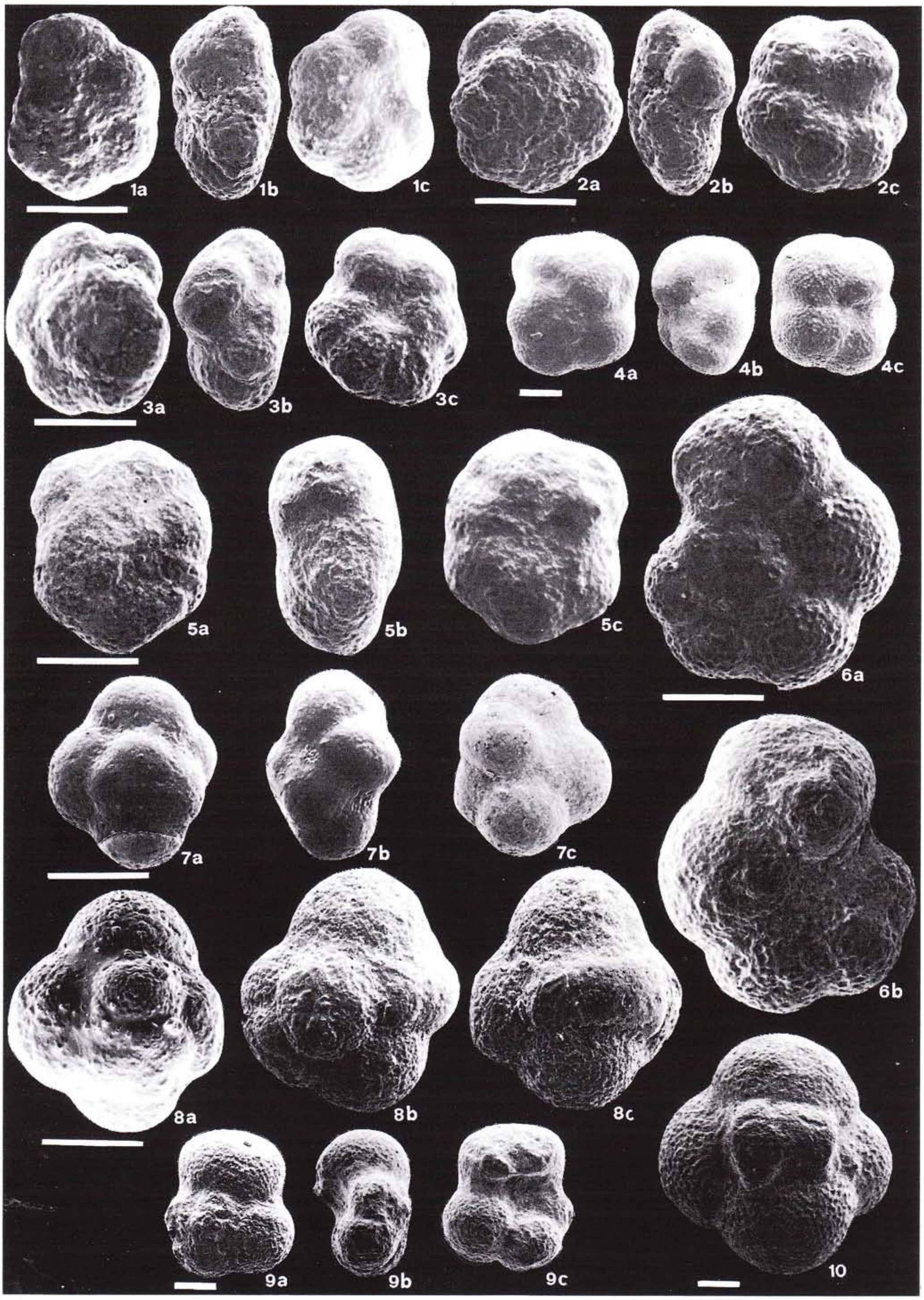
Fig. 7a-c - *Globigerinita boweni* (Bronnimann & Resig, 1971). Sample PDA bis 16.30, Subzone P21b, Late Oligocene. 7a) spiral view; 7b) side view; 7c) umbilical view.

Fig. 8a-c - *Globigerinita incrusta* Akers, 1955. Sample PDA bis 43.50, Zone P22, Late Oligocene. 8a) spiral view; 8b) side view; 8c) umbilical view.

Fig. 9a-c - *Dentoglobigerina baroemoenensis* (LeRoy, 1939). Sample PDA bis 38.50, Zone P22, Late Oligocene. 9a) spiral view; 9b) side view; 9c) umbilical view.

Fig. 10 - *Catapsydrax dissimilis ciperoensis* subsp.1 sensu Molina, 1979. Sample PDA bis 16.30, Subzone P21b, Late Oligocene. Umbilical view.

Scale bars equal 100μ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istic bioevents are primarily observed in the fine fraction (< 150 μm).

Several taxa have shown clear fluctuations and, therefore, the biostratigraphic resolution of this interval is difficult, even if, among them, paleoclimatic indicators are useful for its paleoclimatic interpretation.

In Subzone P21a the first occurrences prevaile over the last occurrences and the main "added" bioevents are recorded in the fine fraction. In this Subzone the LO of *Chiloguembelina* spp. > 63 (m was identified 2 m below the Early Oligocene / Late Oligocene boundary and the genus *Paragloborotalia* grows dominant.

Subzone P21b (early part of the Late Oligocene) records a greater number of significant bioevents and a rich biotite level, 4 mm thick, towards its base. These bioevents are mainly first occurrences and are identified in both fractions. Within this Subzone, in addition to the bioevents listed in Fig. 5, the coarse fraction records a gradual increase in abundance of *Globoquadrina* and "*Globigerina*" *venezuelana* from the middle portion of the Subzone, while *Paragloborotalia opima opima* and "*Globigerina*" *praesepis* gradually decrease in abundance from the base to the top. The genus *Dentoglobigerina* shows a fair increase in abundance in the middle-upper part of the Subzone. *Catapsydrax* and *Tenuitella* groups show a strong positive peak at the top of this Subzone. In the fine fraction a weak increase in abundance of *Tenuitellinata* and *Globigerinita* groups and a slight decrease in abundance of *Gumbelitria* in the upper portion of the Subzone are recorded.

Specimens < 150 μm define better the upper portion of Zone P22, while, in its middle-lower portion, several "added" bioevents were identified in the coarse fraction. In this Zone only first occurrence were observed. *Catapsydrax* displays some fluctuations in abundance, and a temporary decrease of the size of all the forms were observed in the middle portion of this Zone. Throughout Zone P22, a gradual but continuous increase in abundance of *Globoquadrina* was recorded, while *Dentoglobigerina* shows this trend only at the top of the Zone. In the fine fraction, while the *Tenuitellinata* and *Tenuitella* groups decrease in abundance, in the upper portion of this Zone a positive peak of *Paragloborotalia pseudokugleri* was observed.

Within Subzone N4a a gradual increase in size of both *Globigerinita incrusta* and *Tenuitellinata angustiumbilicata* was observed. Several taxa (*Globigerina euapertura*, *Catapsydrax*, *Paragloborotalia* and *Dentoglobigerina*) show a discrete decrease in abundance around 6.50 m above the base of the Subzone, where *Globoquadrina* becomes dominant in the coarse fraction. Particularly, *G. selli* shows a strong increase in abundance in the middle-upper portion of the Subzone (PDA bis section) but it is absent at its top, where a positive peak of *Globigerinoides* spp. is also recorded. In the fine fraction, a decrease of *Tenuitellinata juvenilis* and *Paragloborotalia opima nana*, and the increase in abundance of *Paragloborotalia kugleri* were observed. *Gumbelitria* and *Paragloborotalia mendacis* are absent at the top of the Subzône.

In the basal sample of Subzone N4b, a positive peak of *Catapsydrax* and "*Praeglobigerinoides*" primordius is associated with few and small *Globoquadrina* dehiscens and few *Globigerinoides* spp.

The entire examinated Subzone N4b is characterized by marked fluctuations, mainly in the species > 150 μm such as *Globigerinoides* spp. and *G. dehiscens* (Fig. 11).

Baumann (1970) provided a detailed biostratigraphical analysis based on planktonic foraminifers of

PLATE 2

Fig. 1a-c - *Globoquadrina binaiensis*, Koch, 1935. Sample PDA bis 30.20, Zone P22, Late Oligocene. 1a) spiral view; 1b) side view; 1c) umbilical view.

Fig. 2a-c - *Globoquadrina dehiscens*, Chapmann, Parr & Collins, 1935. Sample PDA 3.00, Subzone N4b, Early Miocene. 2a) spiral view; 2b) side view; 2c) umbilical view.

Fig. 3a-c - *Globoquadrina rohri* (Bolli, 1957). Sample PDA bis 11.50, Subzone P21b, Late Oligocene. 3a) spiral view; 3b) side view; 3c) umbilical view.

Fig. 4a-c - *Globoquadrina sellii*, Borsetti, 1959. Sample PDA bis 11.50, Subzone P21b, Late Oligocene. 4a) spiral view; 4b) side view; 4c) umbilical view

Fig. 5a-c - "*Globigerina*" *ampliapertura* (Bolli, 1957). Sample PDA bis 1.00, Zone P20, Early Oligocene. 5a) spiral view; 5b) side view; 5c) umbilical view.

Fig. 6a-b - *Globigerina angulisuturalis*, Bolli, 1957. Sample PDA bis 5.80, Subzone P21a, Early Oligocene. 6a) spiral view; 6b) umbilical view.

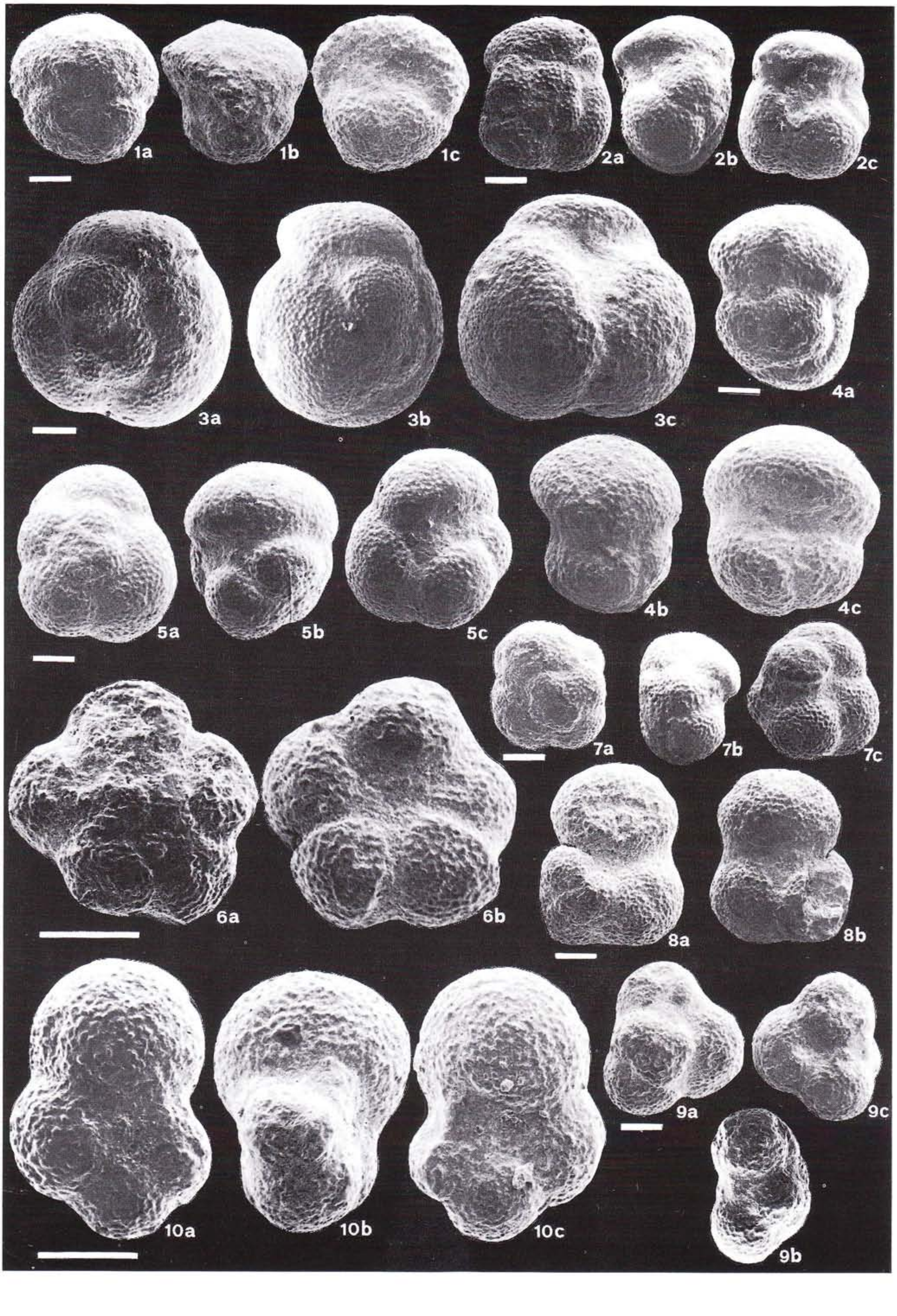
Fig. 7a-c - *Globigerina bulloides criptomphala* Glaessner, 1937. Sample PDA bis 17.30, Subzone P21b, Late Oligocene. 7a) spiral view; 7b) side view; 7c) umbilical view.

Fig. 8a-b - *Globigerinoides primordius* Blow & Banner, 1962. Sample PDA 3.00, Subzone N4b, Early Miocene. 8a) spiral view; 8b) umbilical view.

Fig. 9a-c - *Globigerinoides* sp. (sensu Spezzaferri, 1994). Sample PDA 0.00, Subzone N4a, Early Miocene. 9a) spiral view; 9b) side view; 9c) umbilical view.

Fig. 10a-c-*Globigerinella obesa* (Bolli, 1957). Sample PDA bis 41.50, Zone P22, Late Oligocene. 10a) spiral view; 10b) side view; 10c) umbilical view.

Scale bars equal 100μ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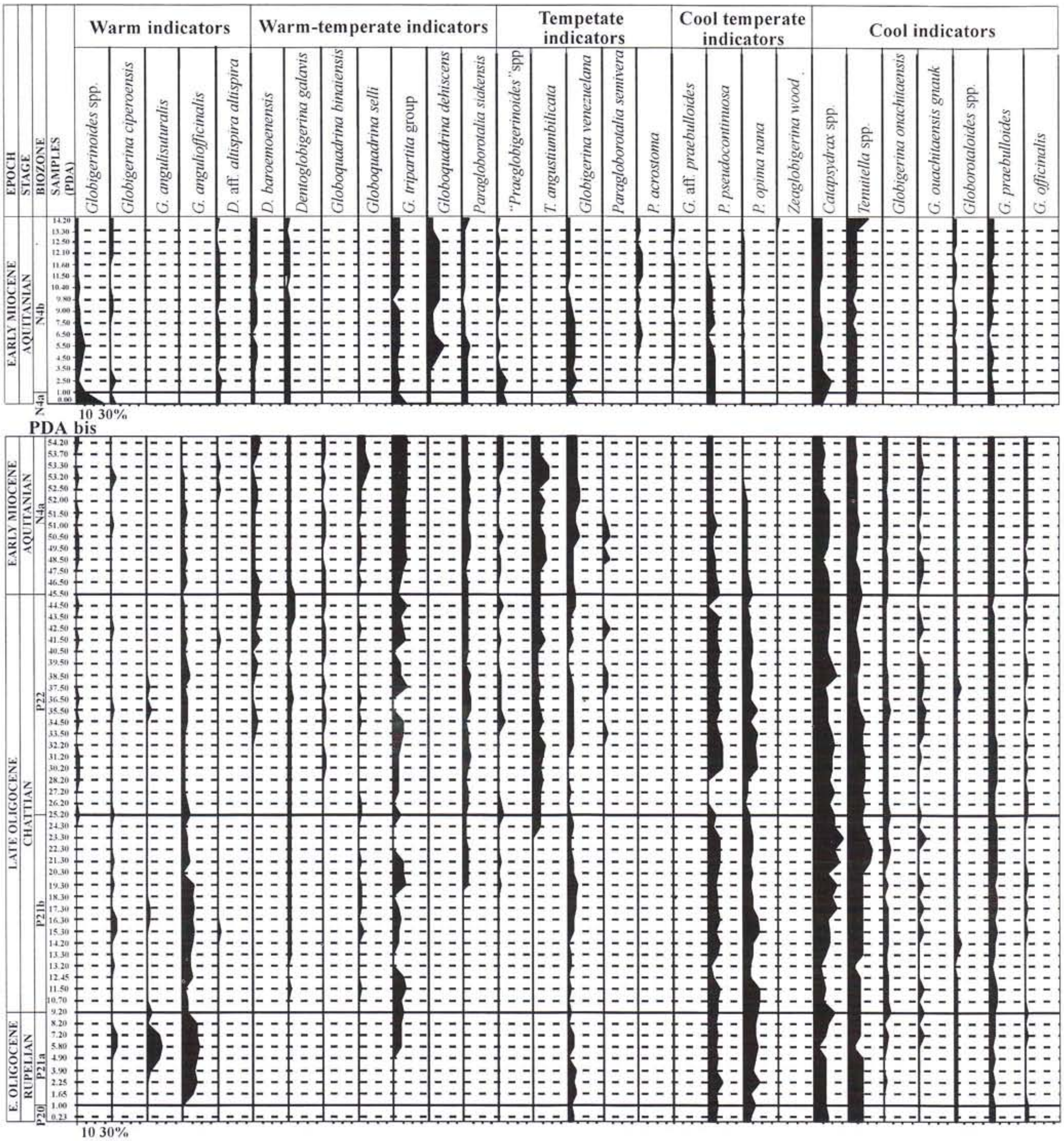
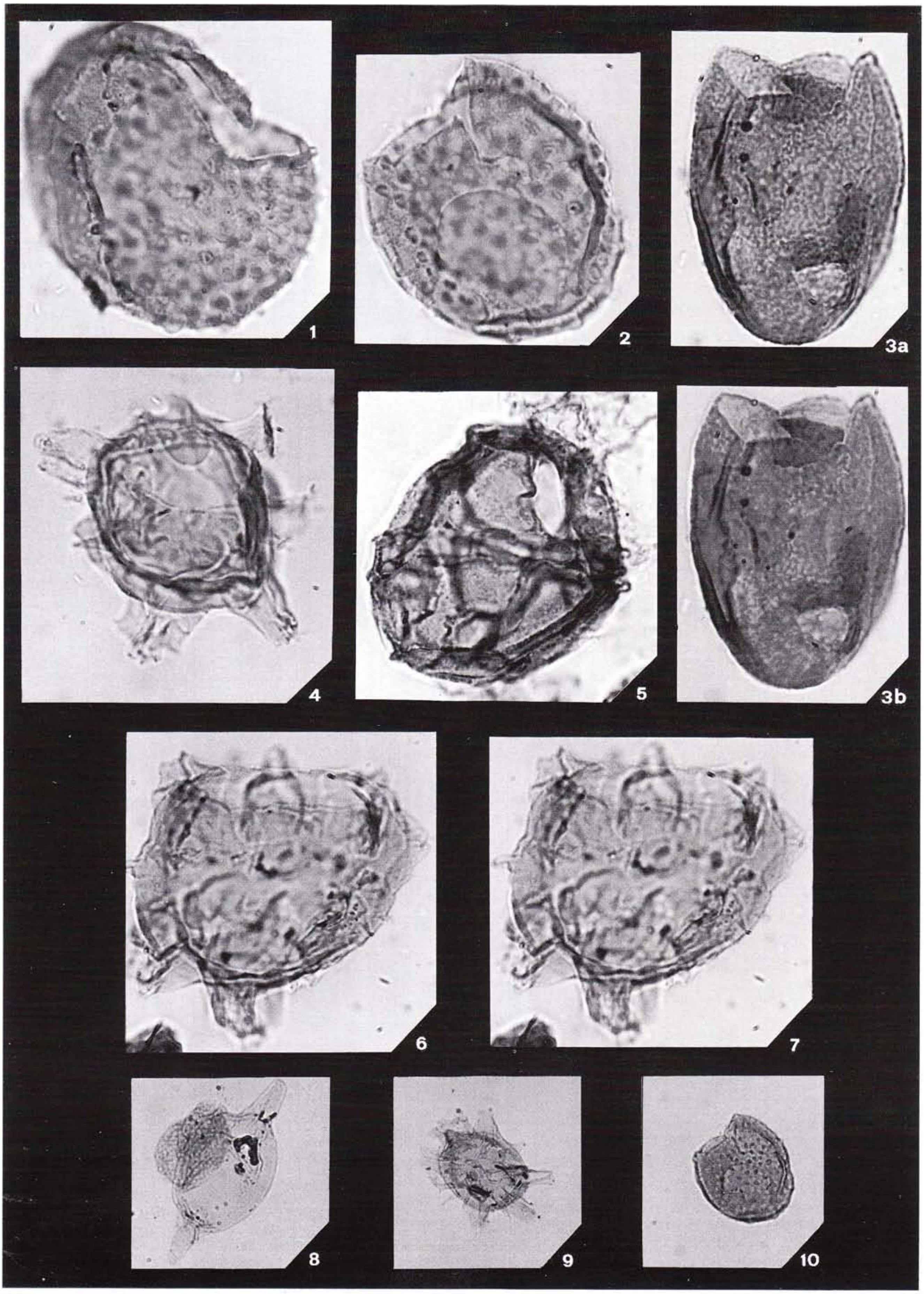


Fig. 11 - Planktonic foraminifers distribution according to their paleoecology.

PLATE 3

Fig. 1, 2 - *Operculodinium* sp. Sample PDA bis 10.70, Late Oligocene.
Fig. 3a-b - *Caligodinium amiculum*, Drugg, 1970b. Sample PDA bis 10.70, Late Oligocene.
Fig. 4 - *Hystrichokolpoma pusillum*, Biffi & Manum, 1988. Sample PDA bis 10.70, Late Oligocene.
Fig. 5 - *Impaginodinium minor*, Biffi & Manum, 1988. Sample PDA bis 26.20, Late Oligocene.
Fig. 6, 7 - *Hystrichokolpoma pusillum*, Biffi & Manum, 1988. Sample PDA bis 10.70, Late Oligocene.
Fig. 8 - *Svalbardella cooksonae*, Manum, 1960. Sample PDA bis 10.70, Late Oligocene.
Fig. 9 - *Hystrichokolpoma pusillum*, Biffi & Manum, 1988. Sample PDA bis 10.70, Late Oligocene.
Fig. 10 - *Operculodinium* sp. Sample PDA bis 10.70, Late Oligocene.
(Magnifications: fig. 1,10 about x575).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the Monte Cagnero section, belonging to the Inner Marchean Basin too. About the interval spanning upper Early Oligocene (Rupelian) and lower Early Miocene, Baumann (1970) defines, in stratigraphical order, 4 biozones as follow: 1) "*Globigerina euapertura* Zone" from the FO of *Globigerina ciperoensis* to the FO of *G. angulisuturalis*; 2) "*Globorotalia opima opima* Zone" from the FO of *G. angulisuturalis* to the LO of *Globorotalia opima opima*; 3) "*Globigerina ciperoensis ciperoensis* Zone" from the LO of *P. opima opima* to the FO of P. kugleri; 4) "*Globorotalia kugleri* Zone" from the FO of *P. kugleri* to the FO of *Globigerinoides*. The bioevents recorded in PDA bis section did not allow to follow Baumann's biozonal scheme. In fact, in PDA bis section, *G. angulisuturalis* and *G. ciperoensis* are very rare and discontinuously present. For this reason it is very difficult to define their real FO and, therefore, the boundaries of both the "*G. euapertura*" and "*G. opima opima*" Zones as defined by Baumann (1970). Moreover, in PDA bis section *Globigerinoides primordius* appears together with the LO of *P. opima opima*, therefore before the FO of *P. kugleri*. For this reason, the definition of "*G. kugleri* Zone" as the interval between the FO of *P. kugleri* and the FO of *Globigerinoides* (Baumann, 1970) cannot be used.

Dinoflagellate cyst bioevents.

Preliminary analysis of dinoflagellate cysts and of significant bioevents known from literature at the Rupelian/Chattian boundary, has been carried out through the analysis of a limited number of samples, primarily investigated around Early Oligocene-Late Oligocene boundary.

The calibration of the identified dinocyst bioevents may be useful for the biostratigraphical determination of sediments poor in calcareous plankton such as the siliciclastic and turbiditic units.

The stratigraphic distribution of the dinocyst species, identified out of the 17 samples analysed (Fig. 12), was placed side by side to the planktonic foraminiferal biostratigraphy.

The samples from the lower portion of the sequence (PDA bis 0.23-7.20) are barren of dinocysts. The palynofacies are dominated by palynomacerals and frequent sphoromorphes (spores and bisaccated pollens). This is probably due to syn- or post-depositional oxidation, responsible for both the degradation of the sea organic matter rich in hydrogen and the preservation of the oxygen-rich organic matter of terrestrial origin.

The successive two samples (PDA bis 920-10.70) record two significant bioevents, The first is the presence of *Hystrichokolpoma pusillum*. This can not be considered as a FO due to the lack of dinocysts in the underlying samples.

SAMPLES	*Deflandrea phosphoritica*	*Hystrichokolpoma pusillum*	*Caligodinium amiculum*	*Operculodidinium* sp.	*Svalbardella cooksonae*	*Spiniferites* spp.	*Thalassiophora velata*	*Impaginodinium minor*	*Stoveracysta* sp.	*Palaeocystodinium golzvense*
PDA bis 48.50										
PDA bis 44.50						C		R		R
PDA bis 40.50	C							C		
PDA bis 36.50								R		C
PDA bis 31.20	R								R	
PDA bis 28.20	C							R		R
PDA bis 26.20	C					C		C	R	
PDA bis 22.30						C				
PDA bis 16.30						C				
PDA bis 14.30	R			R		C				
PDA bis 12.45						C	R			
PDA bis 10.70	C	A	R	R	C	C				
PDA bis 9.20	R	C	R							
PDA bis 7.20										
PDA bis 5.80										
PDA bis 3.90										
PDA bis 2.25										

Fig. 12 - Distribution chart of the dinocysts species identified in the PDA bis A= abundant (more of 20); C= common (between 5 and 20); R= rare (less of 5).

According to Biffi & Manum (1988), this taxon, a long ranging form, appears within Zone DO1 (Early Oligocene/early Late Oligocene) and represents an abundant constituent of the dinos assemblages in the planktonic foraminiferal Zone P20 and P21. Moreover, in sample PDA bis 10.70 a positive peak of *Svalbardella cooksonae* was identified. According to Wilpshaar et al. (1996), this taxon has a peak in abundance around the base of the Chattian. Therefore, the presence of *H. pusillum* in sample PDA bis 9.20 and the positive peak of *S. cooksonae* in sample PDA bis 10.70 are in agreement with the placement of the Early Oligocene/Late Oligocene boundary at sample PDA bis 9.20, where the LO of *Chiloguembelina* spp. also occurs (planktonic foraminifers).

The boundary between Zone P21 and Zone P22 is linked for the planktonic foraminifers with the LO of *Paragloborotalia opima opima*. In the first sample of Zone P22 the dinocyst assemblage records the FO(?) of *Impaginodinium minor.* According to Biffi & Manum (1988), this FO defines the base of Subzone DO3b (Late Oligocene in age) which was correlated to the base of planktonic foraminifers Zone P22. The correlation between these two bioevents was also observed in PDA bis section. In fact, sample PDA bis 26.20, in which the FO (?) of *I. minor* was identified, is the lowermost attributed to Zone P22 (present biozonation), even if about 3 meters below this samples were not investigated. The photographs of the main dinoflagellate cysts are shown in Plate 3.

Paleoclimatological analysis.

The composition of the planktonic foraminiferal assemblages from the two studied sections was estimated (Fig. 11, Fig. 13) from visual observation of presence, abundance of the principal paleoclimatic indicators as they were proposed by Spezzaferri & Premoli Silva (1991), Spezzaferri (1992, 1995, 1996), Luciani & Salvatorini (1996) and Novaretti & Bicchi (1996) for the interval spanning the Early Oligocene to the Early Miocene.

The fluctuations of the paleoclimatic indicators recorded within the two sections are not related to changes both of lithology and/or total abundance of foraminifers, because these characters are almost uniform throughout the sections.

In the lower portion of the PDA bis section, the Rupelian (top of Zone P20 and Subzone P21a) is characterized by a poorly diversifyed assemblages, which are mainly represented by cool and cool-temperate indicators. Within this interval, only a short increase in abundance of warm and warm-temperate indicators were identified in sample PDA bis 5.80. Among samples PDA bis 17.30-23.30 (Subzone P21b) a strong increase in abundance both of *Catapsydrax* and *Tenuitella* groups were identified. This suggests cooler conditions for this interval (Late Oligocene), as it is also confirmed by the almost complete absence of warm indicators. In the upper portion of the PDA bis section, spanning the interval between the mid-upper part of the Chattian and the basal Aquitanian (from Zone P22 to Subzone N4a) a general paleoclimatic instability, characterized by an alternation of pulses of warm-temperate and cool-temperate indicators, was observed. Particularly, a clear increase of cool-temperate indicators among samples PDA bis 30.20-32.20 (Zone P22). On the contrary, a weak increase in abundance of warm-temperate indicators, associated with a decrease in abundance of the cool-temperate ones, was observed around the Oligocene/Miocene boundary. This fact suggests a fair warming of the water masses and, therefore, a change from cool-temperate to warm-temperate conditions. This is supported by the decrease in abundance of the *Catapsydrax* and *Tenuitella* groups, the increase in abundance of the *Globoquadrina* group, *Tenuitellinata angustiumbilicata* and *Paragloborotalia siakensis* s.s., and by the presence of *Globigerinoides* spp. and *Globigerina ciperoensis* among samples PDA bis 48.50-53.20.

The PDA section, referred to the top of Subzone N4a and partially to Subzone N4b (mid-upper portion of the Aquitanian) shows the following trend. In the basal sample the paleoclimatic indicators suggest a warm pulse at the top of Subzone N4a followed by a cool-temperate pulse at the base of Subzone N4b. After, since the subsequent sample (PDA 3.50), a strong decrease in abundance of *Catapsydrax* and *Tenuitella* groups is parallel with an increase in abundance of *Globoquadrina dehiscens* and *Globigerinoides* spp. This trend culminates in sample PDA 5.50 which, therefore, records a fair increase of water masses temperature. In the overlying samples, a partial decrease in abundance of these warm and warm-temperate indicators was observed. Considering the constant presence of *Paragloborotalia acrostoma*, *P. semivera*, *G. tripartita* with bulla and *Dentoglobigerina baroemoenensis*, it is possible to assert that since sample PDA 6.50, the PDA section records a weak cooling which culminates with the FO of *Zeaglobigerina woodi* (cool-temperate indicator) and with the increase in abundance of *Tenuitella* group in sample PDA 14.20.

From the Late Eocene, the Mediterranean has lost its function as principal comunication way among Atlantic, Pacific and Indian Oceans, even if some small deep-sea connections may have existent up to the Miocene. Moreover, during the Late Paleogene-Early Neogene transition, important global changes occurred in response to fluctuations of the extention of ice caps on the Antartic continent which caused changes in water temperature and sea level (Haq et al., 1988; Zevenboom, 1995).

Zevenboom (1995), on the basis of the dinocysts distribution, points out two principal global sea level fluctuations during the Oligocene-Miocene transition and remarks that sea level falls are related to cooler conditions of the water temperature. These identified fluctuations are the same plotted by Haq et al. (1988) for this interval and reflect cycles of 3° order of the global eustatic level related to glacio-eustatic phenomena. Particularly, Zevenboom (1995) analysed the fluctuations of the principal paleoclimatic indicator dinocysts recorded in the Contessa section (Gubbio-PG, Central Italy) and identified a substantially cool period between the Late Oligocene and the Oligocene/Miocene Boundary. This is in agreement with the strong increase in abundance of both *Tenuitella* and *Catapsydrax* groups recorded in the PDA bis section within Subzone P21b, even if a weak warming is recorded just below the Late Oligocene /Early Miocene boundary. Furthermore, Zevenboom (1995) identified a sudden warm pulse in the basal Aquitanian which is followed by the recurrence of substantially cool conditions in the upper portion of Def Subzone (Early-Mid Aquitanian). These are also recorded in the PDA section, where an alternation of warm and cool pulses were observed within the interval from the top of Subzone N4a and the base of Subzone N4b. Particularly, since sample PDA 6.50, a gradual decrease in abundance of the warm, warm-temperate indicators, associated with an increase in abundance of the *Tenuitella* group and the FO of *Zeaglobigerina woodi* (cool-temperate indicator), has been observed upward.

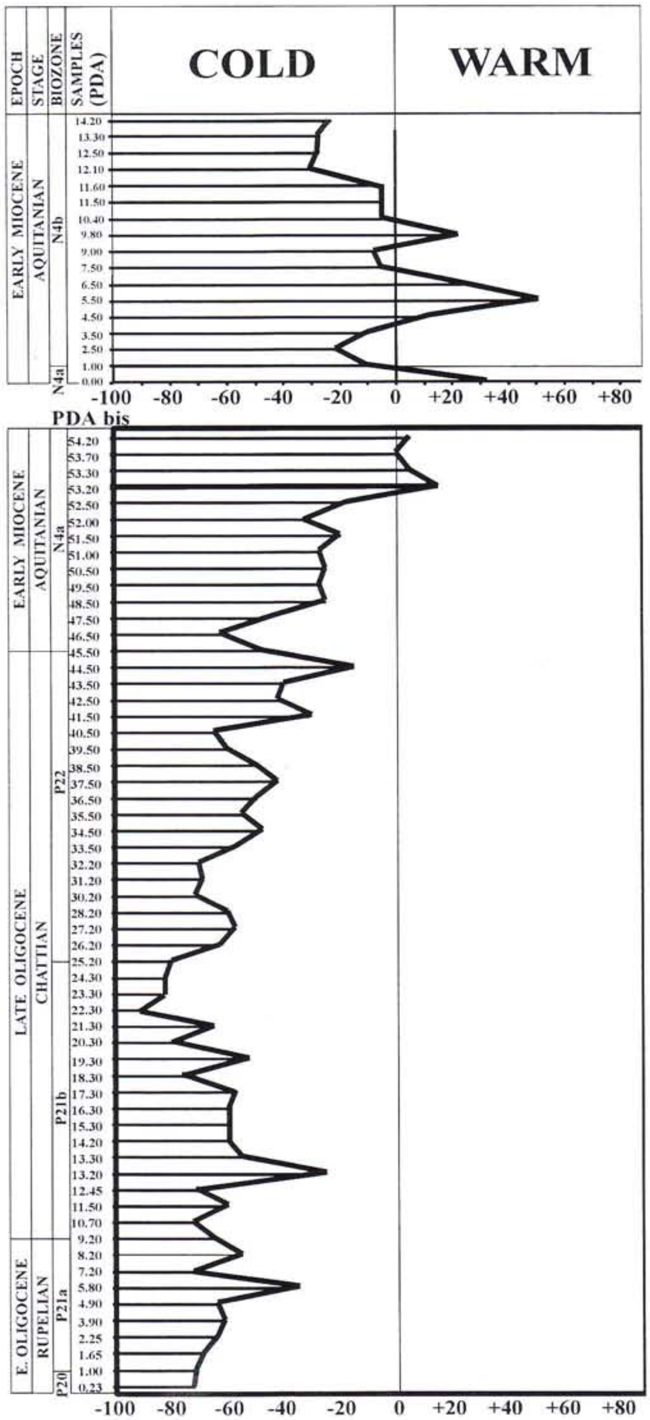

Fig. 13 - Climatic curve from the upper Early Oligocene to lower Early Miocene from the PDA bis and PDA sections. The curve was constructed plotting the sum of percente abundance (semiquantitative valuation) of warm, warm-temperate indicators (considered as positive values) and cool, cool-temperate indicators (considered as negative values). For discussion see text.

Conclusions.

The two studied sections from the Piobbico area span an almost continuous sedimentary record mainly belonging to the Scaglia Cinerea Fm., above which the Livello Raffaello and few meters of the Bisciaro Fm. outcrop. The lower boundary of the Scaglia Cinerea Fm. is not outcropping.

Through the analysis of the planktonic foraminiferal assemblages it is possible to identify "standard" bioevents which enabled the definition of the standard biozones from the top of the Zone P20 up to Zone N4. Several bioevents in addition to the "standard" ones known from literature were identified as well.

Planktonic foraminifers are the most abundant microfossils in washed residues and few radiolarians are recorded around 4 m above the Livello Raffaello.

The preliminary analysis of the dinoflagellate cysts around the Early Oligocene/Late Oligocene and Zone P21/Zone P22 boundaries allowed the identification of two bioevents. Their calibration may be useful for the biostratigraphical determination of sediments poor in calcareous plankton such as the siliciclastic and turbiditic units.

Several peaks in abundance and fluctuations of some planktonic foraminiferal taxa were also detected. Some of these taxa are paleoclimatic indicators and allow the identification of few paleoclimatic changes. Based on semiquantitative estimate of these indicators, three paleoclimatic intervals have been identified:

1) a cool -temperate interval in the latest portion of the Rupelian (top of Zone P20 and Subzone P21a; Early Oligocene).

2) a cooler interval in the lower portion of the Chattian (mid-lower part of Subzone P21b; Late Oligocene).

3) a generalized paleoclimatically instable interval from the latest portion of the Chattian (Zone P22; Late oligocene) to the Aquitanian (Subzone N4b; Early Miocene) with a weak warming around Oligocene/Miocene boundary and a warm pulse followed by a temperate, cool-temperate pulse in Subzone N4b (Early Miocene).

Acknowledgment.

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Appendix.

Planktonic foraminifers:
Catapsydrax africanus (Blow & Banners, 1962)
Catapsydrax dissimilis ciperoensis (Blow & Banners, 1962)
Catapsydrax dissimilis dissimilis (Cushman & Bermudez 1937)
Catapsydrax dissimilis subsp. 1 sensu Molina, 1979
Catapsydrax globiformis (Blow & Banners, 1962)
Catapsydrax martini (Blow & Banners, 1962)
Catapsydrax perus (Todd, 1957)
Catapsydrax unicavus (Bolli, Loeblich & Tappam, 1957)
Chiloguembelina cubensis (Palmer, 1934)
Dentoglobigerina altispira altispira (Bolli, 1957)
Dentoglobigerina altispira globosa (Bolli, 1957)
Dentoglobigerina baroemoenensis (LeRoy, 1939)
Dentoglobigerina galavisi (Bermudez, 1961)
Dentoglobigerina globularis (Bermudez, 1961)
Dentoglobigerina larmeui (Akers, 1965)
"Globigerina" ampliapertura (Bolli, 1957)
Globigerina angulisuturalis Bolli, 1957
Globigerina anguliofficinalis Blow, 1969
Globigerina bulloides criptomphala Glaessner, 1937
Globigerina ciperoensis Bolli, 1957
Globigerina ciperoensis fariasi Bermudez, 1961
Globigerina euapertura Jenkins, 1960
Globigerina officinalis Subbotina, 1953
Globigerina ouachitaensis Howe & Wallace, 1932
Globigerina ouachitaensis gnauki Blow & Banner, 1962
Globigerina senilis Bandy, 1949
Globigerina praebulloides Blow, 1959
Globigerina aff. praebulloides Blow, 1959
Globigerina praesepis Blow, 1969
Globigerina pseudovenezuelana Blow, 1969
Globigerina venezuelana Hedberg, 1937
Globigerinella obesa (Bolli, 1957)
Globigerinita boweni Bronnimann & Resig, 1971
Globigerinita glutinata (Egger, 1893)
Globigerinita incrusta Akers, 1955
Globigerinoides primordius Blow & Banner, 1962
"Globigerinoides" sp. *sensu* Spezzaferri, 1994
Globoquadrina binaiensis Koch, 1935
Globoquadrina dehiscens (Chapman, Parr & Collins, 1934)
Globoquadrina praedehiscens Blow & Banner, 1962
Globoquadrina rohri (Bolli, 1957)
Globoquadrina sellii Borsetti, 1959
Globoquadrina tapuriensis (Blow & Banner, 1962)
Globoquadrina tripartita (Koch, 1926)
Globorotaloides suteri Bolli, 1957
Gumbelitria columbiana Howe, 1939
Paragloborotalia acrostoma (Wezel, 1966)
Paragloborotalia continuosa (Blow, 1959)
Paragloborotalia kugleri (Bolli, 1957)
Paragloborotalia mayeri (Cushman & Ellisor, 1939)
Paragloborotalia mendacis (Blow, 1969)
Paragloborotalia opima opima (Bolli, 1957)
Paragloborotalia opima nana (Bolli, 1957)
Paragloborotalia pseudocontinuosa (Jenkins, 1967)
Paragloborotalia pseudokugleri (Blow, 1969)
Paragloborotalia semivera (Hornibrook, 1961)
Paragloborotalia siakensis (LeRoy, 1939)
Paragloborotalia cf. *siakensis* (LeRoy, 1939)
"Praeglobigerinoides" primordius sensu Spezzaferri, 1994
"Praeglobigerinoides" aff. *trilobus* (Reuss, 1850)
Subbotina gortanii (Borsetti, 1959)
Subbotina praeturritilina (Blow & Banner, 1962)
Tenuitella gemma (Jenkins, 1966)
Tenuitella munda (Jenkins, 1966)
Tenuitella neoclemenciae Li, 1987
Tenuitellinata angustiumbilicata (Bolli, 1957)
Tenuitellinata juvenilis (Bolli, 1957)
Tenuitellinata praestaiforthi (Blow, 1979)
Tenuitellinata pseudoedita (Subbotina, 1960)
Tenuitellinata uvula (Ehremberg, 1861)
Zeaglobigerina brazieri (Jenkins, 1966)
Zeaglobigerina connecta (Jenkins, 1964)
Zeaglobigerina woodi (Jenkins, 1960)

Dinoflagellate cysts:
Caligodinium amiculum Drugg, 1970b
Deflandrea phosphoritica Eisenak, 1939b
Hystrichokolpoma pusillum Biffi & Manum, 1988
Impaginodinium minor Biffi & Manum, 1988
Operculodinium sp.
Palaeocystodinium golzwense Alberti, 1961
Spiniferites spp.
Stoverocysta sp.
Svalbardella cooksonae Manum, 1960
Thalassiphora velata (Deflandre & Cookson, 1955)

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