

THE CAPO ROSSELLO BORE-HOLE (AGRIGENTO, SICILY):
CYCLOSTRATIGRAPHIC AND PALEOCEANOGRAPHIC RECONSTRUCTIONS
FROM QUANTITATIVE ANALYSES
OF THE ZANCLEAN FORAMINIFERAL ASSEMBLAGES

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Received December 10, 1998; accepted May 27, 1999

Key-words: Pliocene; Cyclostratigraphy; Paleoceanography; Benthic Foraminifera.

Riassunto. Lo studio quantitativo dei foraminiferi planctonici rinvenuti nell'intervallo Zancleano (biozone M Pl 1- base M Pl 3) del Pozzo TPM, effettuato in carotaggio continuo ad Est di Capo Rossello (Agrigento, Sicilia), ha permesso di ottenere una accurata ciclostratigrafia ed di riconoscere che la posizione degli eventi biostratigrafici a plancton calcareo corrisponde agli stessi cicli già identificati in precedenza da altri autori. In ogni ciclo litologico nel quale sono stati ipotizzati due cicli di precessione sono state rinvenute due fluttuazioni di *Globigerinoides* spp. Pertanto il numero di fluttuazioni identificate è maggiore del numero dei cicli litologici. Infatti, sono presenti 35 cicli litologici tra la base del Pliocene e la prima comparsa di *Globorotalia puncticulata* mentre sono stati riconosciuti 38 fluttuazioni dei foraminiferi planctonici nello stesso intervallo.

Il confronto delle abbondanze relative dei *Globigerinoides* spp. con quelle dei foraminiferi bentonici ha evidenziato delle fluttuazioni di questi ultimi attribuibili ai cicli astronomici dell'eccentricità (400.000 anni) e della precessione. In particolare, $BN > 125 \mu m$ e la distribuzione quantitativa di *Planulina ariminensis* sembrano legate alla eccentricità, mentre le abbondanze relative di *Siphonina reticulata*, *Cibicidoides bradyi*, *Pullenia bulloides* e *Uvigerina pygmaea* sembrano generalmente legate ai cicli di precessione. In particolare, questa relazione è più evidente durante i periodi coincidenti a massimi di eccentricità, mentre risulta non in fase durante gli intervalli corrispondenti a minimi dell'eccentricità dell'orbita.

La distribuzione di *Siphonina reticulata* è molto abbondante ed ampiamente diffusa in diverse aree del Mediterraneo nell'ambiente epibatiale durante il Pliocene inferiore e medio, mentre il genere si riduce fortemente nel Nord Atlantico a partire dal Miocene medio in coincidenza dell'aumento e stabilizzazione della Northern Component Water (o proto North Atlantic Deep Water). Pertanto, noi consideriamo questa specie quasi-endemica del bacino del Mediterraneo in questo intervallo temporale. Nell'analisi delle associazioni la distribuzione di *S. reticulata* risulta anticovariante con quella di *C. bradyi-robertsonianus*, che è considerata una specie caratteristica della North Atlantic Deep Water (NADW). Questa relazione ci suggerisce che durante il Pliocene inferiore e medio potesse essere presente nel Mediterraneo una particolare massa d'acqua intermedia. Noi proponiamo

per questa massa d'acqua il nome di Early Pliocene Mediterranean Intermediate Water (EPMIW). Poiché i dati di letteratura riportano una brusca riduzione in abbondanza di questa specie durante la biozona M Pl 5, noi supponiamo che questa massa d'acqua (EPMIW) fosse presente nel bacino del Mediterraneo fino a circa 2.5 Ma.

Abstract. Cyclostratigraphy based on the quantitative analyses of planktonic foraminifera in the Zanclean segment (M Pl 1- base of M Pl 3 biozones) of the bore-hole drilled in the Capo Rossello area (Sicily, Southern Italy) allows us to recognize that the calcareous plankton biostratigraphic events occur in the same cycles as identified by previous authors. Exceptional thick cycles which are thought to represent two precession cycles show two fluctuations of *Globigerinoides* spp. Therefore the number of identified fluctuations is greater than the number of lithologic cycles. Between the base of the Pliocene and the first occurrence of *Globorotalia puncticulata* thirty-five lithologic cycles and thirty-eight planktonic foraminifera fluctuations are present.

By comparison with relative abundance fluctuations of *Globigerinoides* spp., a clear relationship between the relative abundance fluctuations in the benthic foraminifera and the astronomical record is recognized. In particular, the $BN > 125 \mu m$ and the *Planulina ariminensis* quantitative distributions are related to the long eccentricity. Conversely, the relative abundance fluctuations of *Siphonina reticulata*, *Cibicidoides bradyi*, *Pullenia bulloides* and *Uvigerina pygmaea* appear to be generally forced by the precession periodicity, but in the intervals coincident with the eccentricity minima such a relationship is less clear.

The very abundant and widespread distribution in several Mediterranean sites of *S. reticulata*, which we consider a quasi-endemic species of this basin during the Early and Middle Pliocene is anticovariant with the quantitative distribution of *Cibicidoides bradyi-robertsonianus*, which is considered a characteristic species of the North Atlantic Deep Water (NADW). This relationship suggests that a peculiar, intermediate water mass was present in the Mediterranean during this time interval. We propose for this water mass the name of Early Pliocene Mediterranean Intermediate Water (EPMIW). According to bibliographic data that report the sharp decrease in abundance of *S. reticulata* during the M Pl 5 biozone, EPMIW was present in the Mediterranean basin until about 2.5 Ma.

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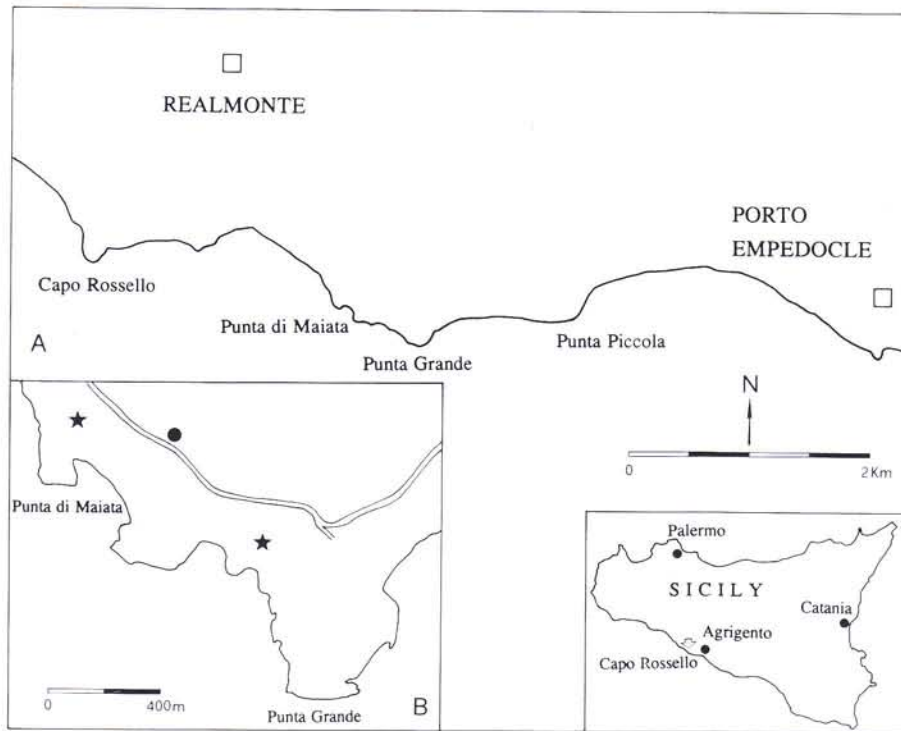


Fig. 1 - Location map of the Punta di Maiata bore-hole. Map of the Sicily: a) location of the Capo Rossello; b) locations of the bore-hole (solid circle) and of the Punta di Maiata and Punta Grande sections (stars) of Hilgen (1987).

Introduction.

The Rossello composite section (Langereis & Hilgen, 1991) is the reference section for the biostratigraphy and cyclostratigraphy of the Zanclean and Piacenzian stratigraphic intervals, between 5.33 Ma and 2.6 Ma. In the outcrops of the Capo Rossello area the "Trubi" marls, which cover a time interval between 5.33 Ma and 3.2 Ma, display a rhythmic quadripartite gray-white-beige-white color alternation, with the gray and beige parts which are CaCO_3 poor (Hilgen, 1987; Hilgen & Langereis, 1988; De Visser et al., 1989; Hilgen, 1991; Hilgen & Langereis, 1993) and with the gray parts slightly enriched in Corg (De Visser et al., 1989; Van Os et al., 1994). The generally easily recognizable calcareous-marls lithologic cycles of the "Trubi" marls and the marls-"sapropels" lithologic couplets of the lower part of the overlying Monte Narbone Formation allowed Hilgen and co-workers to propose a well founded cyclostratigraphic interpretation of the corresponding time interval (Hilgen, 1991). They correlated each lithologic small scale cycle to one astronomical precession cycle, with the marly intervals coincident with the precession minima (Hilgen, 1991; Lourens et al., 1996). Only in a few, thicker than normal lithologic cycles, the precession periodicity had no sedimentary expression, and they were interpreted as including two precession cycles. A total of 119 lithologic

cycles (Hilgen, 1991) and 130 complete precession cycles (Lourens et al., 1996) were identified between the base of the Pliocene and the base of the Gelasian. Since the orbital variations yield climatic modification, and the predominant effects correspond to changes in seasonality (Berger, 1988), also the microfauna was affected by these orbital variations, and therefore Sprovieri (1992, 1993) introduced a different tool to identify the orbital cycles, based on the relative abundance fluctuations of *Globigerinoides* spp., which proved to be forced, in the lower Pliocene stratigraphic interval, by the climatic variations induced by the precession periodicity. To differentiate the abundance cycles from the lithologic cycles, the term fluctuation is used in this paper. The method is independent from any sedimentary expression, appears well suitable to identify all the precession cycles, even in the composite lithologic cycles, in which the precession had no sedimentary expression. On the other hand, it does not allow the more carbonatic intervals to be recognized, which can be interpreted as indicative of the eccentricity minima.

The Rossello composite section derived from several segments, correlated in detail by lithologic, biostratigraphic and magnetostratigraphic methods. In order to obtain only one, continuous section of the entire "Trubi" marls, a bore-hole was drilled near Punta di Maiata (Southern Sicily, Italy) (Fig. 1), with the purpose to cross

Fig. 2 - Integrated calcareous plankton biostratigraphy of the bore-hole. The vertical bar on the left indicates the interval disturbed by repeated slumps.

Period		Stage	Formation	BIOSTR		mbs	cores			
Mioc	Mess. Aren			FORAMS	NANNO					
Pliocene		Zanclean	Narbone	M PI 1	MNN 12	10	7			
										8
										9
										10
										11
										12
										13
										14
										15
										16
Pliocene		Placenzian	Narbone	M PI 2	MNN 13	17	17			
										18
										19
										20
										21
										22
										23
										24
										25
										26
Pliocene		Placenzian	Narbone	M PI 3	MNN 14-15	27	27			
										28
										29
										30
										31
										32
										33
										34
										35
										36
Pliocene		Placenzian	Narbone	M PI 4 a	MNN 16a	37	37			
										38
										39
										40
										41
										42
										43
										44
										45
										46
Pliocene		Placenzian	Narbone	M PI 4 b	MNN 16a	47	47			
										48
										49
										50
										51
										52
										53
										54
										55
										56
Pliocene		Placenzian	Narbone	M PI 5	MNN 16a	57	57			
										58
										59
										60

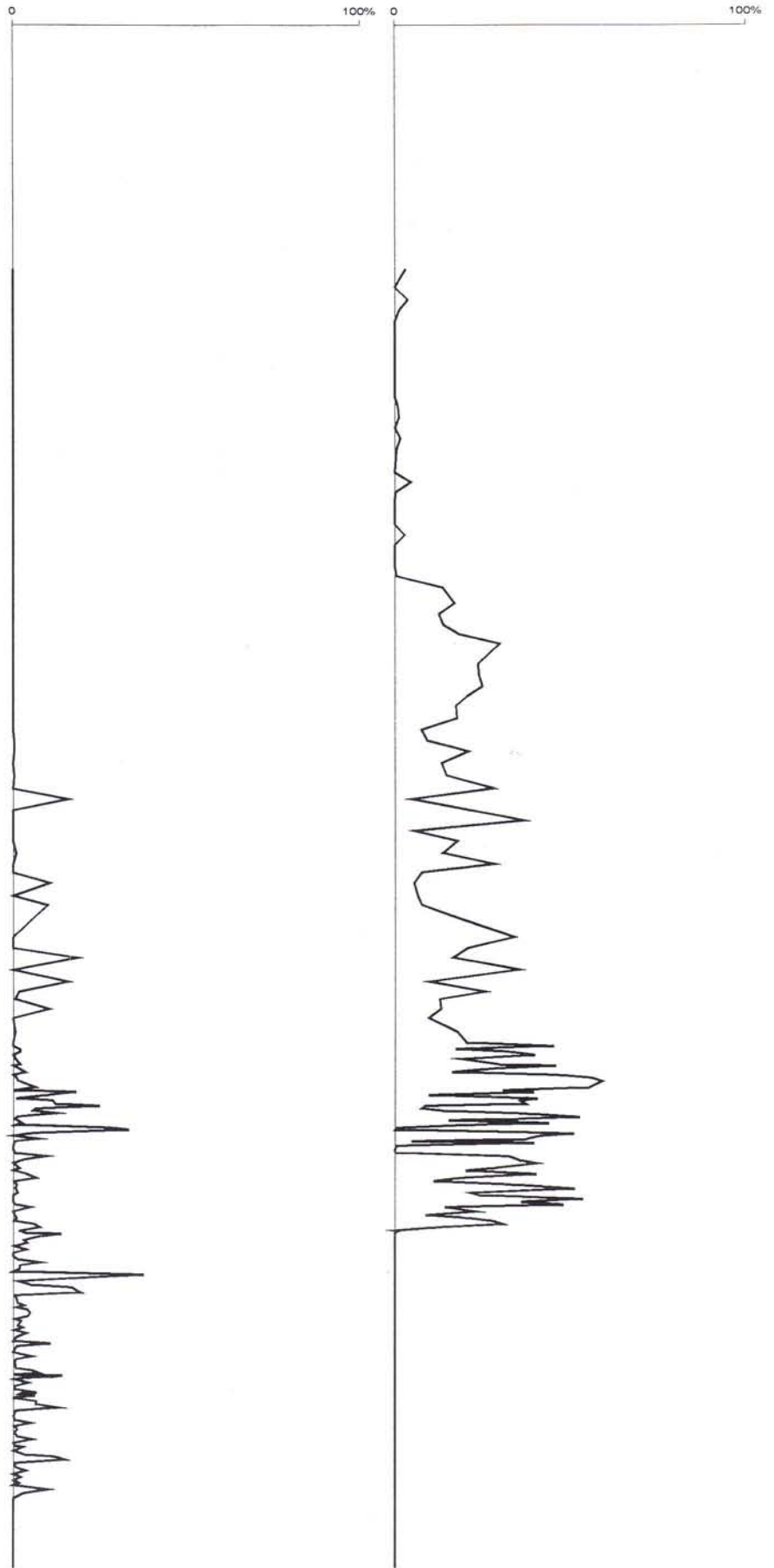
partially disturbed by slumps

D. pentaradiatus paracme

Sphenolithus spp. -

Gt. margaritae

Gt. puncticulata



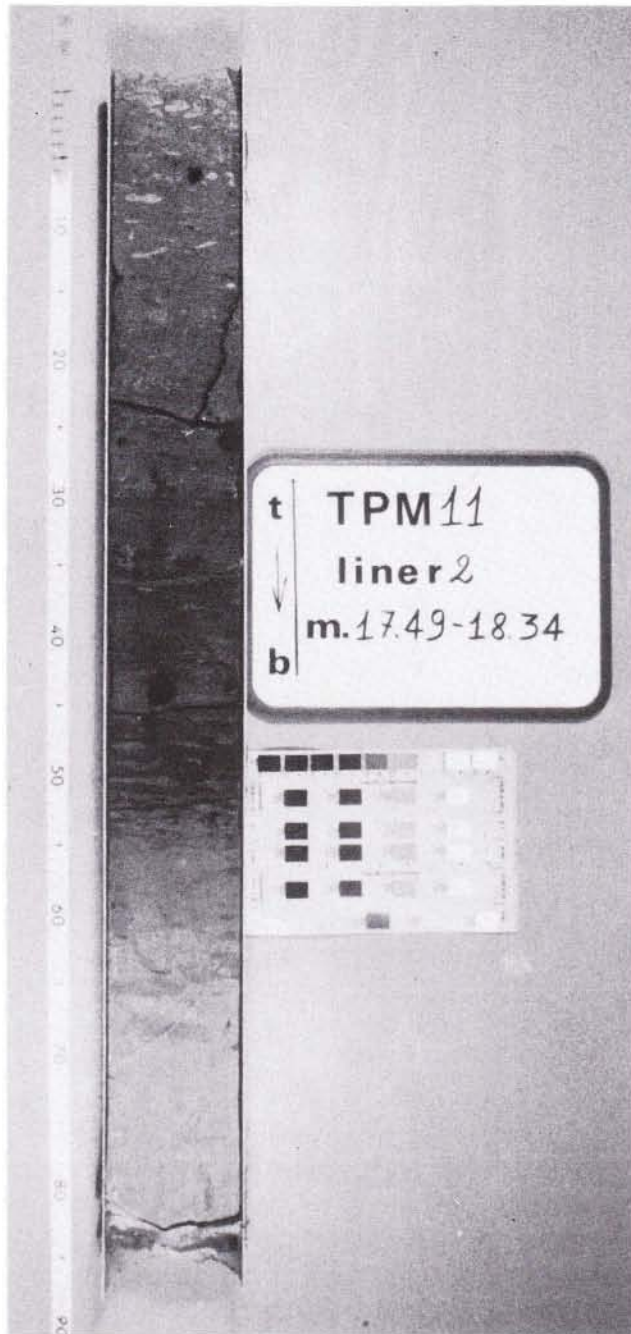


Fig. 3 - Lithological cycle 101 rich in pyrite (core 11).

all the local Pliocene, down to the uppermost Messinian Arenazzolo Formation. We present in this paper the biostratigraphic and cyclostratigraphic results of the study obtained from the continuously recovered sediments of the bore-hole.

The bore-hole.

The complete drilling resulted in 61 core-sections (each about 3 m thick), numbered from the top (Fig. 2).

The recovery of the bore-hole began some 8 meters below the surface (mbs), below a Quaternary yellowish calcarenitic bed which locally cuts the Pliocene sequence.

The uppermost recovered sediments belong to the Monte Narbone Formation. Two blackish, sapropelitic levels were cored at about 16 and 18 mbs, respectively. The lower level is correlatable with lithologic cycle 101 of Hilgen (1991), because just above this level the LO (Last Occurrence) of the benthic foraminifer *Cibicidoides italicus* occurs (see Zachariasse et al., 1989). Lithologic cycle 101 is not reported as "sapropel" by Hilgen (1991), who identified sapropels levels at the base of cycles 102, 103, 105, 106 and 107. The lithologic cycle 101 drilled in the bore-hole is rich in pyrite (Fig. 3), and in the benthic foraminiferal assemblage the relative abundance of species indicative of low oxygen/high productivity environment (*Uvigerina peregrina*) strongly increases (unpublished data). Therefore, also cycle 101 must be considered a "sapropelitic" level.

The "Trubi"/Monte Narbone boundary was crossed at about 23 mbs. All the local "Trubi" thickness was cored, down to 154.20 mbs, where the boundary between the "Trubi" and the uppermost Messinian Arenazzolo Formation was found. The bore-hole bottomed in the Arenazzolo Formation, at 155.26 mbs. The contact between the "Trubi" and the Arenazzolo Formation has a dip of about 25° and in the lowermost part of the "Trubi" some scattered pieces of Arenazzolo are included in the Pliocene matrix (Fig. 4). From 96 mbs to about the top of the bore-hole, frequent slumps are present, which give rise to more or less wavy and contorted contacts between differently colored lithologies. In the not disturbed segment, the color of the sediments in the cut cores varies between whitish cream and pale green, with a generally gradual transition between the two colors. Consequently, the complete sequence of lithologic cycles, generally so well visible in the outcrop (Hilgen, 1991), is not recognizable in detail in the fresh cores of the bore-hole, where weathering could not bring into evidence the alternance of more carbonatic (indurated) and more marly (soft) beds.

Methodology.

Strategy of the location of the site, the drilling operations of the bore-hole, cores handling, sample collection and preparation, and quantitative methods adopted for the analyses were described in detail by Sgarrella et al. (1997) and by Barra et al. (1998). Benthic foraminiferal analyses for this paper come from 162 samples, collected at a mean interval of 25 cm. All the benthic specimens were picked out, identified and counted from the fraction > 125 µm. The fraction was split with a micro-splitter to yield a subsample containing more than 200 specimens. Taxon abundance is expressed as percentage to the total fauna. The benthic number (BN) was calculated

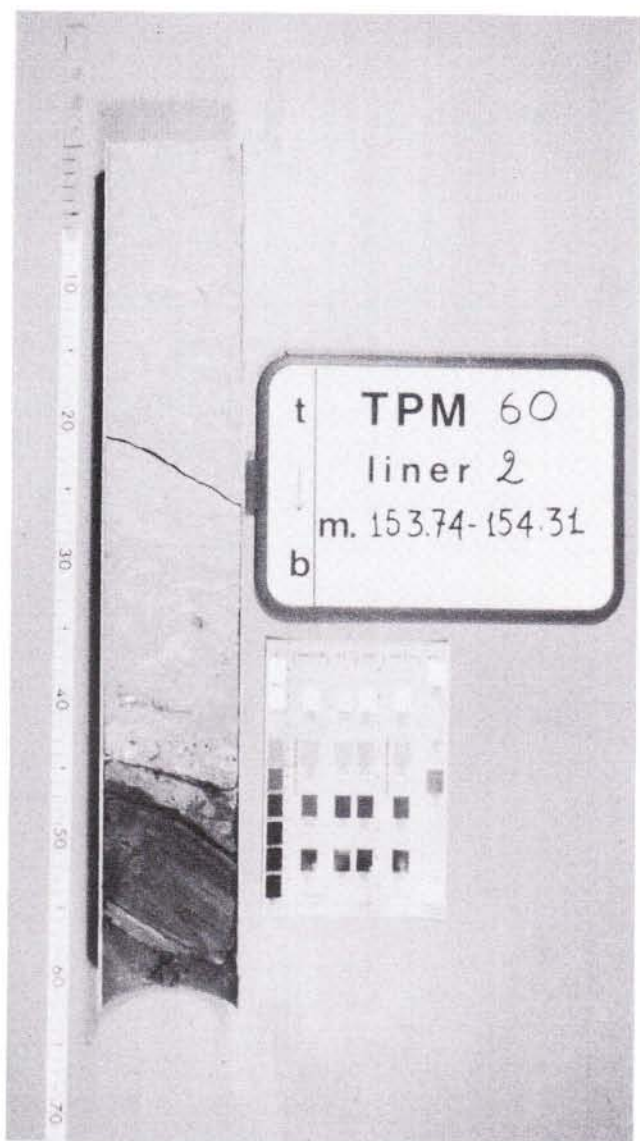


Fig. 4 - Contact between the "Trubi" and the Arenazzolo Formation (core 60).

as the total number of specimens in the fraction $> 125 \mu\text{m}$ per gram of dry sediment and reported as $\text{BN} > 125 \mu\text{m}$. Relative abundance data of *Globigerinoides* spp. were elaborated by Fourier Spectral Analysis and filtered in the precession band, in order to identify the relative abundance fluctuations forced by the precession periodicity.

Chemical data.

Chemical analysis of the same samples used for faunal analyses was carried out by the "Regional X-ray laboratory" (Queen's University of Belfast) using an SRS 303 X-ray spectrometer. For each sample twelve elements were measured, among which we report percentage values of CaCO_3 , Fe_2O_3 and sulfur content (ppm). Since the chemical data are compared with planktonic and benthic foraminifera quantitative distribution, then the

relative curves are reported and discussed below. The CaCO_3 percentage values show numerous fluctuations along the section and in particular four peaks with high carbonate content are recorded between about 123 and 114 mbs. Very high Fe_2O_3 and sulfur values are present from the base of the bore-hole up to about 147 mbs and they are relatively high from 147 to about 135 mbs. They decrease above this level, but with another small increase in the upper part, above 115 m.

Calcareous plankton biostratigraphy.

Planktonic foraminifera.

The cored interval was easily zoned (Fig. 2) with reference to the biostratigraphic schemes of Cita (1975), amended by Sprovieri (1992) for planktonic foraminifera and by Rio et al. (1990a) for the calcareous nannofossils. The biostratigraphic boundaries were identified with accuracy only in the lower part of the section (below 96 mbs), due to the tectonic disturbance (slumps) in the upper part, (Fig. 2). The segment between the local base of the Pliocene and 147.12 mbs, coincident with the FCO (First Common Occurrence) of *Globorotalia margaritae*, is ascribed to the M Pl 1 biozone, but the basal part of the Pliocene is missing: indeed, in the successions in which the Pliocene is complete of the lowermost part, two peaks of left coiled *Neogloboquadrina acostaensis* are present, respectively at the transition between lithologic cycles or abundance fluctuations 1-2 and 2-3 (Di Stefano et al., 1996). Only one peak of left coiled *N. acostaensis* was recognized in the bore-hole at 153.86 mbs by Sgarrella et al. (1997), so that they identified the lowermost fluctuation of the relative abundance of *Globigerinoides* spp., at 153.57 mbs, with Hilgen's lithological cycle 3 (Fig. 5). The same authors numbered the fluctuations between cycle 3 and the FCO of *Gt. margaritae* (base of the M Pl 2 biozone) with a progressive sequence of numbers and proposed the existence of two fluctuations 6a and 6b, corresponding to lithologic cycle 6 in other sections (Di Stefano et al., 1996). In the bore-hole only fluctuation 6b is present at 151.40 mbs, between the top of the acme of *Sphaeroidinellopsis* spp. above and the base of the *Reticulofenestra pseudoumbilicus* paracme below. Fluctuations 6a and 6b in the complete sections can be easily identified by the occurrence of (1) the acme of *Sphaeroidinellopsis* spp. at the top of fluctuation 6b, (2) the base of the paracme of *R. pseudoumbilicus* between fluctuation 6a and 6b, (3) the LO of *Triquetrorhabdulus rugosus* at the base of fluctuation 5 and (4) the upper peak of left coiled *N. acostaensis* at the base of cycle 3 (Di Stefano et al., 1996). In Fig. 5, the interpretation by Sgarrella et al. (1997) is plotted on the left and the interpretation proposed in this paper is plotted on the right. A

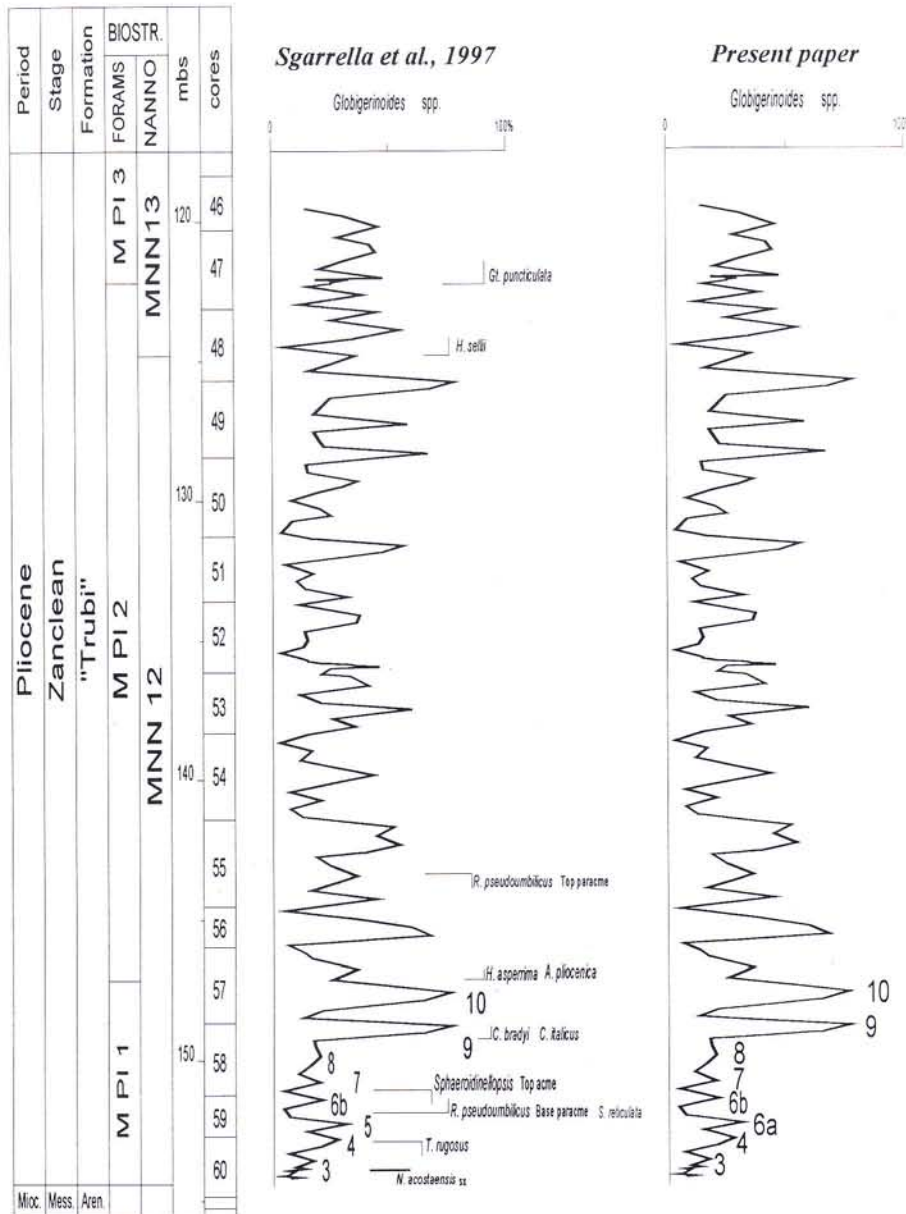


Fig. 5 - Relative abundance fluctuations of *Globigerinoides* spp. Comparison between the interpretation of the M Pl 1 segment proposed by Sgarrella et al. (1997) (on the left) and in this paper (on the right) is reported in the lower part.

new and possibly more reliable interpretation for this interval of the bore-hole, is suggested which also takes into account the new data of the distribution in this segment of *T. rugosus*, which disappears at 152.52 mbs, coincident with the top of fluctuation 4. Fluctuations at 153.57 and 152.80 mbs occur in the upper part of core 60. Based on the presence of dominant left coiled specimens of *N. acostaensis* at 153.90 mbs (and never present above), the fluctuation maximum at 153.57 is labeled with number 3 (Di Stefano et al., 1996). On the assumption of a continuous sedimentation within core 60, fluctuation maximum at 152.80 mbs is labeled with number 4. This is supported by the presence of *T. rugosus*, which in other Mediterranean sections (Di Stefano et al., 1996; Di Stefano, 1998) disappears with cycle 5. Fluctuations at 152.25 and at 151.10 mbs occur in core 59. A maximum at 151.10 mbs is labeled as fluctuation 6b, because of the end of the *Sphaeroidinellopsis* acme interval at its top and

of the base of the *R. pseudoumbilicus* paracme interval at its base (Di Stefano et al., 1996). The underlying fluctuation at 152.25 mbs was labeled with number 5 by Sgarrella et al. (1997) (Fig. 5), but the new data on the distribution of *T. rugosus* in the sequence of the bore-hole prove that this species is not present in the samples referred to this fluctuation. Therefore these samples are younger than the disappearance of *T. rugosus*, and younger than fluctuation 5. Finally, fluctuations at 152.24 mbs and at 151.40 mbs (respectively labeled with number 5 and 6(b) by Sgarrella et al., 1997) occur in the same core 59, which is 1.35 m thick. Fluctuations at 153.57 and at 152.80 mbs (respectively labeled with numbers 3 and 4 by Sgarrella et al., 1997) occur in the upper part of the underlying core 60. Therefore they are separated from the overlying fluctuations by a core break. All these

considerations suggest that the lack of one fluctuation, can be more likely the consequence of un-recovered sediments between the two cores. We conclude (Fig. 5) that the fluctuation at 152.80 mbs, at the top of core 60, is number 4 and that fluctuations at 152.25 and 151.10 mbs, in core 59, are 6a and 6b respectively. Fluctuation 5 is missing due to not recovered sediments between the two cores 59 and 60. In the bore-hole the last occurrence of *T. rugosus* coincides with the top of fluctuation 4 and is slightly older than its LO identified in the other sections (Di Stefano et al., 1996).

Globorotalia puncticulata first occurs at 122.20 mbs, where the base of the M Pl 3 biozone is identified. In the segment disturbed by slumps, the position of the top of the M Pl 3 biozone is ambiguous, because *Gt. margaritae* is common up to 89 mbs, disappears between 89 and 81 mbs, is common again between 81 and 79 mbs and is rare up to 75 mbs (Fig. 2). It is difficult to decide

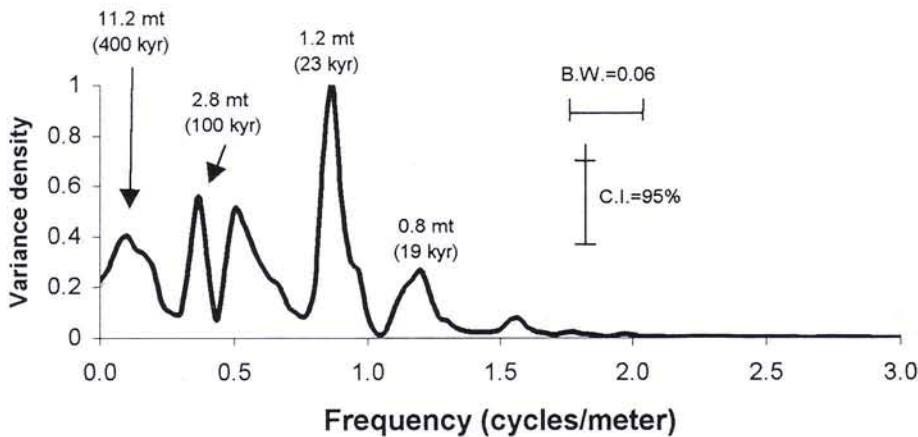


Fig. 6 - Results of Fourier Spectral Analysis on the quantitative data of *Globigerinoides* spp.

whether the common presence of *Gt. margaritae* at 79 mbs represents the true LCO of the species or if it is consequence of reworking due to the presence of slumps. In other sections (Sprovieri, 1992; Hilgen, 1991), in the upper range of the common occurrence of *Gt. margaritae* the species is continuously present. Therefore the upper boundary of M Pl 3, defined by the LCO of *Gt. margaritae* (Sprovieri, 1992) is reported in Fig. 2 by an inclined line. The last occurrence of *Gt. puncticulata* (which defines the top of the M Pl 4a biozone) is also uncertain. The frequency of the species is high up to 60 mbs, where it sharply decreases in abundance, but *Gt. puncticulata* is sporadically present, rare, in several samples above, up to 30 mbs (Fig. 2). We tentatively recognize the top of M Pl 4a in coincidence of the sharp decrease in abundance of *Gt. puncticulata*, and interpret the presence of the rare specimens above this level as reworked. Finally, the last occurrence of *Sphaeroidinellopsis* spp., which defines the top of M Pl 4b, was found at 23 mbs. Only rare, scattered specimens of *Sphaeroidinellopsis* spp. are present in the topmost samples. We approximate the top of the M Pl 4b biozone with the lithologic boundary between the "Trubi" and Monte Narbone Formation. This boundary could not be clearly identified in the cut cores. In the Capo Rossello area this lithologic boundary practically coincides with the extinction level of *Sphaeroidinellopsis* spp. (Zachariasse et al., 1989; Hilgen, 1991; Sprovieri, 1993; Lourens et al., 1996).

Calcareous nannofossils.

The most important biostratigraphic events are reported in Fig. 2. The calcareous nannofossil species *Helicospaera sellii*, indicating the base of the MNN 13 biozone, first occurs at 123.80 mbs (Fig. 5), slightly below the FO of *Gt. puncticulata*. Consequently, the lower part of the bore-hole is ascribed to the MNN 12 biozone. The FCO of *Discoaster asymmetricus*, which defines the base of the MNN 14-15 biozone, was identified at 93.70 mbs. Finally, the base of the MNN 16a biozone, defined by the LO of *R. pseudoumbilicus*, occurs at 81.70 mbs. Other

useful, second order biostratigraphic events identified in the bore-hole are the base and top of the *Discoaster pentaradiatus* paracme, at 86 and 57 mbs, respectively, and the LO of *Sphenolithus* spp., at 76.50 mbs (Fig. 2).

Cyclostratigraphy.

The sequence of lithologic cycles, generally well exposed in the Capo Rossello outcrops (Hilgen, 1991) is not recognizable in detail in the fresh cut cores of the bore-hole. Therefore, in order to identify the sequence of the cycles, the methodology proposed by Sprovieri (1992, 1993) was followed, and the relative abundance fluctuations of *Globigerinoides* spp. were used to identify each cycle. High relative abundance of *Globigerinoides* spp. is interpreted as indicative of the "warm" part of each cycle, and correlates with its marly interval. The relative abundance fluctuations of *Globigerinoides* spp. were estimated only in the segment below the interval disturbed by the slumps, and cyclostratigraphic interpretation was made only up to the FO of *Gt. puncticulata*. Above this level no (bio)stratigraphic constraints are present that can support a cyclostratigraphic interpretation, and, unfortunately, paleomagnetic data could not be obtained from the bore-hole (Napoleone, personal communication). Therefore, above the FO of *Gt. puncticulata* we only tentatively numbered the relative abundance fluctuations between 122.20 and 108.83 mbs, supported by the CaCO₃ record, as discussed below. The relative abundance fluctuations of *Globigerinoides* spp. are plotted in Fig. 5. The quantitative data were elaborated by Fourier Spectral Analysis (Fig. 6). In order to avoid the basal hiatus, coincident with cycle 5, only the interval between 152.25 and 122.05 mbs was considered. The results reported in Fig. 6 show high variance density at 0.87 and 1.20 cycles/meter. They correspond to the thickness of 1.15 m and 0.83 m respectively for the relative abundance fluctuations. These values are totally comparable with the maximum and minimum thickness of the lithologic cycle in the Rossello composite section (Lourens et al., 1996), correlated to the precession peri-

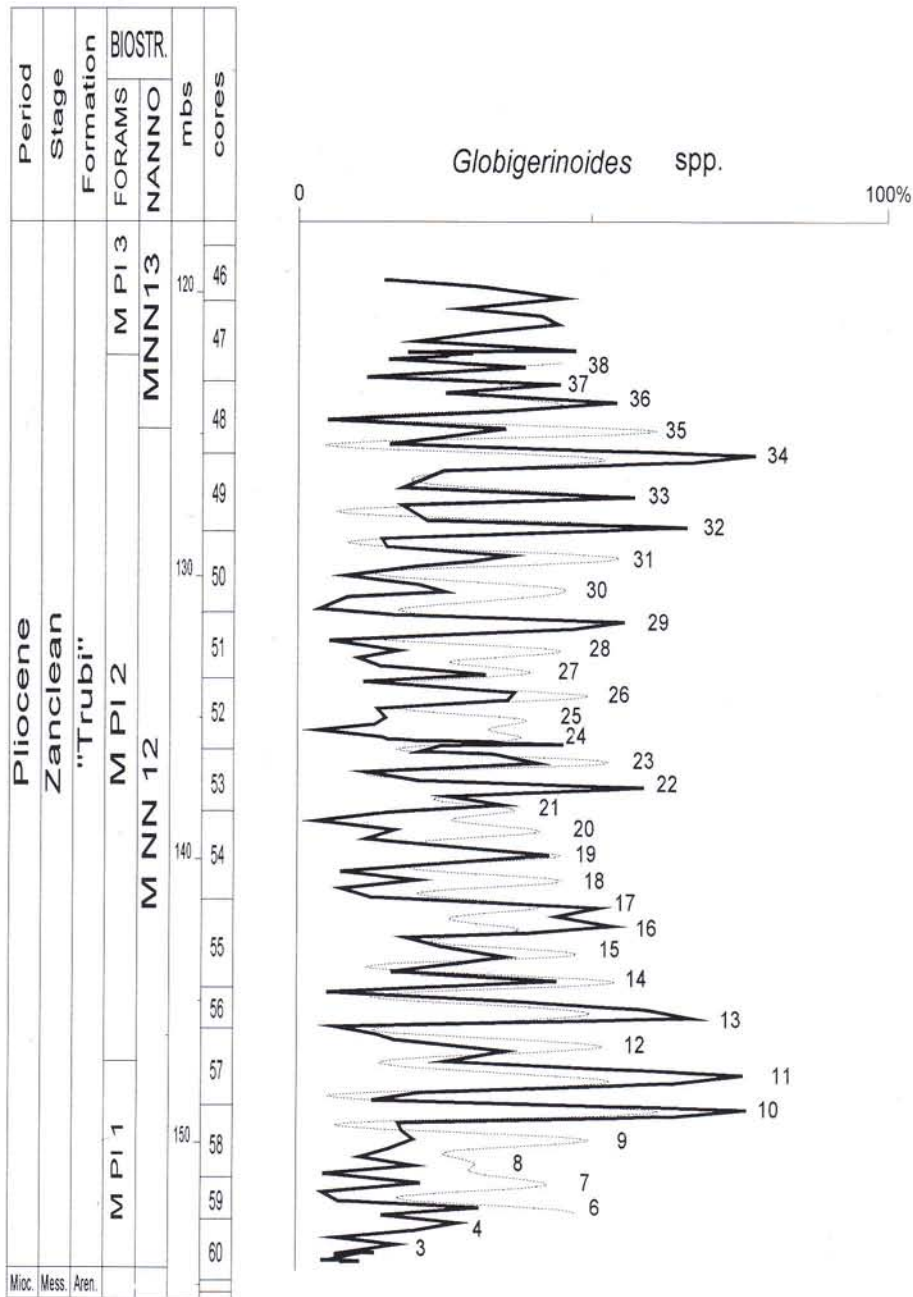


Fig. 7 - Quantitative data of *Globigerinoides* spp. filtered in the precession band. Dashed line = percent values of *Globigerinoides* spp. Thick continuous line = filtered data in the precession frequency band. The filtered interval includes all the frequencies between 0.8 and 1.23 cycles/meter.

odicity by Hilgen (1991). Consequently this band of frequency for the sequence of relative abundance fluctuations is related to the astronomical precession periodicity and the original data were filtered in the precession band (Fig. 7). This procedure allows us to identify all the cycles induced by this Milankovitch fundamental periodicity. The comparison of the relative abundance fluctuations of *Globigerinoides* spp. to the precession astronomical record is given in Fig. 8. For this paper we selected the astronomical curve (La90(1,1)) obtained by Lourens et al. (1996) for the 65° N summer insolation from the astronomic solution of Laskar (1990).

Between the base of the Pliocene and the FO of *Gt. puncticulata* thirty-five lithologic cycles were reported by Hilgen (1991), with cycles 6, 21 and 22 each including two precession cycles. In the left part of Fig. 9

the code numbers of the lithologic cycles proposed by Hilgen (1991) are followed to label the relative abundance fluctuations of *Globigerinoides* spp., and the couple of fluctuations included in lithologic cycles 6, 21 and 22 are distinguished with letters "a" and "b". Consequently the FO of *Gt. puncticulata* is coincident with the upper part of fluctuation 35. On the right side of Fig. 9, the relative abundance fluctuations of *Globigerinoides* spp. are progressively numbered, without the "a" and "b" distinction. Consequently, the FO of *Gt. puncticulata* occurs in the upper part of fluctuation 38. Sprovieri (1993) did not identify the two fluctuations 6a and 6b, and correlated the FCO of *Gt. margaritae* with the top of fluctuation 10. Therefore, in the Capo Spartivento section the base of the M Pl 2 biozone was correlated with fluctuation 10 (Fig. 10, left side) and the four fluctuations labeled as 21a, 21b, 22a and 22b in the left part of Fig. 9,

were reported as number 21, 22, 23 and 24, all within the Sidufjall paleomagnetic interval. Finally, the FO of *Gt. puncticulata* was identified in the upper part of a fluctuation to which number 36 was ascribed. If no "a" and "b" distinction is used to label relative abundance fluctuations that occur in the same lithologic cycle, the FCO of *Gt. margaritae*, and the base of M Pl 2, coincides with the top of fluctuation 11 (Fig. 9) and therefore the fluctuation in which the FO of *Gt. puncticulata* occurs in the Capo Spartivento section would be labeled with number 37 (left side in Fig. 10). The detailed sequence of fluctuations in the Rossello bore-hole proves that the FO of *Gt. puncticulata* occurs at the top of fluctuation 38. We conclude that one fluctuation was lost in the cyclostratigraphic interpretation of the Capo

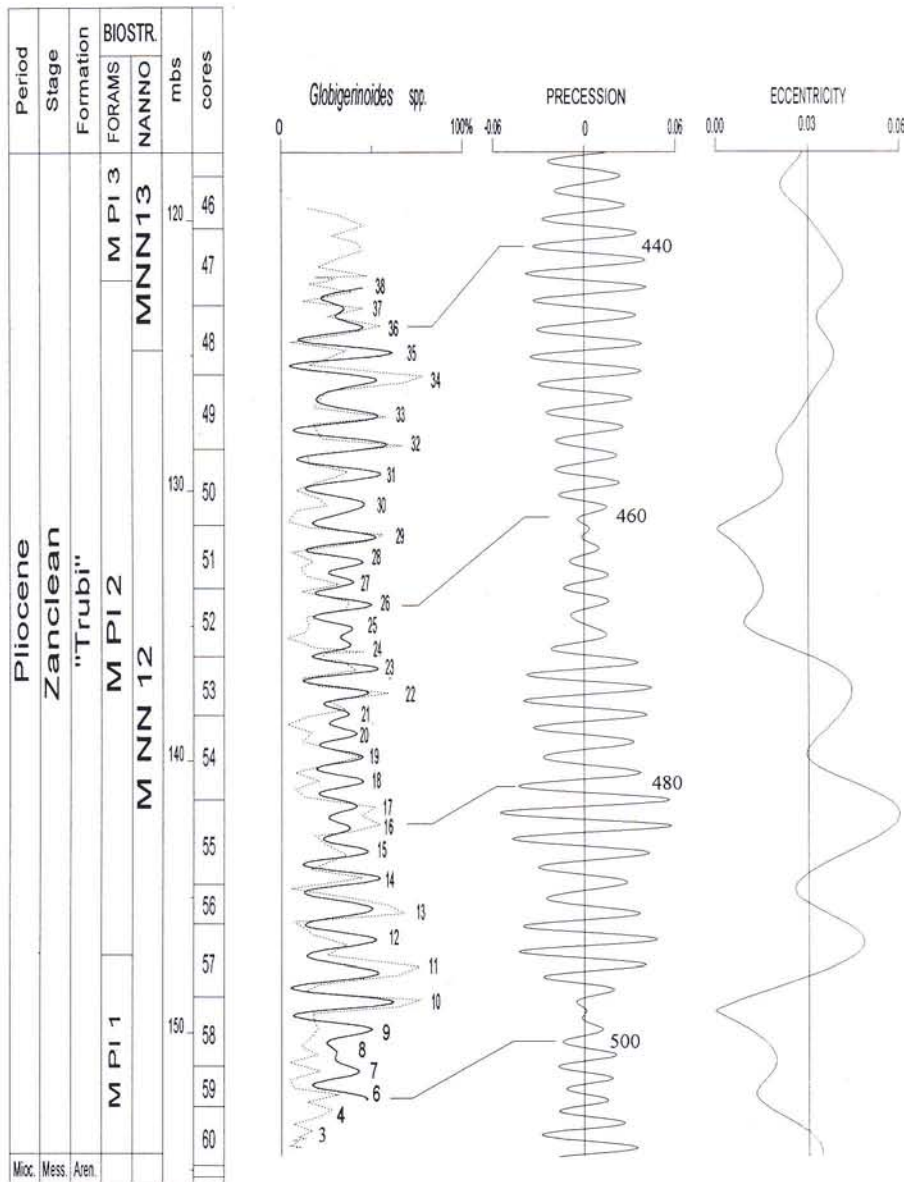


Fig. 8 - Comparison of the individual relative abundance fluctuation of *Globigerinoides* spp. with the precession and eccentricity record.

Chronology.

By correlation of the relative abundance fluctuations to the astronomical precession record (Fig. 8), the age of each fluctuation can be estimated. Consequently, the astronomical age of each bioevent that coincides with one relative abundance fluctuation of *Globigerinoides* spp. can be obtained. They are reported in Table 1. Due to the different reference used to estimate these ages, they are slightly different from the ages reported by Sprovieri (1993) and are in agreement with the ages reported by Lourens et al. (1996). Only the age of the FCO of *Gt. margaritae* is different, due to a different interpretation of the FCO event of this species. According to Lourens et al. (1996) it coincides with lithologic cycle 12 (our fluctuation 13), but we recognize this bioevent in the upper part of fluctuation 11 (lithologic cycle 10 of Lourens et al., 1996). In this cycle *Gt. margaritae*, virtually absent in the underlying interval, is present for the first time with a relative abundance between 5% and 10% in the different sections.

Spartivento section proposed by Sprovieri (1993). We suggest that in the segment between fluctuations 36 and 37 reported in the right side of Fig. 10, where samples spacing increases and no lithologic cycles are distinctly present, one fluctuation was not detected. In conclusion, 38 relative abundance fluctuations of *Globigerinoides* spp. are present between the base of the Pliocene and the FO of *Gt. puncticulata*.

The fluctuations recorded above the FO of *Gt. puncticulata* are confirmed by the CaCO₃ record. Hilgen & Langereis (1989) reported the total CaCO₃ record in the Rossello composite section of the Pliocene "Trubi". The four peaks with high carbonate content between about 123 and 114 mbs (Fig. 11) can be clearly correlated with the four peaks reported by Hilgen & Langereis (1989, p. 411, fig. 2) between cycles 35 and 42. Therefore, we tentatively numbered the relative abundance fluctuations of *Globigerinoides* spp. between 122.20 and 108.83 mbs, marked by an asterisk.

The Rossello bore-hole allowed us to correlate for the first time the FO of *Helicosphaera sellii* to the sequence of relative abundance fluctuations of *Globigerinoides* spp. It coincides with fluctuation 35 (Fig. 7), with an age of 4.60 Ma.

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Benthic foraminifera.

Benthic foraminifera have been generally used for paleoenvironmental reconstruction. Cyclic changes have been reported mostly in Pleistocene deep-sea sediments of the North Atlantic, where they were assumed to reflect modifications in the deep water circulation, and related to cooling of surface water (Streeter, 1973; Lutze, 1979; Schnitker, 1979, inter alios).

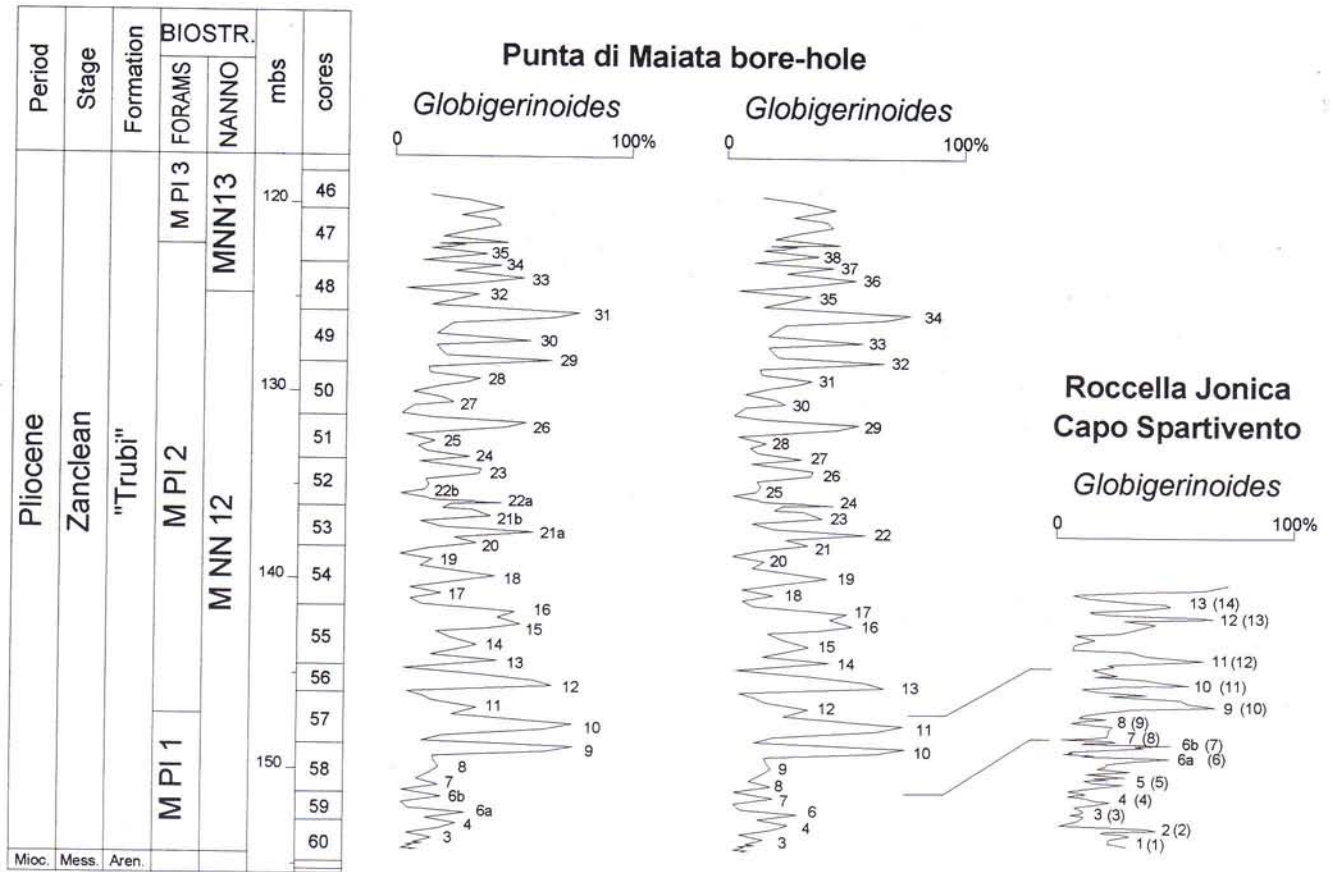


Fig. 9 - Code numbers of relative abundance fluctuations of *Globigerinoides* spp. according to Hilgen's (1991) lithologic cycles (on the left) and according to the sequence of relative abundance fluctuations of *Globigerinoides* spp. reported in the present paper (on the right). The two different code numbers for the Roccella Jonica-Capo Spartivento composite section (Di Stefano et al., 1996) are reported for comparison (in brackets the code numbers reported in this paper).

Schnitker (1984), in the North Atlantic DSDP Hole 552A, related Late Miocene to Quaternary benthic foraminiferal fluctuations to insolation changes. In his study these variations, displayed by Q-mode varimax component analysis and power-spectrum analysis, occurred at about 20 kyr, 40 kyr, 100 kyr and 400 kyr intervals.

The sequence recovered in the bore-hole offers the opportunity to study the benthic foraminifera fluctuations in the Zanclean stratigraphic interval. In the paleoecological study of this segment (Barra et al., 1998) 122 benthic species are reported and the main change in the assemblages has been recognized at the M Pl 1/M Pl 2 boundary. During the M Pl 1 biozone (154.2 - 147 mbs) a dysaerobic event, characterized by high relative values of *Uvigerina pygmaea* (up to 50%) (Fig. 12), associated with *Karreriella bradyi*, was related to sluggish bottom circulation and, probably, enhanced preservation of organic matter (Sgarrella et al., 1997). Above 147 mbs, coinciding with the base of the M Pl 2 biozone, the dominant assemblage abruptly changed and *U. pygmaea* was replaced by *S. reticulata* (Fig. 13), as dominant species, together with *C. bradyi*, *C. robertsonianus*, an Atlantic deep-water species (Schnitker 1994, inter alios), *P. ariminensis* and *P.*

bulloides (Fig. 12) indicative of "normal" bottom conditions. Pflum & Frerichs (1976) pointed out a morphological intergradation between *C. bradyi* and *C. robertsonianus*. Therefore, in this paper the percentage values of the two species are lumped together, even if *C. robertsonianus* is less abundant than *C. bradyi* in the studied segment. The results of the Q-mode Factor Analysis of the quantitative data of the benthic assemblages are reported in Barra et al. (1998). This analysis was performed on the relative abundance of 37 species. We only point out here (Fig. 14) the opposite trend of the stratigraphic distribution of varimax factor loadings of Factor 1 and Factor 6. Factor 1 explains a variance of 59% and is dominated by *S. reticulata* (factor score 0.896), whereas Factor 6 explains only 3% of variance and is dominated by *Cibicides bradyi-robertsonianus* (factor score 0.59), together with *Pullenia bulloides*, *Planulina ariminensis*, *Cibicides ungerianus*, *Bigenerina nodosaria* and *Gyroidina soldanii* as low scored component. Most of the species which dominate Factor 1 and Factor 6 are poorly or not represented at the base of the bore-hole, during the M Pl 1 biozone. Anyway, these species show rhythmic alternations, particularly evident for the more abundant species (Figs. 12 and 13).

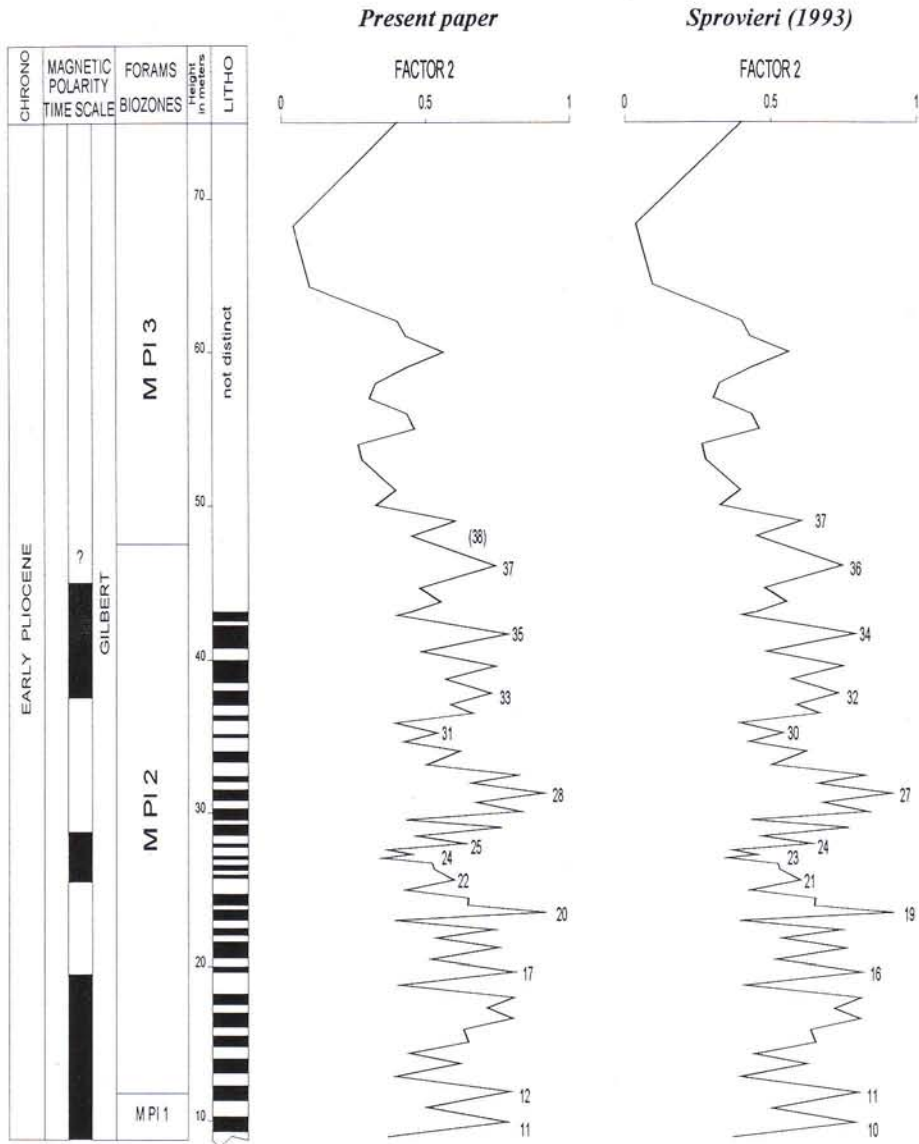


Fig. 10 - Relative abundance fluctuations of *Globigerinoides* spp. in the Capo Spartivento section labeled according to Sprovieri (1993) (on the right) and according to the reinterpretation proposed in this paper (on the left).

Correlation between benthic and planktonic foraminifera fluctuations.

Large-scale rhythmic fluctuations.

Large-scale rhythmic fluctuations were recognized in the BN > 125 μm (Fig. 15) and in the *Planulina ariminensis* quantitative distributions (Fig. 12). BN > 125 μm , compared with the fluctuations of the relative abundance of *Globigerinoides* spp., shows that the three intervals with higher values correspond to fluctuations 9-11, 26-32 and above fluctuation 46*. The base of these intervals with increased abundance of benthic specimens is just above the thick, essentially carbonatic cycles 6, 22 and 41 of Hilgen (1991), respectively (Fig. 9). Abundance of benthic foraminifera (> 150 μm) is generally related to increase in productivity (Berger & Diester-Haass, 1988; Herguera & Berger, 1991; Herguera, 1992).

In the bore-hole the short periods with increase in productivity of benthic foraminifera effectively follow the cycles with high carbonate productivity. We point out that these periods with increased abundance of benthic specimens correspond to the lower part of the high seasonality intervals in the astronomical eccentricity record of 400 kyr (Hilgen, 1991).

The bell-shaped *Planulina ariminensis* quantitative distributions trend occurs between about 4.8 and 4.4 Ma, if a constant sedimentation rate is assumed between the FCO of *G. margaritae* estimated at 5.13 Ma and the FO of *G. puncticulata* estimated at 4.52 Ma (Table 1). Consequently, the maximum values of *P. ariminensis* coincide with a maximum in the eccentricity (400 kyr) astronomical record of Berger & Loutre (1991). The same result is obtained if the *P. ariminensis* distribution is compared with the *Globigerinoides* spp. fluctuations. In fact, the relative abundance progressively increases from about

These small-scale fluctuations are displayed mainly by *U. pygmaea* in the M Pl 1 biozone, and by *S. reticulata*, and by the species which dominate Factor 6 (especially *C. bradyi*, *P. ariminensis* and *P. bulloides*) above this biozone. *Planulina ariminensis*, which occurs with high percent values (up to 20% of the assemblage) also in the M Pl 3- M Pl 5 biozones, displays a peculiar bell-shaped distribution in the segment referable to the M Pl 2 biozone (Fig. 12). This trend seems to indicate a large scale fluctuation on a much longer time scale.

BN > 125 μm is generally low, with 20 to 40 specimens per gram and frequent fluctuations along the section (Fig. 15). Values higher than 40 specimens per gram occur only in coincidence of three intervals: (1) 149.84-147.85 mbs; (2) 133.99-128.28 mbs; (3) 113.01-111.34 mbs. Also this trend seems to indicate a large scale fluctuation.

Both the large-scale and the small-scale benthic foraminiferal fluctuations are discussed below, with reference to the cyclostratigraphic record pointed out by the relative abundance fluctuations of *Globigerinoides* spp.

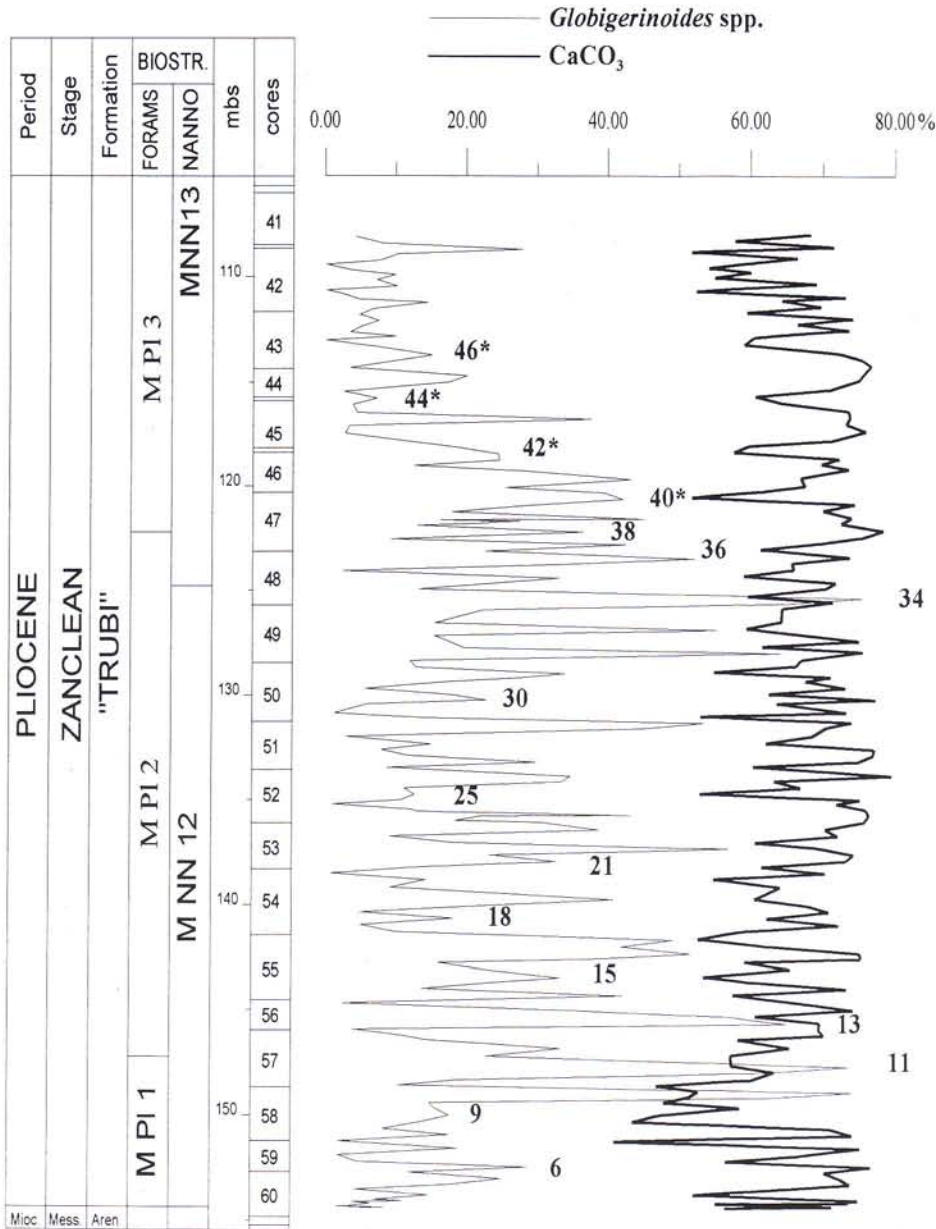


Fig. 11 - CaCO₃ record in the studied segment and comparison with the relative abundance fluctuations of *Globigerinoides* spp. Fluctuations marked by asterisk are tentatively numbered.

136 mbs, in correspondence with fluctuation 24, and gradually decreases from about 117 mbs upwards, in correspondence with fluctuations 43-44.

P. ariminensis is considered an epibenthic foraminifer from elevated microhabitats (Lutze & Thiel, 1989). The species of this particular habitat are related to the bottom water hydrodynamics, because they are generally suspension feeders and from an elevated substrate they are able to obtain the food supply transported by bottom currents (Linke & Lutze, 1993). Therefore, the abundance of *P. ariminensis* testifies a good bottom water circulation during the high seasonality period. This hypothesis is supported by chemical data (Fig. 12), because maxima of *P. ariminensis* correspond to the lowest values of iron and sulphur and, consequently, to well oxygenated bottom conditions.

Small-scale rhythmic fluctuations.

Siphonina reticulata, *Cibicides brady-robertsonianus*, *P. ariminensis*, *P. bulloides* and *U. pygmaea* are the species which display the most evident rhythmic fluctuations of the percentage values.

Tab. 1 - Age of the calcareous plankton biostratigraphic events obtained in this paper. Correlation to the relative abundance fluctuations of *Globigerinoides* spp. and to the lithologic cycles (Hilgen, 1991) are reported.

EVENTS	FLUCTUATION	LITHOLOGIC CYCLE	AGE (Ma)
Base Pliocene	base 1	base 1	5.33
First influx <i>N. acostasensis</i> sx	1-2	1-2	5.32
Second influx <i>N. acostasensis</i> sx	2-3	2-3	5.30
Base acme <i>Sphaerodinellopsis</i> spp.	2-3	2-3	5.30
LO <i>T. rugosus</i>	base 5	base 5	5.26
Base paracme <i>R. pseudoumbilicus</i>	base 6-7	mid 6	5.22
Top acme <i>Sphaerodinellopsis</i> spp.	top 7	top 6	5.20
FCO <i>Gt. margaritae</i>	top 11	top 10	5.13
Top paracme <i>R. pseudoumbilicus</i>	base 15	base 14	5.04
FO <i>H. sellii</i>	mid 35	mid 32	4.60
FO <i>Gt. puncticulata</i>	top 38	top 35	4.52

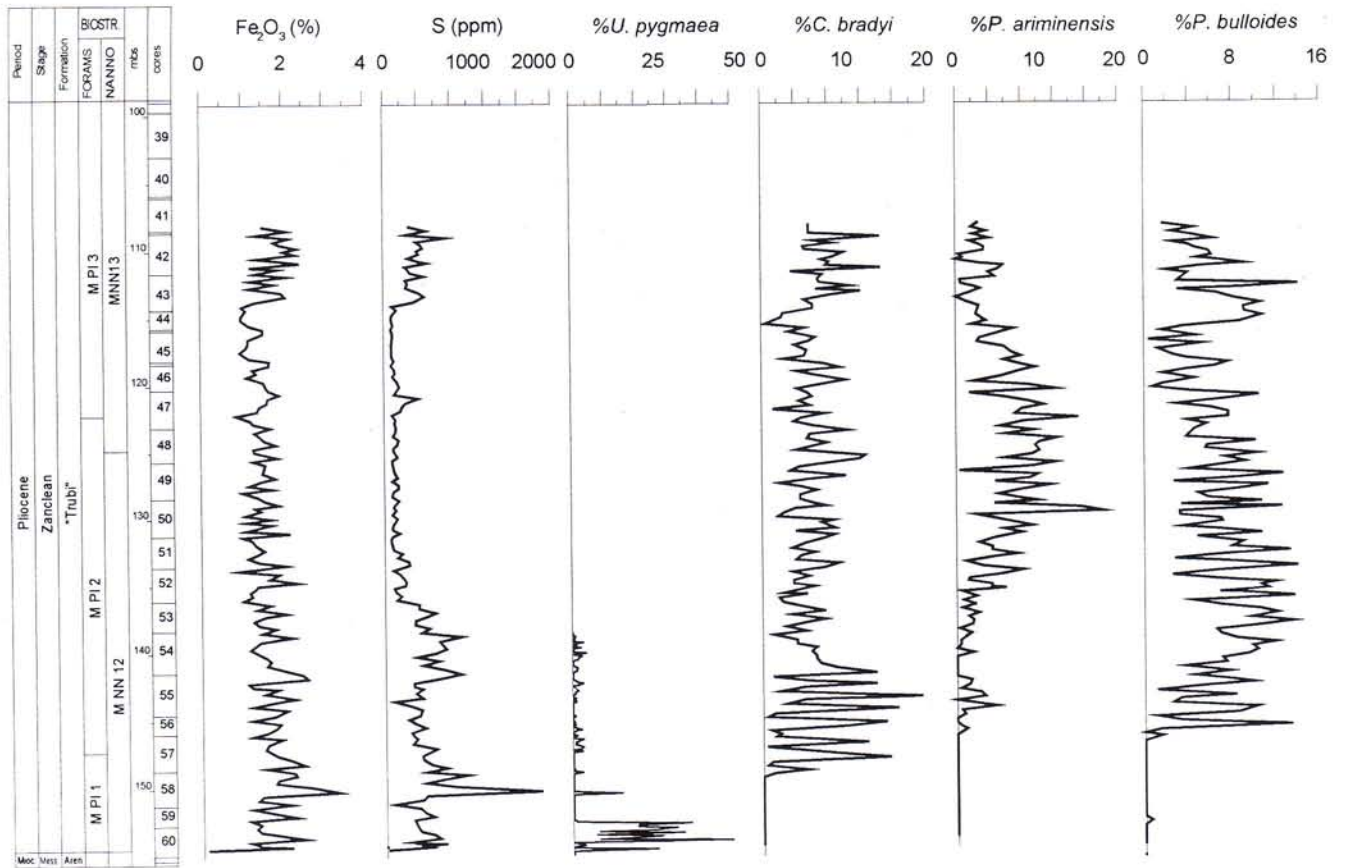


Fig. 12 - Quantitative distribution of Fe_2O_3 and S, and comparison with the quantitative distribution of four benthic foraminifera.

Relative abundance distribution of *S. reticulata* has been compared with the *Globigerinoides* spp. fluctuations (Fig. 13). The two curves show a general opposite trend. *S. reticulata* fluctuations are not evident in the interval corresponding to fluctuation 19-20 and 28. In contrast, two peaks are registered in correspondence with fluctuation 33.

If percentage values of the species listed above in Factor 6 and which show an opposite trend to that of *Siphonina* are added to the percentage values of *U. pygmaea* and *K. bradyi*, the first of which is abundant only in the M Pl 1 biozone, we obtain the curve of this assemblage which is compared with the curve of the relative abundance fluctuations of *Globigerinoides* spp. in Fig. 16.

In this figure the benthic curve is reported as "diagram 2". These two curves are generally phase coincident, with the exclusion of the intervals between fluctuations 18-28 and 41-46, which straddle minima of astronomical eccentricity record of 400 kyr.

We have considered the relative high abundance of *Globigerinoides* spp. as a proxy record of the marly beds. Since the curve of "diagram 2" is generally phase coincident with the relative abundance fluctuations of *Globigerinoides* spp., we suggest that the peaks of this benthic assemblage also coincide with the marly layers. At present only the *U. pygmaea* distribution supports this hypothesis, as the species showed positive peaks of abundance in the marly beds of the Calabria sections (Di

BENTHIC DIAGRAM 2			
LITHOLOGIC CYCLES	PLANKTONIC CYCLES	DOMINANT SPECIES	CO-DOMINANT SPECIES
3-10	3-11	<i>U. pygmaea</i>	<i>K. bradyi</i> , <i>G. soldanii</i>
11-16	12-17	<i>C. bradyi-robertsonianus</i> , <i>P. bulloides</i>	
17-25	18-28	<i>P. bulloides</i>	<i>B. nodosaria</i> , <i>K. bradyi</i>
26-37	29-40	<i>P. bulloides</i> , <i>P. ariminensis</i> , <i>C. bradyi-robertsonianus</i>	
38-42	41*- 45*	<i>C. bradyi-robertsonianus</i> , <i>P. bulloides</i> , <i>B. nodosaria</i>	<i>K. bradyi</i>
above 42	above 46*	<i>C. bradyi-robertsonianus</i>	

Tab. 2 - Intervals of dominant and co-dominant species of the benthic assemblage, and their correlation to the lithological cycles (sensu Hilgen, 1991) and planktonic cycles.

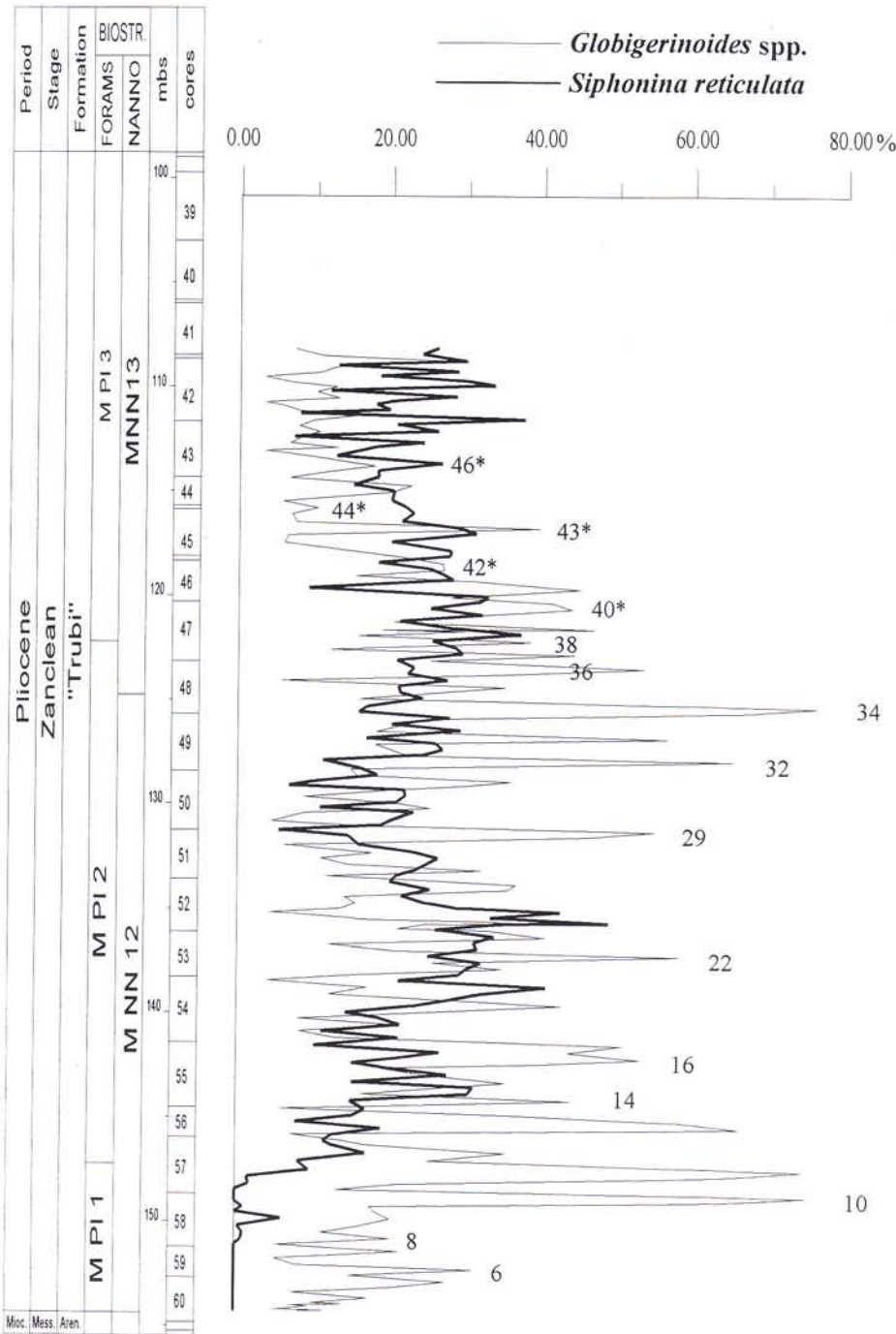


Fig. 13 - Comparison between the relative abundance fluctuations of *Globigerinoides* spp. and *Siphonina reticulata*. Only some fluctuations of *Globigerinoides* spp. are numbered for reference.

assemblage of "diagram 2" trends are less evident during minima of eccentricity. Since the effect of the precession is amplitude-modulated by the eccentricity, we suggest that: 1) benthic cycles, reflecting bottom seasonality effects, are more evident during the maxima than during the minima of eccentricity of 400 kyr; 2) during the minima the agglutinated species increase in abundance.

Discussion.

Origin of the Small-scale benthic fluctuations.

The *Siphonina reticulata* fluctuations.

Siphonina reticulata is an epifaunal to transitional form and is reported from areas with relatively low oxygen content (Rathburn & Corliss, 1994; Rathburn & Miao, 1995). In sapropelitic Mio-Pliocene sediments of the eastern Mediterranean Katz & Thunell (1984) record this species in "non-sapropel" assemblage. Therefore it seems tolerant of relatively low oxygen conditions, but able to live in an oxic environment.

Siphonina is never abundant or frequent in Recent sediments, and its distribution is not included in the synthesis papers on benthic foraminifers by Boltovskoy & Wright (1976) and Murray (1991). Nevertheless, its stratigraphic distribution in the North Atlantic provides an important documentation. *S. reticulata* was reported as abundant from the late Oligocene to middle Miocene in the North Sea (King, 1989). A more or less abundant presence of *Siphonina* in the North Atlantic DSDP Site 548 was reported in the same interval, with only one, rare occurrence at the base of the late Miocene (Poag & Low, 1985). At lower latitudes of the North Atlantic *S. reticulata* is recorded by Cita & Ryan (1978) up to the

Stefano et al., 1996; Sgarrella et al., 1997). The dominant species of the benthic assemblage clearly show changes along the studied segment (Table 2). In addition to the reported change at the M PI 1/ M PI 2 boundary, small differences in the dominant species are also present above the M PI 1 biozone. In particular, *B. nodosaria* and *K. bradyi* are dominant or co-dominant during minima of eccentricity.

The comparison with the cyclicity present in the planktonic foraminiferal assemblage suggests that the benthic rhythmicities are also related, even if not in the same detail, to the astronomical precession cycles. Above the M PI 1 biozone, both the *Siphonina* and the benthic

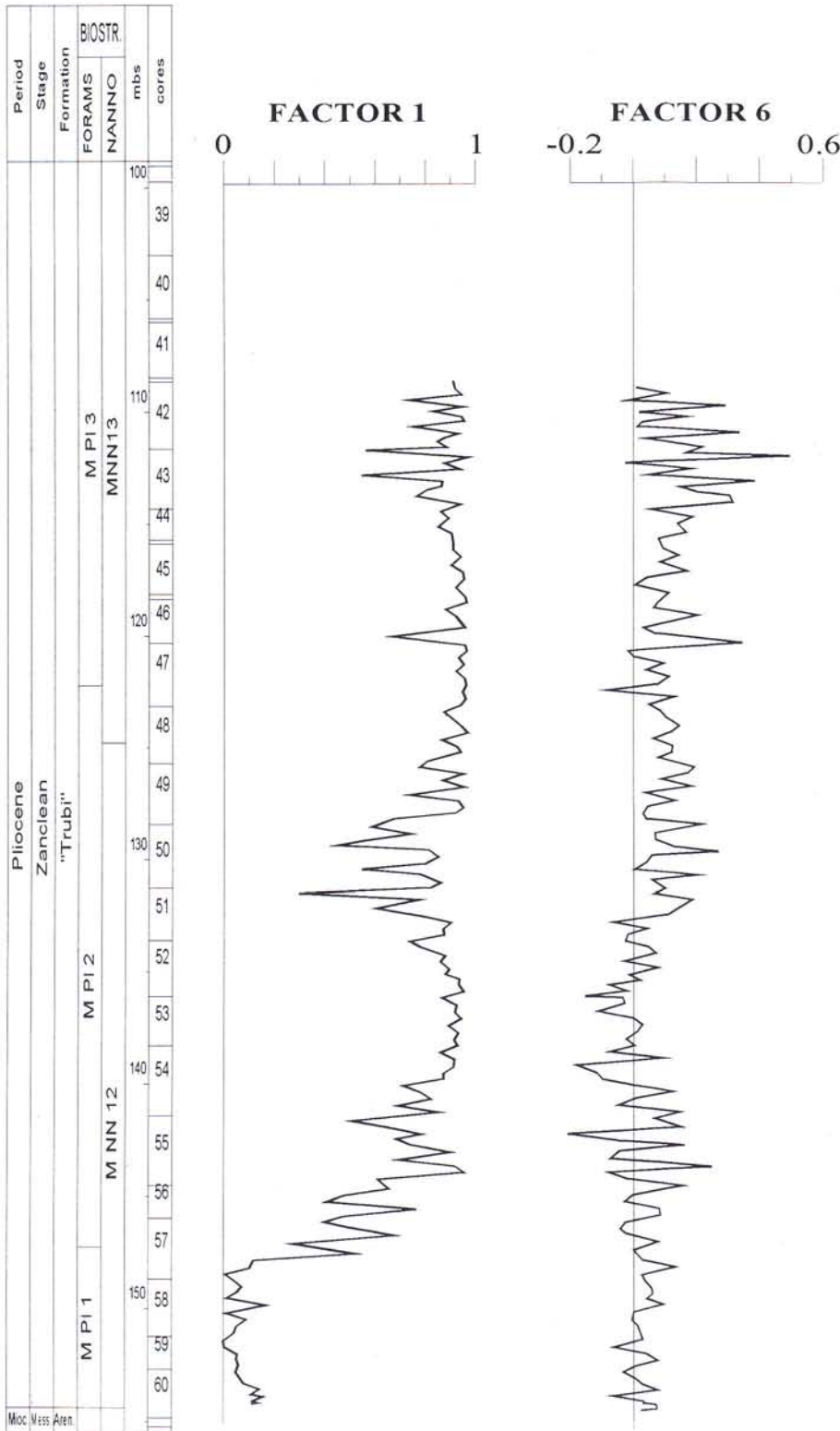


Fig. 14 - Stratigraphic distribution of the benthic foraminifera factor loadings (Factor 1 and Factor 6) in the studied segment.

lata in this stratigraphic interval was endemic or quasi-endemic in this area. The strong reduction or total absence of this species and of the genus during the middle Miocene seems an event restricted to the North Atlantic area, where Neogene deep-water circulation patterns indicate that Northern Component Water-proto NADW (NCW) was established just during the middle Miocene (Wright & Miller, 1996). We suggest that this relationship indicates that *Siphonina* was not tolerant of this deep-water circulation change. Consequently, in the North Atlantic the northernmost boundary of the areal distribution of this genus shifted to lower latitudes (during the late Miocene), and then it was restricted to the Mediterranean during the lower part of the Pliocene. Near the top of the middle Pliocene (middle part of the M Pl 5 biozone) *S. reticulata* was strongly reduced even in the Mediterranean (Sprovieri, 1978; Sprovieri & Hasegawa, 1990). We conclude that relative high abundance of *Siphonina* may be indicative, in the Mediterranean epibathyal lower Pliocene, above the M Pl 1 biozone, of coeval dominance of peculiar Mediterranean water masses, very different from the deep or intermediate Atlantic waters (NCW-proto NADW).

late Messinian of the Bou Regreg section (Morocco). In the epibathyal zone of the Mediterranean (Tyrrhenian, Calabria and Sicily) it is frequent to abundant during the late Miocene (AGIP, 1982; Sprovieri et al., 1996), and from the lower Pliocene (AGIP, 1982; Thunell et al., 1991; Barra et al., 1998) to middle Pliocene (Sprovieri & Hasegawa, 1990). Its abundance only in the Mediterranean during the Pliocene seems to indicate that *S. reticu-*

S. reticulata and *Globigerinoides* spp. trends are generally antithetical (Fig. 13). Since *Globigerinoides* spp. peaks are indicative of warm surface waters, we suggest that *S. reticulata* peaks coincide with periods of relatively cooler and more dense surface waters. These cool surface waters, sinking to the bottom, gave origin to mixing and promoted the mechanism of Mediterranean deep water formation. Until 2.5 Ma the Mediterranean

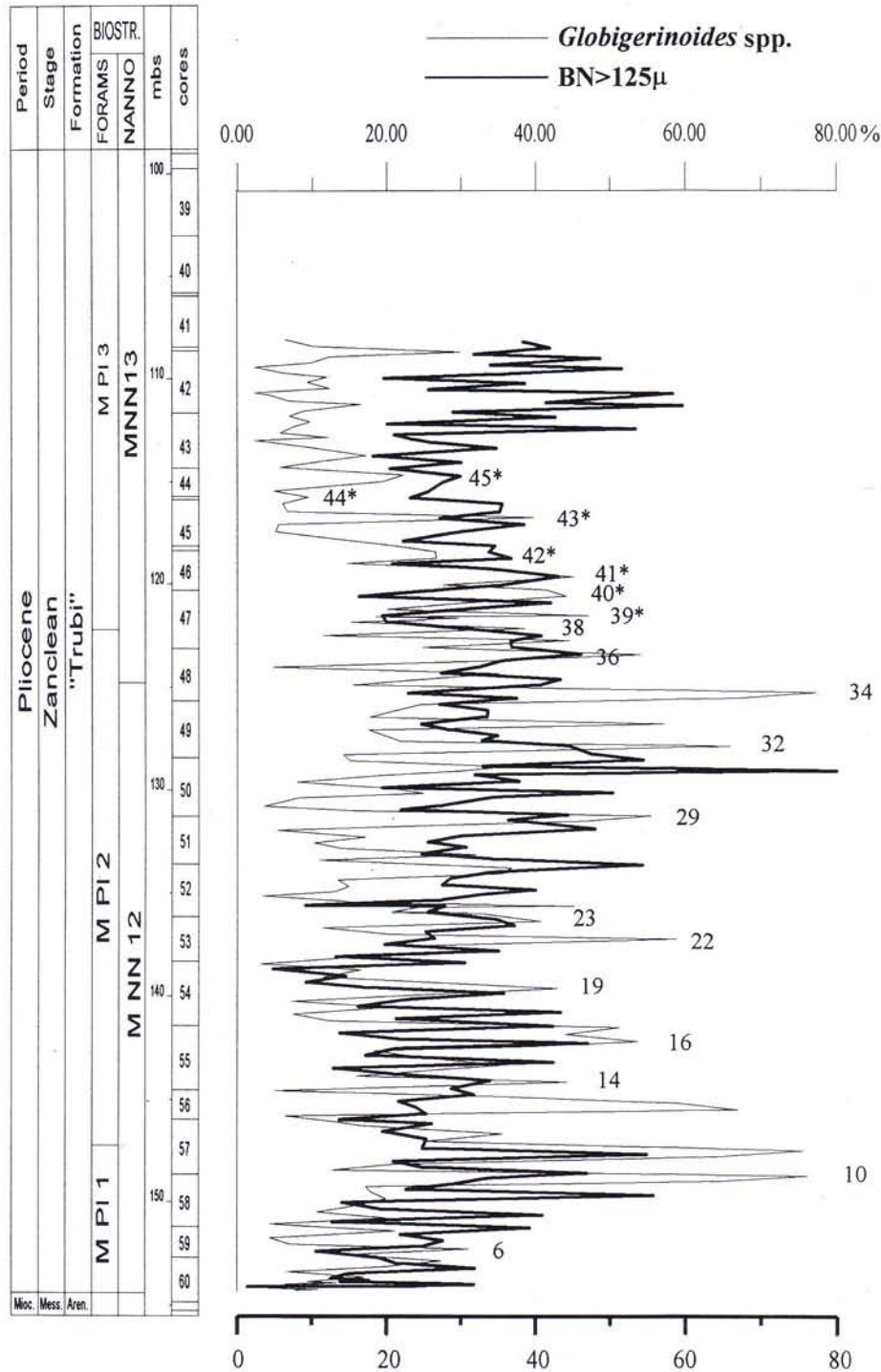


Fig. 15 - Stratigraphic distribution of *Globigerinoides* spp. BN > 125 μ m in the studied segment and comparison with the relative abundance fluctuations of *Globigerinoides* spp. Only some fluctuations are numbered for reference.

The assemblage fluctuations

Frequencies of *U. pygmaea*, abundant in the M Pl 1 biozone, of *C. bradyi-robertsonianus* *P. ariminensis* and *P. bulloides*, abundant in the M Pl 2 biozone, are plotted in Fig. 12. In the present paper also chemical data are reported in Fig. 12 and compared with *Uvigerina pygmaea* quantitative distributions. They show very high Fe_2O_3 and sulfur values in the same interval (M Pl. 1 biozone) and, therefore, support the previous interpretation of dysaerobic bottom conditions. High sulphur values are reported from all the sapropels of the Leg 160 Site 969 (Emeis et al., 1996).

P. bulloides is a well identified ecological marker, reported as a shallow infaunal species (Corliss, 1991; Rathburn & Corliss, 1994) and related to high flux of organic matter to the sea floor both in the North Atlantic (Haake et al., 1992; Mackensen et al., 1985) and in the South Atlantic (Mackensen et al., 1993). Conversely, *C. bradyi-robertsonianus* ecological data are not so clear, because usually the species *C. bradyi* and *C. robertsonianus* were grouped together. *C. robertsonianus* is reported as a typical species of North Atlantic Deep Waters (NADW) (Schnitker, 1994). *C. bradyi* is considered an intermediate infaunal (Corliss, 1991) to transitional infaunal species (Rathburn & Corliss, 1994), tolerant of low oxygen conditions (about 1.25 ml/l) in the deep-waters of the modern Sulu Sea (Miao & Thunell, 1993). Rathburn & Corliss (1994) pointed out that *C. bradyi* seems able to make use of limited or alternate food resources. Although this species is reported by these authors in areas with low organic carbon content, in the same area it is also recorded as abundant during glacial

had an estuarine circulation (Rio et al., 1990b) and bottom or intermediate Mediterranean water masses were not present in the North Atlantic (Hay, 1993). Possibly, this Mediterranean deep water originated as an intermediate layer above the cooler deep or intermediate Atlantic waters (NCW ?) present in the Mediterranean and their westward areal distribution was delimited by the presence of the Atlantic waters. We propose for this water mass the name of EPMIW (Early Pliocene Intermediate Mediterranean Water). On the base of the distribution of abundant *S. reticulata*, EPMIW was present until 2.5 Ma.

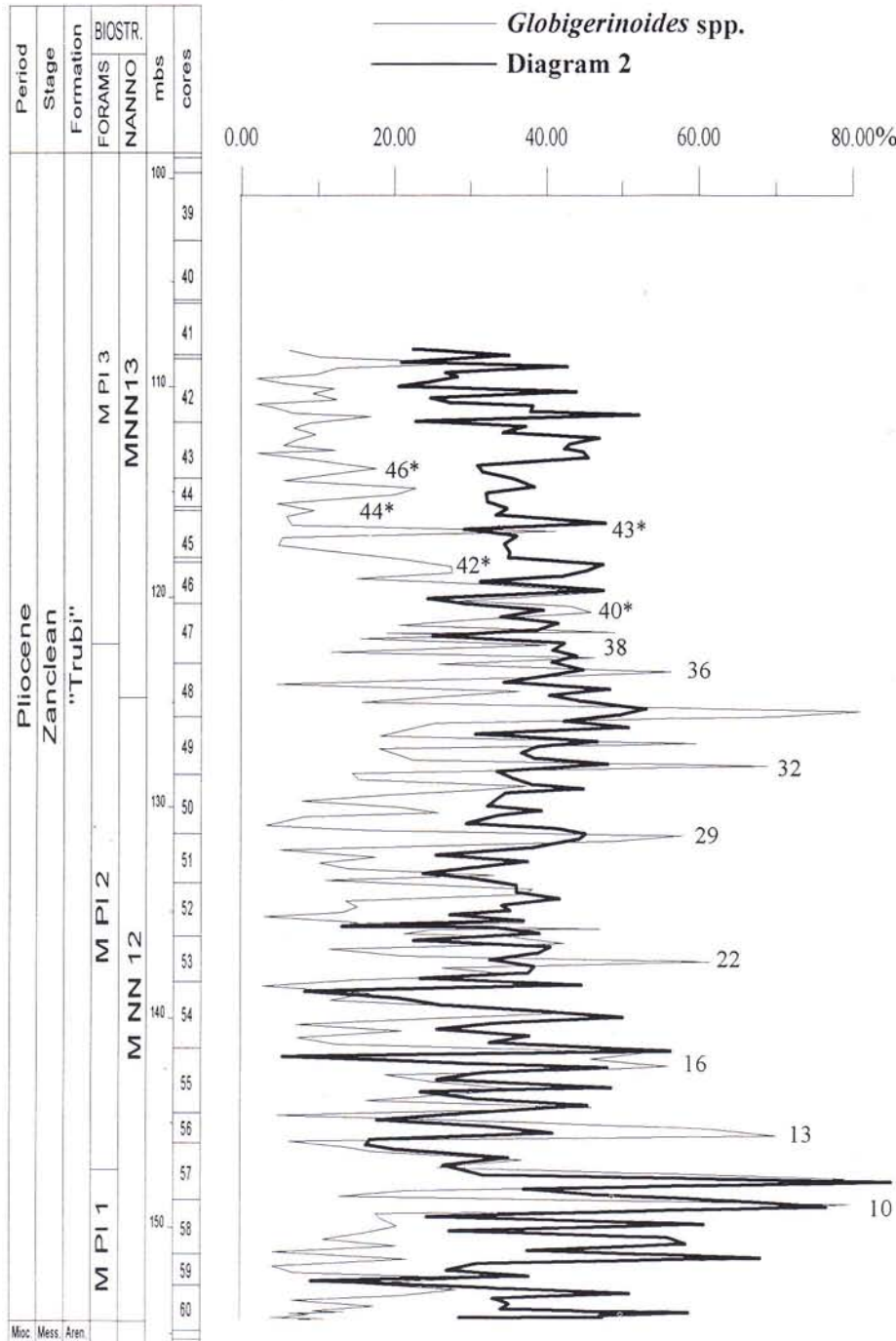


Fig. 16 - Comparison between the relative abundance fluctuations of *Globigerinoides* spp. and the total percent values of diagram 2. Only some fluctuations of *Globigerinoides* spp. are numbered for reference.

suspension feeding. Generally, elevated suspension feeders spreading pseudopodial net into the water ingested richer and fresher food particles originated from lateral advection and not depended on high vertical flux rates (Linke & Lutze, 1993).

Globigerinoides spp., indicative of warmer surface waters, are abundant in the marls, in good agreement with surface oxygen isotopic data from the outcropping sections of Sicily and Calabria, in which they are lighter in marly than in limestone beds (De Visser et al., 1989; Thunell et al., 1991; Van Os et al., 1994). Both data are indicative that surface waters were warmer and/or less saline in marly (gray) beds. These less dense surface waters could promote stratification of the water column and reduced deep mixing. Above the M PI 1 biozone, this mechanism induced a decrease of the intermediate Mediterranean water formation, testified by the relative abundance decrease of *S. reticulata*, balanced by the increase of the Atlantic intermediate or deep water in

conditions with a probably higher flux of organic carbon to the sea floor (Miao & Thunell, 1996). Consequently, it seems that *C. bradyi* can be considered an opportunistic species. The comparison with the sulphur and iron distribution shows that *C. bradyi-robertsonianus* increase in abundance, above the M PI 1 biozone, during intervals of relative high values of these elements (Fig. 12). Probably *C. bradyi* (which is more abundant than *C. robertsonianus* in the studied segment) is tolerant of slightly dysaerobic conditions due to increase in productivity or sluggish bottom circulation.

As stated before, *P. ariminensis* is an epibenthic foraminifer from elevated microhabitat and is considered a

the epibathyal zone, testified by the increased abundance of *P. bulloides*. Moreover, *P. ariminensis* testify the presence of food supply mostly originated from lateral advection. Consequently, during intervals characterized by peaks of the assemblage of Factor 6 (Fig. 16) the following two hypotheses are possible: 1) increase of the Atlantic colder deep water (NCW ?) in epibathyal zone and relatively increase in productivity (food supply) at the bottom due to lateral advection, and not necessarily related to high surface productivity; 2) enhanced preservation of organic matter at the bottom originated by the stratification of the water column with reduced deep-mixing.

Conclusion.

Quantitative analysis of closely spaced samples from the lower part of the bore-hole drilled across the "Trubi" marls at Punta di Maiata, near Capo Rossello (Sicily) allowed us to recognize several calcareous plankton biostratigraphic events. By correlation with the sequence of relative abundance fluctuations of *Globigerinoides* spp. and with the precessional astronomic record, their ages were obtained. They are well comparable with the ages proposed by Lourens et al. (1996), but the age of the FCO of *Gt. margaritae* is different, due to a different interpretation of this bioevent, which we recognize in coincidence with fluctuation 11 (lithologic cycle 10 of Hilgen, 1991) and not with fluctuation 13 (lithologic cycle 12 of Hilgen, 1991). If the relative abundance fluctuations of *Globigerinoides* spp. are labeled with progressive numbers, without "a" and "b" distinction for the fluctuations included in the thicker than normal lithologic cycles 6, 21, 22 and 41 of Hilgen (1991), 38 fluctuations are present between the base of the Pliocene and the FO of *Gt. puncticulata*, which coincides with the upper part of fluctuation 38. According to the relative abundance fluctuations present in the M Pl 1 segment of the bore-hole, two fluctuations are missing at the base of the Pliocene sequence, and therefore the very base of the Pliocene is locally not represented. The sediments corresponding to fluctuation 5 were lost in the core break between core 59 and core 60. For the first time the Pliocene FO of *H. sellii* was correlated to the sequence of relative abundance fluctuations of *Globigerinoides* spp. It coincides with fluctuation 35, with an age of 4.60 Ma.

Compared with planktonic relative abundance fluctuations, we have observed a relationship between fluctuations in the benthic foraminiferal assemblage and the astronomical record. $BN > 125 \mu\text{m}$ and *P. ariminensis* distributions seem related to the eccentricity of 400 kyr. *Siphonina reticulata*, *Cibicidoides bradyi-robertsonianus*, *P.*

ariminensis, *P. bulloides* and *U. pygmaea* relative abundance fluctuations seem related to the precessional record. High $BN > 125 \mu\text{m}$, which indicates periods of high productivity, follows intervals of high carbonate productivity. Increase in abundance of *P. ariminensis* indicates good bottom water circulation during maxima of eccentricity.

S. reticulata and *Globigerinoides* spp. fluctuations are generally antithetical. Above the M Pl 1 biozone, during maxima of *S. reticulata* the Mediterranean circulation was probably characterized, in the epibathyal zone, by deep-mixing and increased production of Mediterranean intermediate water. In contrast, the quantitative distribution of benthic assemblage of Factor 6 on one side and of *Globigerinoides* spp. on the other side are generally covariant. During maxima of this benthic assemblage, stratification of the water column and reduced deep mixing occurred in the epibathyal zone of the Mediterranean. In the M Pl 1 biozone, the dominance of *U. pygmaea*, together with high sulphur and iron content, indicate under-oxygenated bottom conditions, induced by sluggish bottom circulation and enhanced preservation of organic matter. Above the M Pl 1 biozone, the relative reduction of *S. reticulata* probably testifies the decreased formation of the Mediterranean intermediate water balanced by an increase or thickening of the Atlantic deep or intermediate water, testified by an increase in abundance of *P. bulloides* and *C. bradyi-robertsonianus*. This mechanism gave rise to an increase in productivity at the bottom due to the growth of the Atlantic water or to enhanced preservation of organic matter at the bottom, as consequence of stratification of the water column.

Acknowledgements.

This paper was supported by 40% funds to G. Bonaduce and by MURST 60% funds to R. Sprovieri. We thank W. Schwarzacher, who made available the results of the sedimentological and chemical analyses. The review of M.B. Cita, M. Howell, I. Premoli Silva and W. Schwarzacher greatly improved the manuscript.

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