Rivista Italiana di Paleontologia e Stratigrafia	volume 108	numero 2	pagine 275-287	Luglio 2002

BENTHIC FORAMINIFERA AS INDICATORS OF PALEOECOLOGICAL BOTTOM CONDITIONS IN THE SERRAVALLIAN TREMITI SECTIONS (EASTERN MEDITERRANEAN, ITALY)

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Received July 15, 2001; accepted Juanuary 9, 2002

Key-words: Middle Miocene, Tremiti Islands, eastern Mediterranean, benthic foraminifera, paleoecology.

Riassunto. L'analisi quantitativa dei foraminiferi bentonici della sezione composita dell'Isola di San Nicola (Isole Tremiti, Mare Adriatico), spessa circa 37 m e riferita al Serravalliano, ha evidenziato cambiamenti nelle condizioni paleoecologiche al fondo in quest'area del Mediterraneo orientale durante l'intervallo di tempo studiato. Le associazioni rinvenute, tipiche di ambiente batiale, indicano una paleobatimetria costante di circa 1.000 m. I cambiamenti nelle associazioni a foraminiferi bentonici hanno permesso di suddividere la sezione composita in cinque intervalli, che sono stati successivamente calibrati sulla scala astrocronologica per ricostruire l'evoluzione paleoambientale delle condizioni al fondo durante l'intervallo studiato. In particolare a partire dalla base della sezione, sono state individuate le seguenti differenti condizioni al fondo: 1) tra circa 12.62 e 12.29 Ma è stata individuata un'alta produttività di superficie con circolazione al fondo attiva e, di conseguenza, con un accumulo relativo di materia organica al fondo; queste condizioni si sono modificate parzialmente nell'intervallo tra circa 12.49 e 12.29 Ma, dove le associazioni bentoniche indicano condizioni al fondo instabili, caratterizzate da alternanza di circolazione attiva e circolazione rallentata, rispettivamente testimoniate dall'abbondanza relativa di *Cibicidoides wuellerstorfi* e da picchi di abbondanza del gruppo *Bulimina subulata*; 2) relativa ossigenazione e basso contenuto di materia organica tra circa 12.29 e 12.08 Ma; 3) condizioni deteriorate per aumento della produttività di superficie e/o maggiore preservazione della materia organica al fondo, testimoniate dall'abbondanza di *Uvigerina peregrina-pygmaea*, tra 12.08 e 11.81 Ma; 4) relativa ossigenazione e scarso apporto di materia organica tra circa 11.81 e 11.45 Ma; 5) condizioni simili a quelle della parte basale della sezione (12.62 - 12.29 Ma circa) tra circa 11.45 e 11.10 Ma, ma con un incremento dell' apporto di materia organica.

Infine, il confronto tra la ricostruzione paleoecologica della sezione composita delle Tremiti e quella della sezione composita di Ras il-Pellegrin a Malta, oggetto di un altro lavoro, nell'intervallo compreso tra circa 12.6 e 12.2 Ma, ha evidenziato paleobatimetrie stimate molto diverse, ma condizioni paleoecologiche al fondo piuttosto simili e produttività di superficie relativamente alta.

Abstract. Quantitative analysis of benthic foraminifera from the Serravallian S. Nicola composite section (Tremiti Islands, Adriatic Sea) and about 37 m thick, pointed out changes of bottom paleoecological conditions in this eastern Mediterranean area during the analyzed time interval. Benthic foraminiferal assemblages are typical of bathyal environment and indicate a constant paleobathymetry of about 1,000 m. Changes in benthic foraminiferal assemblages allowed us to identify five intervals, which were afterward calibrated on the astrochronological scale to reconstruct the paleoecological evolution of bottom conditions. In particular starting from the base of the section the following different bottom conditions have been identified: 1) between about 12.62 to about 12.29 Ma high surface productivity, active bottom water circulation and, consequently, moderate bottom food supply; this paleoenvironment slightly changed between about 12.49 and 12.29 Ma, where benthic assemblages testify unstable bottom conditions with periods of active circulation (relative abundance of *Cibicidoides wuellerstorfi*), alternated with periods of sluggish circulation (peaks of *Bulimina subulata* group); 2) relatively oxygenated paleoenvironment together with low food supply between about 12.29 and 12.08 Ma; 3) increase of organic matter content (abundance of *U. peregrina-pygmaea*), due to higher surface productivity and/or greater preservation of organic matter at bottom from 12.08 to 11.81 Ma; 4) relatively oxygenated conditions with low food supply from 11.81 to about 11.45 Ma; 5) similar conditions to those of the basal part of the section (about 12.62 - 12.29 Ma) from about 11.45 to 11.10 Ma, but with an increase of organic matter content.

Finally, the comparison between the paleoecological reconstruction of the S. Nicola composite section and Ras il-Pellegrin (Malta) composite section, reported in another paper in the interval between about 12.6 and 12.2 Ma, pointed out very different extimated paleobathymetries, but similar paleoecological bottom conditions as evidence of relatively high surface productivity.

Introduction

Benthic foraminifera have been used successfully for paleoenvironmental and paleoceanographic bottom reconstructions (Streeter 1973; Schnitker 1979; Gebhardt 1999; Sgarrella et al. 1999) since their Recent distribution is generally controlled by changes of bottom water properties, such as temperature, salinity, oxygen and food supply, and is also related to autoecology of species. Generally, species of different microhabitats indicate bottom oxygen and organic matter contents; in

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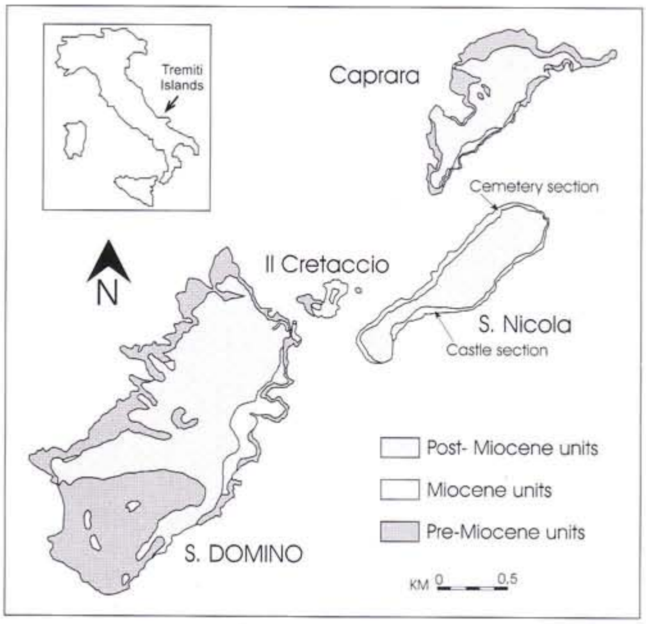


Fig. 1 - Location map of Cemetery and Castle sections.

fact epifaunal species are abundant in well oxygenated and food-limited environments (Corliss & Chen 1988; Corliss & Emerson 1990; McCorkle et al. 1990; Jorissen et al. 1992, inter alios), whereas infaunal taxa are able to live with low oxygen (Corliss 1985) and high organic matter contents. Therefore, bottom conditions affect the benthic foraminiferal assemblages. In fact, when bottom oxygen content values increase also the pore water oxygen concentration is higher and its penetration is deeper (Rutgers van der Loeff 1990) and favour the development of both epifaunal and infaunal assemblages. On the contrary, with bottom water low oxygen values and/or high organic matter content, oxygen of pore water decreases. According to Van der Zwaan & Jorissen (1991) infaunal species recorded in the sediment during periods of well oxygenated bottom waters are also able to change their microhabitat and to shift upward to epifaunal microhabitat during periods of low oxygen bottom content and very low oxygen penetration depth in the sediments. Consequently, many authors (Van der Zwaan & Jorissen 1991; Kaiho 1994; Jorissen et al. 1995; den Dulk et al. 2000) pointed out that benthic foraminifera are very good indicators of bottom oxygen content, which is inversely related to organic matter content.

According to Linke & Lutze (1993) epibenthic foraminifera from elevated microhabitat are considered indicative of good bottom circulation, since they are suspension feeding depending on food supply originated from lateral advection.

In this paper we report data on paleoecological analysis of benthic foraminiferal assemblages from Middle Miocene sections cropping out at the Tremiti Islands (Adriatic Sea, eastern Mediterranean Sea). The biostratigraphic reconstruction of these sections by means of calcareous plankton (Foresi et al. 2002a) indicates that the investigated time interval is comprised between the middle Serravallian and the basal Tortonian.

This study represents the second step of our investigations on Middle Miocene Mediterranean paleoecological and paleoceanographic evolution, which follows that concerning the faunal and geochemical study of the Ras il-Pellegrin composite section (Bellanca et al. 2002), cropping out at the Malta Island (central Mediterranean) and attributed to the upper Langhian - middle Serravallian interval by Foresi et al. (2002b).

Our major goals are: 1) the paleoecological reconstruction of the bottom water conditions in the eastern Mediterranean Tremiti area during the Serravallian, by means of benthic assemblages, and 2) the comparison of these results with those obtained in the coeval sediments of the central Mediterranean Malta area (Bellanca et al. 2002).

Materials

We studied the Cemetery and the Castle sections, which are located in the NW and SE sides, respectively of the S. Nicola Island (Fig. 1). The Cemetery section is 19 m thick . The Castle section has a total thickness of 26.03 meters and consists of two lower and upper subsections of 7.61 and 18.42 meters thick, respectively, separated by a shear plane. Bioturbations and scattered molluscs such as *Flabellipecten* and *Neopycnodonte* are present throughout the sections. More detailed stratigraphic informations on these sections are reported in Foresi et al. (2002a).

Correlation between the two sections was established on the base of the calcareous plankton events. Combining the two sections which partially overlap the S. Nicola composite section (Fig. 2) whose thickness is about 37 m thick, has been obtained (Foresi et al. 2002a; Lirer et al. 2002).

The S. Nicola composite section consists of deep-marine cyclically bedded hemipelagic sediments of Serravallian age. According to Lirer et al. (2002) it shows a quasi-regular rhythmic alternation of red-grey coloured less indurated, $CaCO_3$-poor-marly beds and whitish-coloured, $CaCO_3$-rich marly limestones (Fig. 2).

Methods

The benthic foraminiferal assemblages from 57 samples (Fig. 2; Tab. 1) have been studied and more precisely we analyzed 20 samples, from the base to 9 m, with the aim to correlate this interval with the coeval upper part of the Ras il-Pellegrin composite section, studied in greater detail by Bellanca et al. (2002). From 9 m up to the top, 37

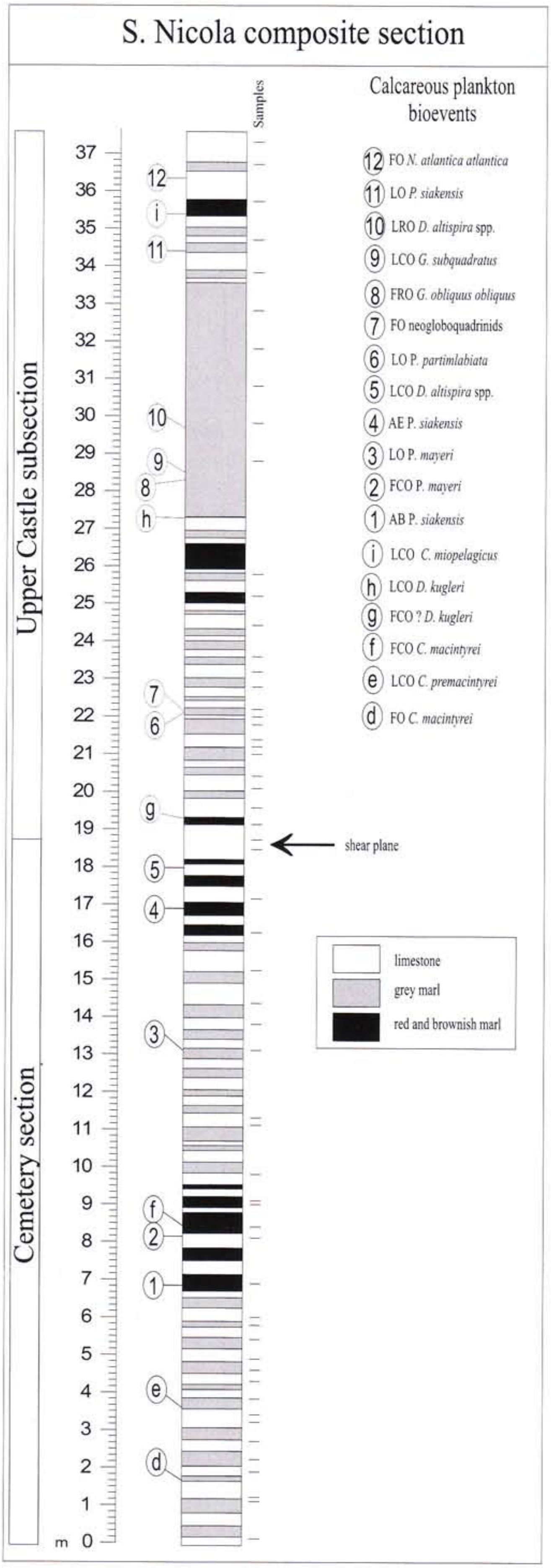


Fig. 2 - Location of the analyzed samples along the S. Nicola composite section. Lithology and calcareous plankton bioevents are reported.

S. Nicola composite section			
Cemetery section		upper Castle subsection	
Sample number	depth (m) composite section	Sample number	depth (m) composite section
0,1	0,10	113	18,70
1,1	1,10	117	19,10
1,2	1,20	121	19,56
1,8	1,90	125	20,08
2,2	2,20	127	20,37
2,6	2,70	133	20,97
3,2	3,20	135	21,17
3,4	3,40	137	21,37
3,7	3,80	141	21,77
4,3	4,30	143	21,97
4,5	4,60	145	22,17
4,9	4,90	151	22,77
5,4	5,40	155	23,19
5,6	5,80	159	23,59
5,8	6,00	167	24,39
6,7	6,90	175	25,19
7,9	8,10	181	25,79
8,2	8,40	211	28,79
8,8	9,00	221	29,79
8,9	9,10	231	30,79
9,6	9,80	241	31,79
10,9	11,10	251	32,79
11,1	11,30	261	33,79
12,9	13,10	284	34,69
19,1	13,80	294	35,69
20,0	14,35	304	36,69
21,0	15,25	310	37,29
22,1	16,25		
23,0	17,15		
24,3	18,45		

Tab. 1 - List of analyzed samples along the S. Nicola composite section.

more spaced samples have, been studied.

The samples analyzed from 25 m to the top of the section are relatively few and, therefore, it has not been possible to discriminate the influence of the astronomical forcing in the long-term paleoecological interpretation.

For each sample all the benthic specimens were picked out, identified and counted from the fraction > 125 μm. The fraction was split with a microsplitter to obtain a sub-sample containing more than 200 - 300 benthic specimens. Taxon abundance is expressed as percentage of the total fauna. The benthic number (BN) was calculated as the total number of specimens in the fraction >125 μm per gram of dry sediment and reported as BN >125 μm.

The quantitative data were elaborated by Q-mode Factor Analysis using CABFAC program (Imbrie & Kipp 1971; Klovan & Imbrie 1971).

Benthic foraminiferal analyses

Abundance

The distribution of BN > 125 μm along the S. Nicola composite section is reported in Fig. 3a. The average value is 471 specimens per gram of sediments. The BN > 125 μm shows a general increasing trend upward with peaks of highest values. Between 0 and 9 m the values range from 200 to 400, but in the upper part of this interval three peaks with values higher than 800 are recorded. Between 9 and 15 m the values range from 200 to about 400. Between 15 and 22 m peaks with values higher than 800-1,000 are recorded. Between 22 - 30 m the values range from 300 to 600, and finally, between 30 and 37.3 m BN > 125 μm shows an increasing trend, with values ranging from 500 to 800 and only one very high value of about 1,200 on the top of the section.

Species distribution

The distributions of abundant or common species are reported in Fig. 3 b-c. *Cibicidoides dutemplei* and *C. subhaidingerii* species are lumped together and are reported as *C. dutemplei* (the most abundant between these two species) because they show a very close similarity (Van Morkhoven et al. 1986) and are represented by many intergraded specimens, which are difficult to separate since they are not well preserved. Moreover, we lumped together *Uvigerina peregrina* and *U. pygmaea*, because they are difficult to separate for a quantitative analysis, since they occur with typical and well developed specimens, but many tests are broken and show only the initial part, which is similar in both species. Finally, we reported the *Bulimina subulata* group counting *B. subulata*, which is the most abundant species, together with *B. elongata* and *B. lappa*, which are subordinate species.

Species or group of species reported in Fig. 3b-c, show distinct fluctuations. *C. ungerianus* and *Lenticulina* spp. are constantly present with percentage values generally ranging from 5 to 10%.

The species *Uvigerina proboscidea* and *Cibicidoides dutemplei* (Fig. 3b) show similar distribution trends. They show highest percentage values in the lowest part of the section up to about 8 m and a slight increase from about 29 m up to the top of the section. Only *U. proboscidea* shows a further intermediate increase between 16 and 19 m.

The following species display fluctuating values along the section with three intervals of higher abundance (Fig. 3b): *Cibicidoides pachyderma* from 0 to 7 m, from 11 to about 17 m and from 21.5 m to the top; *Uvigerina rutila* from 0 to about 9 m; from 17 to 20 m and from 32 to 34 m; *Siphonina reticulata* from 2 to 3.6 m, from 11 to 16.5 m and from 28.5 m to the top; *Pullenia bulloides* from 6 to 9.5 m, from 17 to 21 m and from 25 m to the top; *Cibicidoides wuellerstorfi* from 6 to 11 m, from 21 to 23 m and a reduced third peak from about 30 to 35 m; *Uvigerina barbatula* from 8 to 16.5 m, from 22 to 23 m and from about 31 to 32 m. Moreover, *C. pachyderma*, *U. rutila* and *C. wuellerstorfi* show a superimposed upward decreasing trend.

Cibicidoides bradyi and *Bulimina subulata* group (Fig. 3b) are significant only in the lowest part of the section up to about 4 and 9 m respectively, and show a clear upward decrease.

The following species or group of species (Fig. 3c) are relatively abundant up to about 18-22 m and decrease upward: *Spiroplectinella carinata*, *Gyroidina* spp., *Bulimina minima*, *Cibicidoides incrassatus* and *Oridorsalis umbonatus*.

The middle part of the section (15-22 m) is characterized by abundance of *Uvigerina peregrina-pygmaea*, together with *Rotalia ecuadorana*, *Bulimina alazanensis*, *Hanzawaia boueana* and *Cibibidoides cicatricosus* (Fig. 3c). Among these species *R. ecuadorana* and *B. alazanensis* first occur from 13.8 and 19.5 m, respectively.

G. subglobosa, *Bolivina albatrossi* and *Bolivina reticulata* (Fig. 3c) are abundant in the upper part of the section from 22 m to the top. Among these species only *B. albatrossi* first occurs from about 22 m upward.

Moreover, we point out the rare occurrence of *Globocassidulina punctata* from 3.4 to 16.5 m. This species was instituted by Van Morkhoven et al. (1986) from Eureka core material (Gulf of Mexico) who reported an of Early Miocene (N 6) to Late Miocene (N 17) stratigraphic range.

Quantitative data treatment

The relative abundance of 31 species and 4 groups of species (comprehensive taxonomic units) in 57 samples were elaborated by Q-mode Factor Analysis. All the species with percentage values less than 2% have been discarded. Four factors have been rotated and they explain a total variance of 83%, with high communalities. Rotated Varimax Factor Scores are reported in Tab. 2. Varimax Factor Loadings are plotted in Fig. 4.

Factor 1, which explains a variance of 29%, is dominated by *U. barbatula, C. ungerianus, C. pachyderma, Lenticulina* spp., with *C. wuellerstorfi, C. dutemplei* and *S. carinata* as low scoring components.

Factor 2, which explains a variance of 25%, is dominated by *U. proboscidea*, with *U. rutila* as second low scoring component.

Factor 3, which explains a variance of 15%, is dominated by *Uvigerina peregrina-pygmaea*, with *R. ecuadorana, H. boueana, C. cicatricosus* and *C. ungerianus* as low scoring components.

Factor 4, which explains a variance of 14%, is dominated by *Bulimina subulata* group, with *O. umbonatus, Gyroidina* spp., *P. bulloides* and *U. rutila* as low scoring components.

Discussion

Paleobathymetry

The benthic foraminiferal assemblage, recorded all along the S. Nicola composite section, is represented by species typical of bathyal environment (see Murray 1991 and Van Morkhoven et al. 1986, for a review).

In particular, we point out the continuous and significant presence of *C. wuellerstorfi* (Fig. 3b), which shows percentage values up to 8%, but with an average zone of 3%. This species is characteristic of bathyal at depth greater than 1,000 m in the oceans (Murray 1991). Van Morkhoven et al. (1986) reported, as personal communication of Schnitker, percentage values of *C. wuellerstorfi* from about 1 to 4% at depths of 980-4,700 m in the North Atlantic. The percentage values of this species would indicate a wide paleobathymetric range, but the contemporaneous presence of *S. reticulata* and the abundance of *U. proboscidea* allow us to carry out a better paleobathymetric reconstruction. In fact, *S. reticulata* is recorded in Recent Mediterranean Sea between 80 and 1,000 m (Parker 1958; Bizon & Bizon 1984), and *U. proboscidea* is recorded as most common species at depths near 1,000 m in open oceans sites, particularly at low la-titudes (Boersma 1984). Therefore, we can estimate a paleobathymetry of about 1,000 m all along the composite section.

Benthic foraminiferal assemblages: paleoecological interpretation

Varimax Factor Loadings plotted along the S. Nicola composite section (Fig. 4) evidenced, four different assemblages:

- Assemblage 1 (Factor 1, Tab. 2): *U. barbatula, C. ungerianus, C. pachyderma, Lenticulina* spp. are dominant species together with *C. wuellerstorfi, C. dutemplei* and *S. carinata*, as relatively subordinate species. *U. barbatula* is considered a species tolerant of moderate oxygen deficiency (Borsetti et al. 1986), *C. ungerianus* and *C. pachyderma* are considered epifaunal and oxic species (Corliss 1985; Corliss & Chen 1988). In particular, *C. pachyderma* is recorded by Miao & Thunell (1993) in South China Sea when oxygen content increases and organic carbon decreases. In Mediterranean Sea this species is recorded (as *Heterolepa pseudongeriana*) as abundant in würmian sediments (Blanc-Vernet et al. 1983; Sgarrella 1988), when bottom waters were well oxygenated and with sufficient food supply due to increase of water mixing during cold periods. On the contrary, *Lenticulina* spp. are considered as suboxic indicators (Kaiho, 1994). *C. wuellerstorfi* is an epibenthic species from elevated microhabitats (Lutze & Thiel 1989), which according to Linke & Lutze (1993) is indicative of bottom water hydrodynamism. *C. wuellerstorfi* is also considered indicative of the North Atlantic Deep Water in Recent Oceans sediments (see a synthesis in Murray 1991); whereas it decreases in the Mediterranean during Late Pliocene (Sprovieri & Hasegawa 1990). *C. dutemplei* is considered as oxic species (Van der Zwaan 1982), but also tolerant of relatively low oxygen conditions (Sgarrella et al. 1999), whereas *S. carinata* is recorded as oxic species (Van der Zwaan 1982). Since most of previous reported species are considered oxic, whereas suboxic genera or species are subordinate, the Assemblage 1 may be considered an index of relatively oxygenated bottom waters.

- Assemblage 2 (Factor 2, Tab. 2): *U. proboscidea* is the dominant species together with *U. rutila* as subordinate species. *U. proboscidea* is reported by Boersma (1984) as most common species in open oceans sites at depths near 1,000 m, particularly at low latitudes, and as index for low rates of organic accumulation. On the other hand, abundance peaks of the same species in Late Neogene Indian Ocean DSDP Site 214 are inferred to represent times of high surface productivity and increased upwelling with input of organic carbon at bottom (Gupta & Srinivasan 1990; 1992). Gupta & Srinivasan (1990) pointed out that positive peaks of *U. proboscidea* are associated also to intensified bottom water circulation. *U. rutila* seems tolerant of moderate oxygen deficiency (Borsetti et al. 1986). Following more recent literature data of Gupta & Srinivasan (1990; 1992), we infer that Assemblage 2 testifies high surface productivity, input of organic carbon, but with active bottom water circulation and, consequently moderate bottom food supply.

- Assemblage 3 (Factor 3, Tab. 2): it is dominated by *Uvigerina peregrina-pygmaea*, with *R. ecuadorana, H. boueana, C. cicatricosus* and *C. ungerianus* as subordinate species. *U. peregrina- pygmaea* is indicative of high

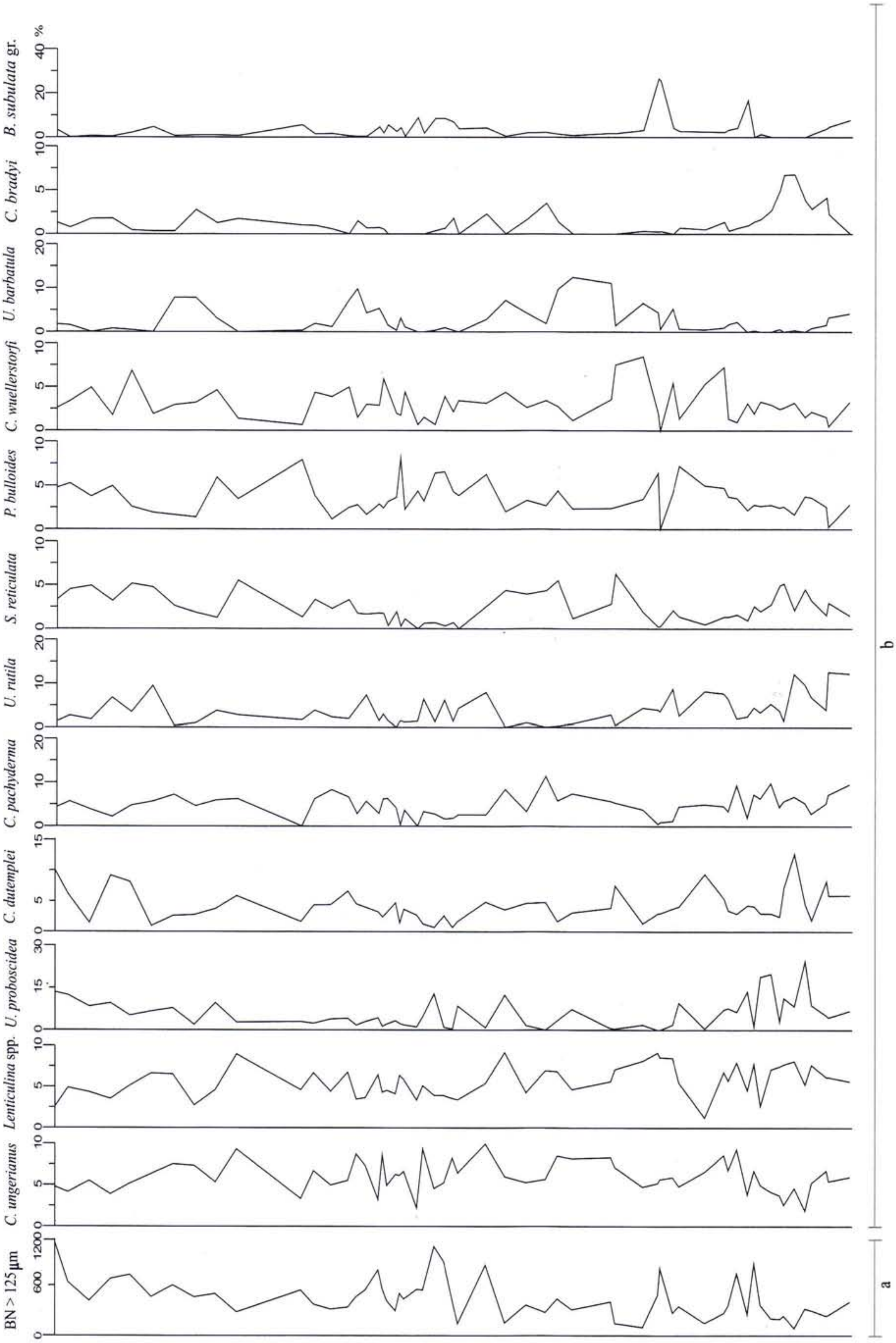
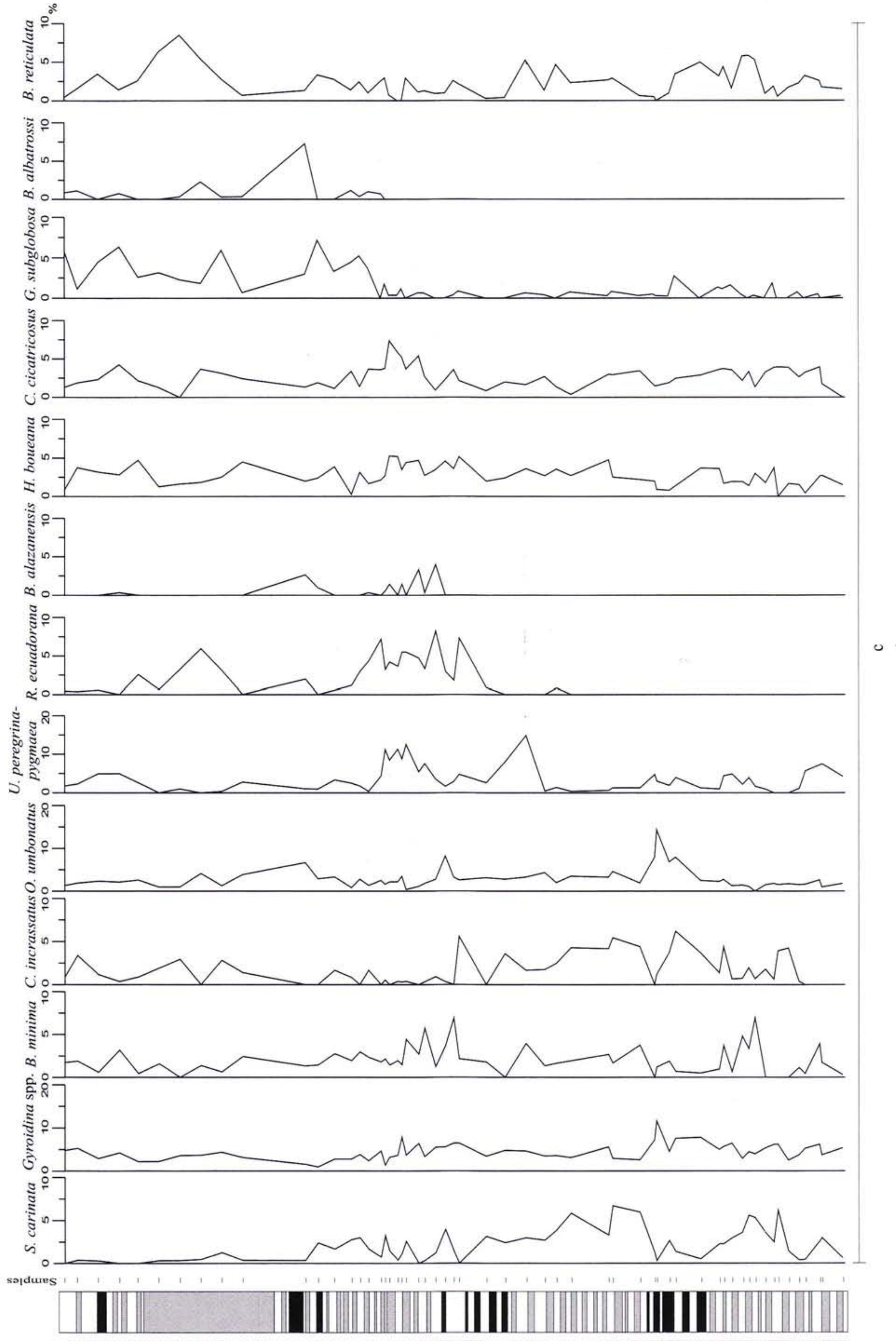


Fig. 3 - Fluctuations of BN > 125 µm(a) and relative abundance of the most significant benthic foraminifera taxa along the S. Nicola composite section (b-c).


c
B. reticulata
B. albatrossi
G. subglobosa
C. cicatricosus
H. boueana
B. alazanensis
R. ecuadorana
U. peregrina-pygmaea
O. umbonatus
C. incrassatus
B. minima
Gyroidina spp.
S. carinata
%
0
5
10
20
Samples
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
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17
16
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12
11
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9
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m

Taxa	1	2	3	4
Angulogerina angulosa	0,038	0,022	-0,003	0,02
Anomalinoides spissiformis	0,077	0,016	0,108	-0,051
Astrononion umbilicatulum	0,045	0,003	0,074	-0,023
Bolivina albatrossii	0,008	0,005	-0,016	0,043
Bolivina arta	0,037	0,048	0,141	0,001
Bolivina reticulata	0,147	0,068	0,052	-0,023
Bulimina alazanensis	-0,05	0,005	0,051	0,057
Bulimina costata	0,032	0,065	-0,04	0,177
Bulimina subulata group	-0,136	-0,025	-0,029	**0,777**
Bulimina minima	0,036	-0,004	0,171	0,068
Burseolina calabra	0,126	-0,008	-0,002	-0,019
Cassidulina laevigata	0,045	0,075	0,087	-0,043
Cibicidoides bradyi	0,071	0,105	-0,063	-0,004
Cibicidoides cicatricosus	0,057	0,032	**0,224**	0,04
Cibicidoides dutemplei	**0,231**	0,175	-0,003	0,015
Cibicidoides incrassatus	0,143	0,072	-0,087	0,006
Cibicidoides pachyderma	**0,357**	0,173	0,058	-0,161
Cibicidoides ungerianus	**0,378**	0,003	**0,21**	0,082
Cibicidoides wuellestorfi	**0,241**	0,029	0,053	-0,006
Globocassidulina subglobosa	0,097	0,078	0,019	-0,054
Gyroidina spp.	0,063	0,128	0,115	**0,259**
Hanzawaia boueana	0,064	0,008	**0,227**	0,054
Lenticulina spp.	**0,309**	0,12	0,04	0,148
Oridorsalis umbonatus	0,132	-0,036	-0,054	**0,32**
Pullenia bulloides	0,03	0,109	0,107	**0,221**
Rotalia ecuadorana	-0,078	-0,028	**0,333**	0,045
Siphonina reticulata	0,198	0,106	-0,016	-0,083
Sphaeroidina bulloides	0,068	-0,036	0,124	0,041
Spiroplectammina wrighti	0,052	-0,003	0,012	-0,019
Spiroplectinella carinata	**0,214**	-0,004	-0,042	0,017
Trifarina bradyi	0,038	0,028	0,06	0,004
Uvigerina barbatula	**0,421**	-0,147	-0,013	-0,053
Uvigerina peregrina-pygmaea	-0,142	-0,015	**0,746**	-0,028
Uvigerina proboscidea	-0,229	**0,881**	0,003	-0,072
Uvigerina rutila	0,186	**0,201**	-0,191	**0,219**

Tab. 2 - Benthic foraminiferal Varimax Factor Score matrix. The most significant variables are reported in bold.

organic matter bottom content (Lutze & Coulbourn 1984; Lutze 1986; Van Leeuwen 1986; Van der Zwaan et al. 1986; Altenbach 1988), which is inversely related to low oxygen content (Miller & Lohman 1982; Miao & Thunell 1993; Schnitker 1994). Among subordinate species, *H. boueana* is reported as tolerant of increased bottom salinity (Van der Zwaan 1982), *C. cicatricosus* is reported from South Atlantic DSDP Site 532 in area of coastal upwelling (Boersma 1984) and therefore it may be considered also tolerant of low oxygen bottom content, whereas *C. ungerianus* is an oxic indicator, as reported before. Therefore, this assemblage may be considered indicative of high food supply and/or greater preservation of organic matter bottom content.

- Assemblage 4 (Factor 4, Tab. 2): it is dominated by *Bulimina subulata* group, with *O. umbonatus*, *Gyroidina* spp., *P. bulloides* and *U. rutila* as subordinate species. *B. subulata* group is considered a species indicative of low oxygen bottom conditions (Cita 1973; Van der Zwaan 1982; Kaiho 1994; Bellanca et al. 2002). *O. umbonatus* is considered as opportunistic species by Sgarrella et al. (1997) since it is among the first re-colonizing species in the Mediterranean basin after the earliest Pliocene flooding. On the other hand, *O. umbonatus* is also recorded in bottom environments with low organic carbon content and relatively high oxygen values by Mackensen et al. (1985) and Miao & Thunell (1993). *P. bulloides* is considered indicative of high flux of organic matter to the bottom in the north Atlantic (Mackensen et al. 1985; Haake et al. 1992). *Gyroidina* spp. are typical of suboxic environments (Kaiho 1994), whereas *U. rutila* seems tolerant of moderate oxygen deficiency, as stated before. Tacking into account the clear dominance of *B. subulata* group in the Factor 4, we believe this assemblage is indicative of low bottom oxygen content.

Bottom conditions along the S. Nicola composite section

Varimax Factor Loadings plotted along the S. Nicola composite section (Fig. 4) display numerous fluctuations without a single trend and allow us to identify four principal changes in benthic foraminiferal assemblages which divide the S. Nicola composite section into five intervals, named with letter from A to E (Tab. 3). Each of them is characterized by high factor loadings, and by dominant, associated species, and also additional species (Tab. 3). These last are significant species only in a short segment of the interval. In Tab. 3 also BN >125 µm is reported for each interval, since its high values are generally related to increase in productivity (Berger & Diester-Haass 1988; Herguera & Berger 1991; Herguera 1992).

In Fig. 5 the five identified intervals are calibrated on astrochronological time scale, reconstructed by Lirer et al. (2002) through the tuning of sedimentary cycles to the different components of the insolation curve of Laskar et al. (1993).

Paleoecological interpretation of the five identified intervals together with their chronological attribution are reported below.

Interval A (0 - 9 m; 12.62 - 12.29 Ma about):

It is characterized by the Assemblage 2 (Factor 2) with dominance of *U. proboscidea* and subordinately by species of the Assemblage 1 (Factor 1), such as *C. pachyderma, Lenticulina* spp., *C. ungerianus* (Tab. 3). Among associated species also *Gyroidina* spp., considered suboxic indicators, are recorded. Between additional species, *C. bradyi*, an opportunistic species able to live both in oxic and suboxic environments (Sgarrella et al. 1999), and *S. reticulata* and *B. reticulata*, both reported as oxic species (Van der Zwaan 1982), are recorded. BN > 125 µm shows low values (Tab. 3).

In the upper part of this interval, starting from 4.5 m, alternance of *C. wuellerstorfi* and *B. subulata* group and two peaks of high values of BN >125 µm have to be pointed out.

Dominance of Assemblage 2 testifies high surface productivity, input of organic carbon, but active bottom water circulation and, therefore, moderate bottom food supply during Interval A. This active circulation is confirmed also by subordinate species of Assemblage 1, which indicate relatively oxygenated bottom conditions, and by low values of BN > 125µm, which seems to indicate a moderate bottom food supply.

The upper part of this interval corresponds to unstable bottom conditions, with periods of "normal" bottom oxygen content and good circulation, mostly testified by *C. wuellerstorfi*, alternated with periods of reduced bottom oxygen content and sluggish circulation, testified by *B. subulata* group peaks.

Interval B (9 -15 m; 12.29 - 12.08 Ma about)

It is characterized by dominance of the Assemblage 1 (Factor 1), with dominance of *U. barbatula, C. pachyderma, C. ungerianus* and *Lenticulina* spp., and by low values of BN >125 µm (Tab. 3). Dominance of Assemblage 1 indicates relatively oxygenated bottom waters and low food supply during Interval B.

Interval C (15 -22 m; 12.08 - 11.81 Ma about):

This interval is characterized by Assemblage 3 (Factor 3), dominated by *U. peregrina-pygmaea*, together with species of the Assemblage 4 (Factor 4) and subordinately of Assemblage 2 (Factor 2). BN > 125 µm shows high values (Tab. 3).

Therefore, the Interval C testifies high food supply and/or greater preservation of organic matter.

Interval D (22 - 30 m; 11.81 - 11.45 Ma about)

It is similar to Interval B, since most of species of the Assemblage 1 (Factor 1) are recorded (Tab. 3). In particular, *C. ungerianus* and *C. pachyderma* are dominant.

Nevertheless, following differences are recorded between these two intervals: 1) *S. carinata*, an associated species of the Interval B shows a decreasing trend in the upper part of the S. Nicola composite section start-

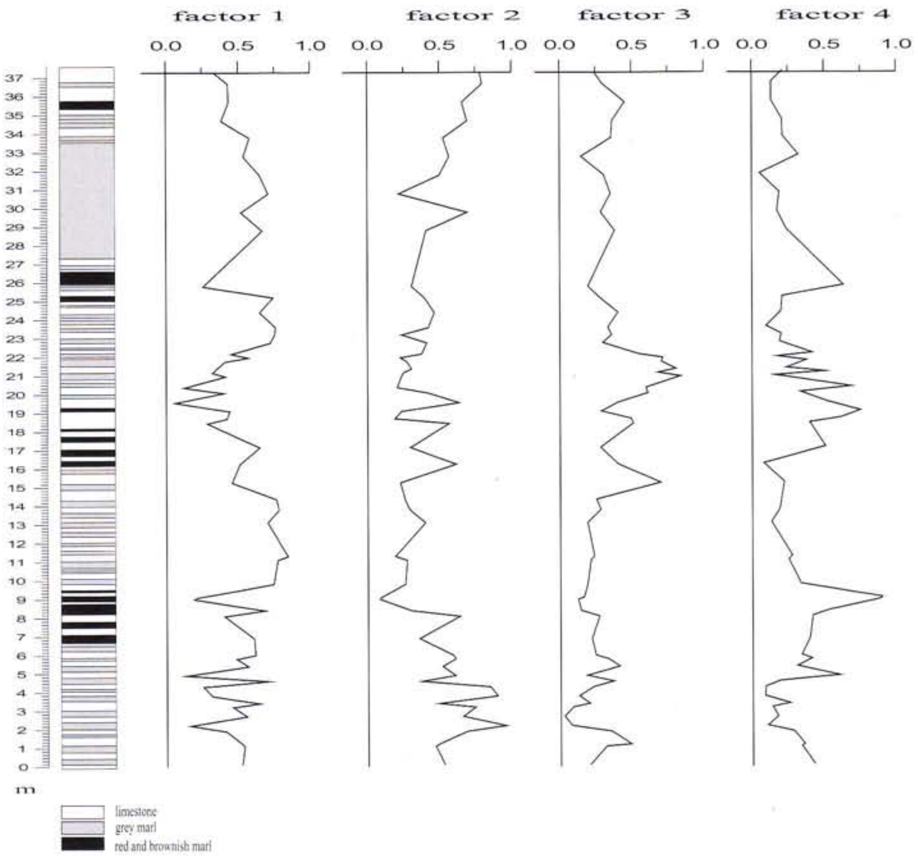

Fig. 4 - Stratigraphic distribution of Varimax Factor Loadings along the S. Nicola composite section.

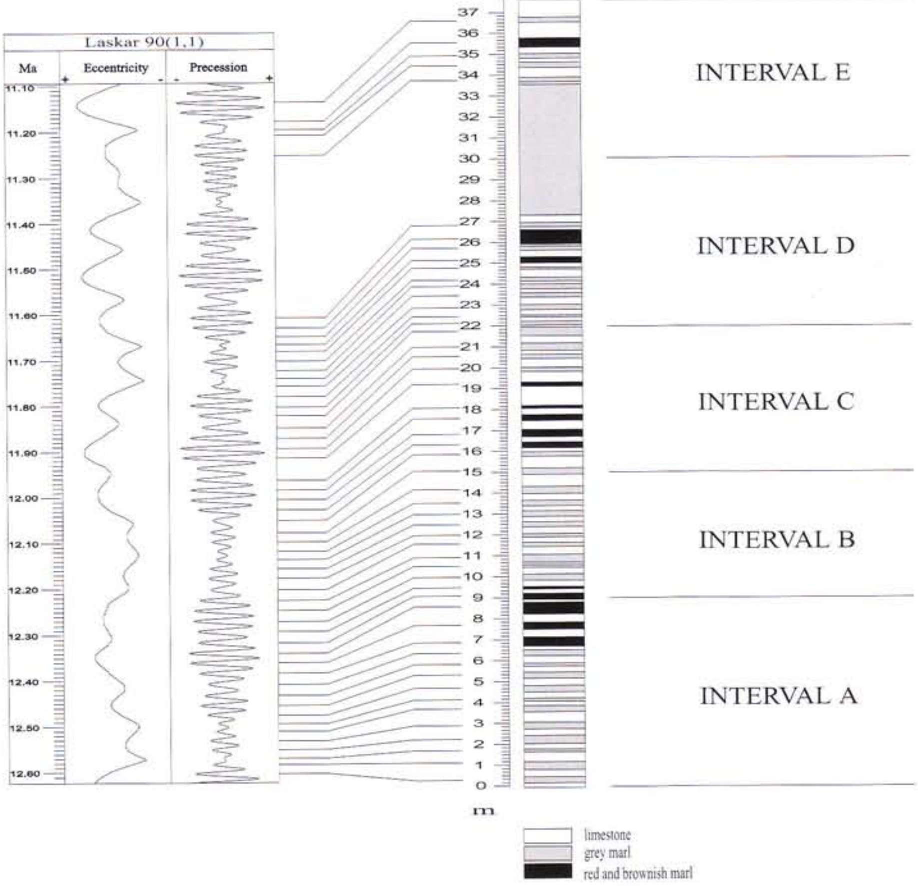

Fig. 5 - Intervals identified along the S. Nicola composite section by means of benthic foraminiferal assemblages, afterwards calibrated on the astrochronologic scale.

INTERVALS (m)		HIGH FACTOR LOADINGS	DOMINANT SPECIES	ASSOCIATED SPECIES	ADDITIONAL SPECIES	BN > 125μm
E	30 - 37.3	Factor 2	*U. proboscidea*	*C. ungerianus, C. pachyderma, Lenticulina* spp. and *C. dutemplei*	*C. wuellerstorfi, G. subglobosa, P. bulloides, B. reticulata, U. barbatula, U. rutila* and *S. reticulata*	Increasing trend average values 500 - 800
D	22 -30	Factor 1	*C. ungerianus* and *C. pachyderma*	*Lenticulina* spp. and *C. dutemplei*	*U. barbatula, U. rutila and G. subglobosa*	average values 300 - 600
C	15 - 22	Factor 3 and subordinately Factors 4 and 2	*U. peregrina-pygmaea*	*C. ungerianus, Gyroidina* spp., *Lenticulina* spp., *R. ecuadorana, B. subulata* and *H. boueana*	*U. proboscidea, U. rutila, P. bulloides* and *C. cicatricosus*	Peaks of abundance
B	9 - 15	Factor 1	*U. barbatula, C. pachyderma, C. ungerianus* and *Lenticulina* spp.	*S. carinata* and *S. reticulata*	*C. wuellerstorfi* and *C. dutemplei*	average values 200 - 400
A	0 - 9	Factor 2, subordinately factor 1. Upper part: factor 4.	*U. proboscidea*	*U. rutila, C. pachyderma, Lenticulina* spp., *C. ungerianus* and *Gyroidina* spp.	*C. dutemplei, C. bradyi, S. reticulata, S. carinata, B. reticulata.* Upper part: *C. wuellerstorfi* and peaks of *B. subulata*	average values 200 - 400. Upper part: peaks of abuncance.

Tab. 3 - Intervals identified along the S. Nicola composite section and characterized by: high factor loadings; dominant, associated and additional species; BN > 125 μm.

ing from about 19 m (Fig. 3c); 2) *G. subglobosa* becomes significant in this interval among additional species, and it relatively increases upward (Fig. 3c). This species is considered as opportunistic by Weston & Murray (1984) and by Sgarrella (Barra et al. 1998), as adapted to seasonal fluctuations of food supply by Gooday (1993), and as abundant in areas with high carbon content by Sen Gupta et al. (1981) and by Miao & Thunell (1993); 3) *C. wuellerstorfi* is not significative in the Interval D, whereas it is recorded as additional species in the Interval B (Tab. 3). Finally, relatively higher values of BN > 125 μm than Interval B are recorded (Tab. 3).

The Interval D may be considered as indicative of relatively oxygenated bottom waters, but with a slight increase of food supply compared to Interval B.

Interval E (30 - 37.3 m; 11.45 - 11.10 Ma about)

In this interval Assemblage 2 (Factor 2) dominates again, with abundance of *U. proboscidea*, togeher with species of Assemblage 1. Consequently, Interval E is similar to Interval A, which testifies high surface productivity and input of organic carbon, but active bottom water circulation. Nevertheless, significant presence of *P. bulloides* together with the opportunistic species *G. subglobosa* and high values of BN > 125 μm (Tab. 3) point out an higher food supply than Interval A.

Bottom conditions of Tremiti and Malta sections

The Tremiti and Malta composite sections are stratigraphically correlated and they overlapped between about 12.6-12.2 Ma (Lirer et al. 2001).

Comparison in this time interval between the reported paleoecological reconstruction of the basal part (Interval A) of the S. Nicola composite section and that of the coeval upper part of the Blue Clays Formation of the Malta composite section (Bellanca et al. 2002), points out very different extimated paleobathymetries, since a paleo-depth of about 1,000 m and of about 500 m have been inferred for the Tremiti and Malta composite sections, respectively.

Dominance of Assemblage 2 (dominant species: *U. proboscidea*) in the basal part of S. Nicola composite section is indicative of high surface productivity, input of organic carbon, but active bottom water circulation and, consequently, moderate bottom food supply. The inferred paleoecological bottom conditions from the whole Malta composite section point out generally under oxygenated environment, since the Blue Clays Formation is interpreted as deposited near or within a (paleo)Oxygen Minimum Zone (Bellanca et al. 2002). Moreover, according to the same authors, in the upper part of this composite section (about 12.6-12.2 Ma) the abundance of *U. peregrina* and geochemical data (Ba increasing trend) indicate a general increase in productivity and/or enhanced preservation of bottom organic matter content.

Therefore, similar paleoecological bottom conditions and relatively high surface productivity may be inferred for both Tremiti and Malta composite sections during the about 12.6-12.2 Ma time interval.

The continuous and significant presence of *C. wuellerstorfi* in the S. Nicola composite section is indicative of a cold Atlantic bottom water. In fact this species, recorded as characteristic of "true North Atlantic Deep Water" (NADW), is also recorded in Antarctic Bottom Water (AABW), and it is reported in oceans with temperature not exceeding 5 °C (see a synthesis in Murray 1991).

Consequently, relatively good connections and a "Gibraltar" paleo-sill deep enough to allow the relative abundance of *C. wuellerstorfi* in the eastern Mediterranean Sea are inferred to exist between Mediterranean and Atlantic during the Serravallian.

Conclusion

The benthic foraminifera from the Serravallian S. Nicola composite section (Tremiti Islands) indicate a constant paleobathymetry of about 1,000 m. The inferred paleoecological bottom conditions are the following: from the base of the section (about 12.62 Ma) up to about 12,29 Ma benthic foraminiferal assemblages testify high surface productivity, input of organic carbon, but active bottom water circulation and, consequently, moderate bottom food supply; in the upper part of this time interval, starting from 12.49 up to 12.29 Ma, benthic assemblages testify unstable bottom conditions with periods of active circulation alternated with periods of sluggish circulation. These conditions change upward (12.29 - 12.08 Ma about) to relatively oxygenated bottom conditions with low food supply. Upward (12.08-11.81 Ma) bottom conditions shift to high surface productivity and/or greater bottom preservation of organic matter. From about 11.81 -11.45 Ma relatively oxygenated bottom conditions and low food supply are again recorded, and finally from about 11.45 up to 11.10 Ma similar paleoecological bottom conditions to those of the basal part of the section are recorded again, but with an increased food supply.

The comparison between the basal part of the Tremiti composite section with the coeval upper part of the Malta composite section allowed us to point out very different estimated paleobathymetries (about 1,000 m and 500 m for Tremiti and Malta composite sections, respectively), but similar paleoecological bottom conditions and evidence of high surface productivity during the about 12.6- 12.2 Ma time interval.

The sigificant presence in the Tremiti composite section of *C. wuellerstorfi*, species indicative of lower bathyal depths and also typical of the Recent cold Atlantic water (as NADW and AABW), suggested the existence of relatively good connections between Mediterranean and Atlantic during the Serravallian and a "Gibraltar" paleo-sill, deep enough to allow the relative abundance of *C. wuellerstorfi* also in the eastern Mediterranean Sea.

Acknowledgements. We thank T. Kouwenhoven and A. Arnaud Vanneau for the critical review of the manuscript. Their partly followed suggestions improved this work. This research has been supported by MURST Cofin 1998.

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