



Paleoecology and paleoceanography of a Langhian succession (Tremi Islands, southern Adriatic Sea, Italy) based on benthic foraminifera

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KEY WORDS - Middle Miocene, Tremi Islands, Southern Adriatic Sea, Benthic foraminifera, Paleoecology, Paleoceanography.

ABSTRACT - The results of a detailed quantitative and statistical analysis on benthic foraminiferal assemblages from the Langhian Cretaccio composite section cropping out at Tremi Islands (southern Adriatic Sea, eastern Mediterranean Sea) are presented. The distribution patterns of the species allowed us to estimate a paleodepth of about 600 m for the entire composite section. The abundance curve of the oxic species indicates relatively well-oxygenated conditions of bottom water masses with a weak but gradual decline which culminates at about 37-38 m after the First Occurrence (FO) of *Orbulina suturalis*. The discontinuous distribution of *Cibicidoides wuellerstorfi* is suggested to be indicative of alternating episodes of active and relatively sluggish circulation of bottom water masses. Two major changes in the benthic foraminiferal assemblages are recorded along the succession. The first one occurring in correspondence of the lithological colour change at about 15 m is characterized by the sharp decrease of *Bulimina costata*, *Gyroidina* spp., *Hanzawaia boueana* and *Melonis barleeianum* testifying a decrease in productivity. The second one is more gradual and it is characterized by the regular increase of *Uvigerina semiornata* and *U. striatissima* from 8 m to 37-38 m indicating a gradual change in oxygen content. A third, less pronounced change concerns the last meters of the section, suggesting an amelioration of the bottom conditions. These changes are interpreted as the first response to paleoceanographic variations related to the closure of the connections between Tethyan and Indo-Pacific water masses. In term of chronology the section is estimated spanning the interval preceding the Paracme End (PE) of *Sphenolithus heteromorphus* (estimated approximately at 15.65 Ma) and postdating the FO of *O. universa* (dated at 14.36 Ma).

RIASSUNTO - [Paleoecologia e paleoceanografia di una successione langhiana (Isole Tremi, Mare Adriatico meridionale, Italia) basata sullo studio dei foraminiferi bentonici] - Lo studio quantitativo e statistico di dettaglio delle associazioni a foraminiferi bentonici di una successione (sezione composta del Cretaccio) del Miocene Medio (Langhiano) affiorante alle Isole Tremi (Mare Adriatico meridionale, Mediterraneo orientale) ha permesso di stimare la paleobatimetria e di riconoscere variazioni paleoecologiche e paleoceanografiche delle masse d'acqua al fondo, che si verificarono durante il Langhiano in questo settore del Mediterraneo orientale. In particolare l'abbondanza di *Uvigerina semiornata* ed *U. striatissima*, specie tipiche rispettivamente della piattaforma continentale-batiale superiore e del batiale medio, in associazione con *Bulimina reticulata*, *Cibicides lobatulus*/cf. *refulgens* e *Cibicidoides ungerianus* permette di stimare una paleobatimetria di circa 600 m per l'intera sezione composta. La curva di abbondanza delle specie ossiche indica condizioni al fondo relativamente ben ossigenate con un peggioramento lieve ma graduale che culmina a circa 37-38 m dopo la First Occurrence (FO) di *Orbulina suturalis*. La distribuzione discontinua di *Cibicidoides wuellerstorfi* permette di ipotizzare il susseguirsi, durante l'intervallo di tempo studiato, di episodi di circolazione attiva (presenza di *C. wuellerstorfi*) alternati con episodi di rallentamento relativo della circolazione (assenza di *C. wuellerstorfi*). I pattern di distribuzione delle specie mettono in evidenza due cambiamenti principali delle associazioni lungo la successione. Il primo si verifica in corrispondenza del cambio litologico di colore, a circa 15 m, ed è caratterizzato dalla improvvisa e forte diminuzione di *Bulimina costata*, *Gyroidina* spp., *Hanzawaia boueana* e *Melonis barleeianum*, che indica una diminuzione della produttività. Il secondo cambiamento è più graduale ed è caratterizzato dall'aumento regolare delle specie subossiche *Uvigerina semiornata* ed *U. striatissima* tra 8 m e 37-38 m, che testimonia una graduale e relativa riduzione del contenuto di ossigeno al fondo. Un terzo cambiamento delle associazioni, meno pronunciato, caratterizza la parte alta della successione e consiste in un aumento della percentuale delle specie ossiche ed in una riduzione di *U. semiornata* ed *U. striatissima*, che suggeriscono un miglioramento delle condizioni al fondo. Questi cambiamenti delle associazioni a foraminiferi bentonici, osservati lungo la successione della sezione composta del Cretaccio, vengono interpretati come una prima risposta alle variazioni paleoceanografiche controllate dalla chiusura delle connessioni tra le masse d'acqua tetidee ed indo-pacifiche. In termini di cronologia, è stato stimato che la sezione studiata copre l'intervallo di tempo che precede la fine del Paracme (PE) di *Sphenolithus heteromorphus* (stimato approssimativamente a 15.65 Ma) ed è successivo alla FO di *O. universa* (datata a 14.36 Ma).

INTRODUCTION

The Middle Miocene was a period of major paleoenvironmental and paleogeographic changes in the global oceanographic system (from the Indo-Pacific to Atlantic through the Tethys). The transition towards a thermohaline circulation system similar to the modern one occurred during this time interval (Woodruff & Savin, 1989; Roth et al., 2000; Nisancioglu et al., 2003). In fact, the paleoceanographic changes during Middle Miocene have been related to the intensification of deep Southern Component Water in relation to the expansion of the

Antarctic ice cap (Miller et al., 1991; Flower & Kennett, 1994).

The major paleogeographic event occurred in the Mediterranean Middle Miocene was the closure of the eastern connections between Tethyan and Indo-Pacific water masses, which culminated at about 14 Ma according to Rögl & Steininger (1983), Rehault et al. (1985), Steininger et al. (1985), Woodruff & Savin (1989), Ramsay et al. (1998), Rögl (2001).

The importance of benthic foraminifera as tool to study the modern and past oceans is widely documented, above all to monitor deep water-mass circulation, oxygen

variation, and organic flux supply. For a synthesis, the reader is referred to Bernhard & Sen Gupta (1999), Jorissen (1999), Loubere & Fariduddin (1999).

Many studies revealed a close relationship between benthic foraminiferal assemblages and water masses, in relation with their chemical and physical features (Lohmann, 1978; Miller & Katz, 1987; Woodruff & Savin, 1989; Iaccarino & Gaborardi, 1990; Boltovskoy et al., 1992; Jorissen et al., 1995; Smart & Ramsay, 1995; Schmiedl et al., 1997; Yasuda, 1997; Bellanca et al., 2002; Russo et al., 2002; Sprovieri et al., 2004). In particular, Kaiho (1991, 1994) showed the relationships between oxygen concentration of bottom water masses and benthic foraminiferal assemblages, and Gooday (1993), Loubere & Fariduddin (1999), Van der Zwaan et al. (1999) pointed out that the organic matter supply is one of the factors which exerts an important control on the distribution of benthic assemblages.

In this paper the benthic foraminifera have been used as proxy to evaluate the main paleoecological and paleoceanographic changes of the bottom water masses occurred in the Mediterranean during the Langhian.

This study represents a first contribution of a multidisciplinary Italian research project on Mediterranean Middle Miocene, whose purpose is to better constrain the age of the closure of the eastern Tethys and to point out the biological response to this geodynamic event through biostratigraphy (planktonic foraminifera and calcareous nannoplankton), magnetostratigraphy and cyclostratigraphy, geochemistry (stable isotopes analyses) and benthic foraminiferal paleoecology.

The results obtained from the quantitative and statistical study of benthic foraminifera of the Cretaccio composite section cropping out at the Tremiti Islands (southern Adriatic Sea) are presented.

GEOLOGICAL SETTING AND GEOGRAPHIC LOCATION

As far as it concerns the stratigraphy of Tremiti Islands, the reader is referred to Selli (1971), who described in detail the Paleocene to Quaternary sedimentary sequence exposed at the Tremiti Islands. This author distinguished three pre-Neogene formations, cropping out mainly at S. Domino and Caprara islands, and two marine Neogene formations, the Cretaccio Formation and the S. Nicola Formation, cropping out the first mainly at Cretaccio Islet and along the steep slopes of S. Nicola Island, the second only at the homonymous island. According to Selli (1971) and Cotecchia et al. (1996) the Cenozoic marine sediments are capped by Quaternary continental conglomerates, strips of loess and calcareous crusts (caliches) of middle to late Pleistocene age. The Miocene succession shows a general SE dipping monocline structure, characterized by an intense fracturing and variously oriented subvertical faults, related to prevailing extensional tectonic (see Iaccarino et al., 2001). The Miocene sedimentary sequence (Cretaccio Fm.) starts with green/red doloarenites, which represent the base of the transgression, whose precise age is not detectable because the basal sediments do not contain microfossils; the first fossiliferous layers containing few planktonic foraminifera and calcareous nannofossils occur few meters above the base of the transgression, and are referable to the lower Langhian (Foresi et al., 2001; Iaccarino et al., 2001). According to these authors it is possible that the transgressive event could have begun during the late Burdigalian, as reported for a similar sedimentary sequence cropping out at the Salento area, South of the Tremiti Islands (Bossio et al., 1987, 1988).

A schematic map with the main geological units of Tremiti Islands is reported in Fig. 1a. The composite section analyzed for this paper crops out at the Cretaccio

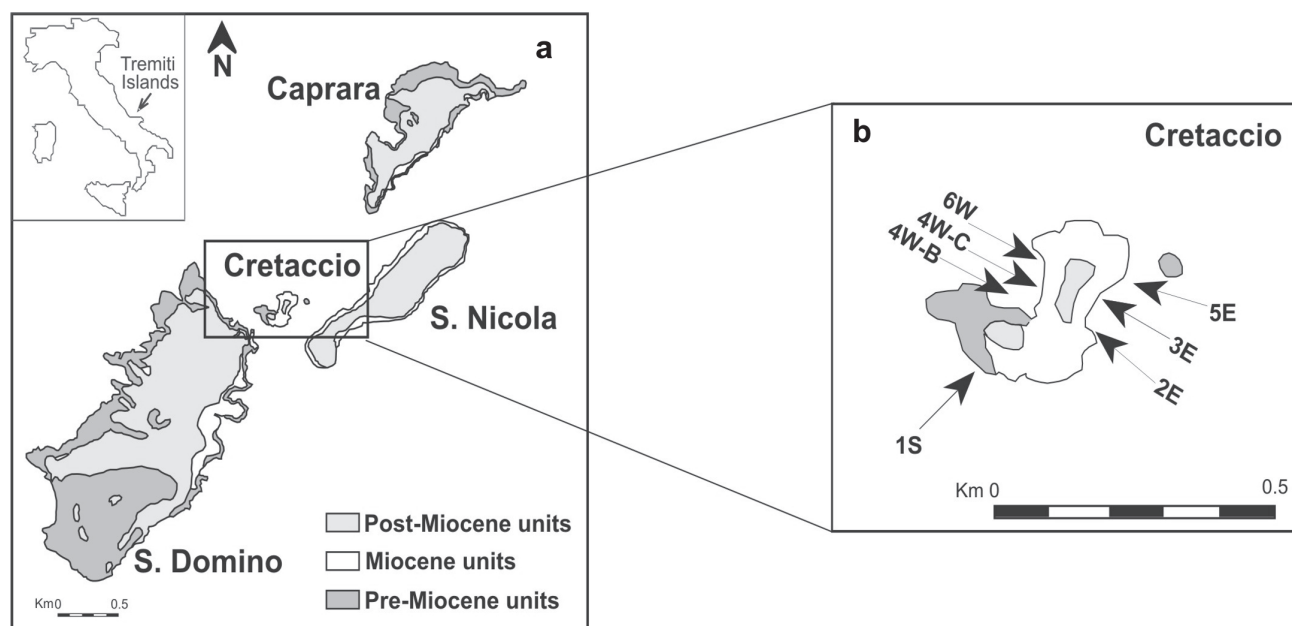


Fig. 1 - a) Geographic location of the investigated area and schematic geological map of the Tremiti Islands (modified by Lirer et al., 2002); b) geographic location of the analyzed seven subsections cropping out at the Cretaccio Islet.

Islet (Fig. 1b) and consists of seven subsections as follows: Subsection 1S at the southern side, Subsections 2E, 3E, 5E at the eastern side, and Subsections 4W-B, 4W-C, 6W at the western side. Geological field survey, the presence of biostratigraphic markers, ash layers, and sedimentary cyclicity allowed the correlation of the seven partially overlapping subsections and the reconstruction of the composite section (Fig. 2), which is about 45 m thick and entirely referred to the Langhian (Iaccarino et al. 2001, Di Stefano et al. in press).

LITHOLOGY AND BIOSTRATIGRAPHY

Iaccarino et al. (2001) distinguished four lithofacies in the Cretaccio Fm., of which the first three are well exposed at Cretaccio Islet: the *lithofacies 1* represents the base of the transgressive sequence and consists of glauconitic doloarenites intensely coloured (red or green), including some horizons rich in fish teeth; the *lithofacies 2* consists of ochraceous-yellow dolomitic sandy limestones grading upwards into calcareous sandy marls locally thinly stratified and with sparse glauconites; the *lithofacies 3*, the most representative of the Cretaccio Fm., consists of alternating whitish homogeneous more indurated marls and light grey marls. The *lithofacies 4*, outcropping only at S. Nicola Island, consists of biocalcarenes very rich in glauconites and in macrofossils (*Neopycnodonte* and *Flabellipecten*). The Cretaccio composite section studied in this paper is described by Di Stefano et al. (in press) as a nearly regular rhythmic alternation of indurated yellow dolomitic marls and yellow dolomitic marls and/or distinct grey marls corresponding to the *lithofacies 2*, and indurated whitish marls and soft grey marls corresponding to the *lithofacies 3* (Fig. 2); the distinct colour change from yellow/grey to whitish/grey is recorded at 15.24 m. Three distinct ash layers at about 10 m, 23 m and 30 m, two reddish dolomitic marly levels at about 6 m and 9 m and two calcareous turbidite layers at about 36.5 m and 39 m are also distinguished (Fig. 2) by Di Stefano et al. (in press).

The main calcareous plankton events (planktonic foraminifera and calcareous nannofossils) occurring within the investigated interval are the *Paragloborotalia siakensis* Acme a Base (A_B) at 4.09 m, *P. siakensis* Acme a End (A_E) at 9.35 m, *Praeorbulina glomerosa* First Occurrence (FO) at 19.28 m, *Paragloborotalia siakensis* Acme b Base (A_B) at 24.65 m, *Praeorbulina circularis* FO at 24.98 m, *Orbulina suturalis* FO at 32.82 m, *O. universa* FO at 40.97 m, *Sphenolithus heteromorphus* Paracme End (PE) at 5.2 m, *Helicosphaera waltrans* First Common Occurrence (FCO) at 6.34 m, *H. waltrans* Last Occurrence (LO) at 45.06 m (Di Stefano et al., in press). The ages of these events have not been calibrated astronomically since the tuning of the sedimentary cyclicity is still in progress. Therefore, the Langhian Cretaccio composite section (Fig. 2) is constrained between the planktonic foraminiferal Subzones MMi4b and MMi5b, and calcareous nannoplankton Zones MNN4b and MNN5b (Di Stefano et al., in press).

In term of chronology, the section is estimated spanning the interval preceding the PE of *S. heteromorphus* (estimated approximately at 15.65 Ma in Lourens et al., 2004) and post dating the FO of *O. universa* (dated at 14.36 Ma by Lourens et al., 2004).

MATERIAL AND METHODS

Benthic foraminiferal analyses were performed on 125 samples (Tab. 1) collected both in the yellow *lithofacies 2* and in the whitish/grey *lithofacies 3*. Sample spacing generally ranges from 20 to 40 cm, but it is closer (down to 2 cm) in 5E Subsection (Tab. 1). Moreover, the indurated yellow dolomitic marls and the indurated whitish marls, which should represent the undisturbed marine sediments (Guasti et al., 2004), were investigated with more detail.

The samples were processed using standard laboratory procedures. They were washed and sieved into two size fractions (mesh sizes 63 μ m and 125 μ m). The fraction >125 μ m was then splitted by an Otto microsplitter to obtain a representative fraction, preferentially containing 200-300 benthic foraminiferal specimens. These specimens were picked out, identified at specific or supraspecific level, counted and stored in Chapman slides.

Generally, all samples are rich in foraminifera; their preservation is usually good in the indurated whitish marls and soft grey marls, poorer in the yellow interval (Subsections 1S and 2E), where recrystallized and sometimes deformed tests often occur. In particular, samples from 0-1.95 m interval are barren or contain very scarce and badly preserved benthic foraminiferal assemblages and, therefore, not reliable for quantitative analysis. From 2 m to 8 m the data are too scanty to be interpreted. Quantitative analyses were carried out on both indurated marls and marls in order to establish long- and short-term variations in the benthic foraminiferal trends.

The dataset was utilized to obtain the following parameters:

- plankton/benthic ratio (P/B ratio), calculated as the percentage of planktonic specimens on the total foraminiferal assemblage [%P = $100 \times P / (P+B)$]. The P/B ratio used to estimate the paleobathymetric evolution follows the formula of Van der Zwaan et al. (1990);
- benthic number (BN), expressed as the total number of benthic specimens in the fraction >125 μ m per gram of dried sediment ($BN_{>125 \mu m}$ = total number of specimens/dried sample weight). This parameter is useful to assess the paleoproductivity trend (Herguera & Berger, 1991; Herguera, 1992);
- relative frequencies of the different taxa;
- percentage of oxic species, calculated as $100 \times O / (O+S)$, where O are the oxic species and S the suboxic ones mainly following the classification established by Kaiho (1994) based on the modern species.

The principal component (PCA) and the hierarchical cluster analyses were performed only on the samples taken from the indurated yellow marls and indurated

Cretaccio composite section

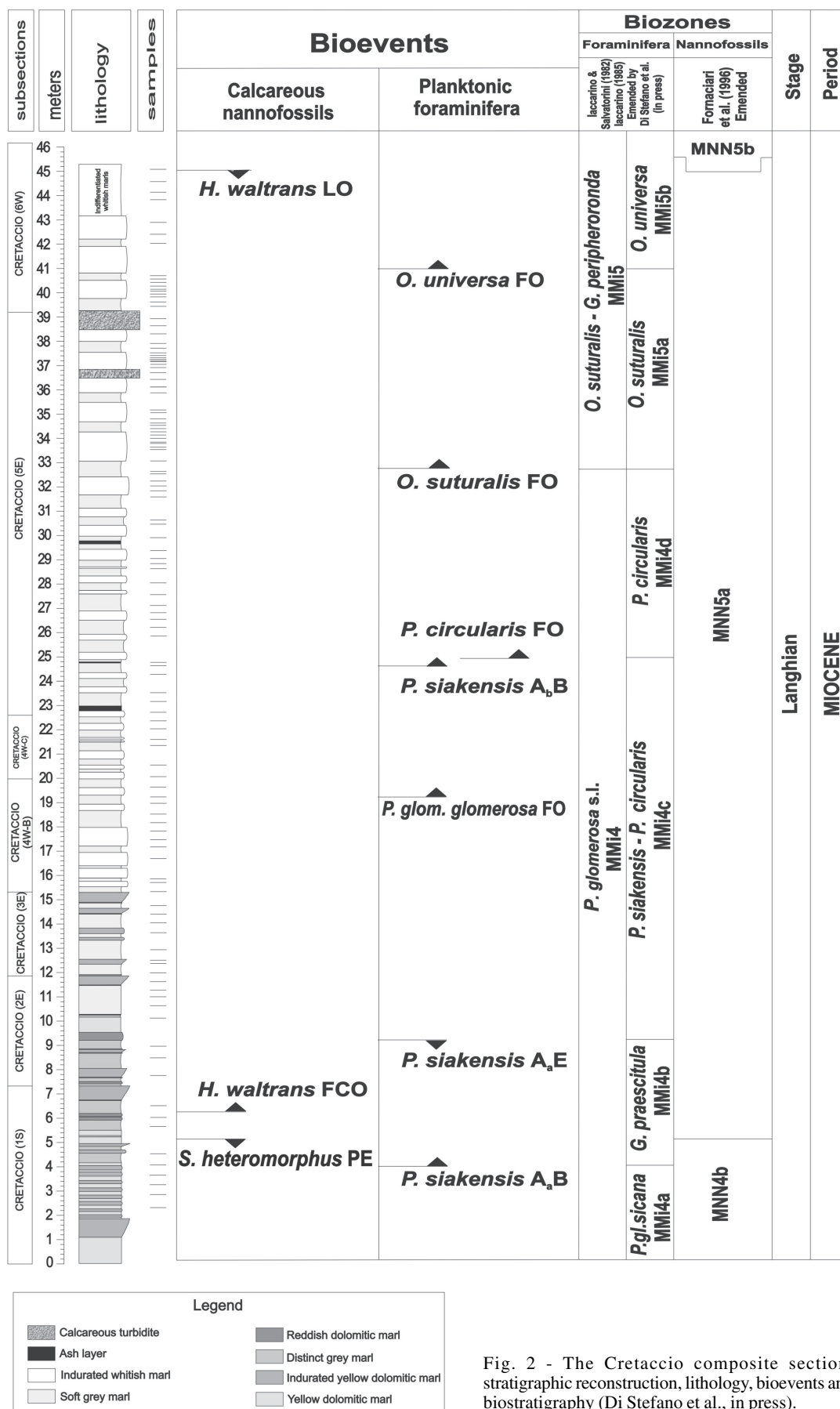


Fig. 2 - The Cretaccio composite section: stratigraphic reconstruction, lithology, bioevents and biostratigraphy (Di Stefano et al., in press).

sample	subsection	stratigraphic position (m)	relative thickness (cm)	lithology	sample	subsection	stratigraphic position (m)	relative thickness (cm)	lithology
92	5E	28.69	18	SGM	56	6W	44.84	32	IWM
91		28.51	79	SGM	53		44.52	36	IWM
85		27.72	18	SGM	50		44.16	34	IWM
84		27.54	23	IWM	47		43.82	40	IWM
82		27.31	50	SGM	43		43.42	43	IWM
78		26.81	32	SGM	39		42.99	37	IWM
75		26.49	17	IWM	36		42.62	24	IWM
74		26.32	22	SGM	34		42.38	76	IWM
72		26.10	66	SGM	27		41.62	34	IWM
66		25.44	47	SGM	24		41.28	45	IWM
61		24.97	61	IWM	19		40.83	32	IWM
56		24.36	28	SGM	16		40.51	37	SGM
53		24.08	31	IWM	12		40.14	36	IWM
51		23.77	29	SGM	7		39.78	38	IWM
49		23.48	33	IWM	3		39.40	30	SGM
46		23.15	60	SGM	0		39.10	84	SGM
40		22.55	63	IWM	184	5E	38.26	41	IWM
242	4W-C	21.92	37	IWM	180		37.85	39	SGM
237		21.55	76	IWM	178		37.46	127	SGM
230		20.79	37	IWM	173		36.19	07	IWM
226		20.42	59	IWM	172		36.12	07	IWM
217	4W-B	19.83	34	SGM	171		36.05	08	IWM
213		19.49	34	IWM	170		35.97	07	IWM
210		19.15	44	SGM	169		35.90	04	IWM
205		18.71	25	IWM	168		35.86	11	IWM
202		18.46	13	SGM	167		35.75	11	SGM
201		18.33	68	SGM	166		35.64	23	SGM
194		17.65	48	IWM	164		35.41	23	SGM
186		17.17	42	IWM	163		35.18	50	IWM
180		16.75	40	IWM	154		34.68	31	IWM
174		16.35	27	IWM	152		34.37	24	SGM
171		16.08	45	IWM	150		34.13	41	IWM
165		15.63	39	IWM	146		33.72	19	IWM
154		15.24	31	IYDM	144		33.53	19	IWM
147		14.93	48	IYDM	142		33.34	10	IWM
141		14.45	84	IYDM	141		33.24	08	IWM
133	3E	13.61	35	IYDM	140		33.16	09	IWM
129		13.26	18	SGM	139		33.07	07	IWM
127		13.08	58	SGM	138		33.00	02	IWM
121		12.50	34	IYDM	137		32.98	19	IWM
118		12.16	77	SGM	136		32.79	13	SGM
111		11.39	72	SGM	135		32.66	21	SGM
105		10.67	43	SGM	133		32.45	28	SGM
101		10.24	12	AL	131		32.17	26	IWM
99	2E	10.12	40	YDM	129		31.91	19	IWM
95		9.72	38	YDM	127		31.72	45	IWM
92		9.34	34	RDM	121		31.27	05	SGM
89		9.00	27	DGM	120		31.22	13	SGM
87		8.73	38	IYDM	118		31.09	12	SGM
84		8.35	51	DGM	117		30.97	04	IWM
80		7.84	168	IYDM	116		30.93	06	IWM
339		6.16	50	RDM	115		30.87	07	IWM
332	1S	5.66	35	DGM	114		30.80	07	IWM
326		5.31	113	YDM	113		30.73	06	IWM
310		4.18	46	DGM	112		30.67	04	IWM
302		3.72	42	IYDM	110		30.63	07	SGM
296		3.30	41	IYDM	111		30.56	06	SGM
293 bis		2.89	40	YDM	109		30.50	10	SGM
289		2.49	54	IYDM	108		30.40	10	SGM
281		1.95		IYDM	107		30.30	31	SGM
					103		29.99	53	IWM
					98		29.46	12	SGM
					97		29.34	23	SGM
					96		29.11	19	IWM
					94		28.92	23	IWM

Tab. 1 - List of the examined samples: sample number, subsection, stratigraphic position, relative thickness, lithology (YDM = yellow dolomitic marl; IYDM = indurated yellow dolomitic marl; DGM = distinct grey marl; RDM = reddish dolomitic marl; SGM = soft grey marl; AL = ash layer; IWM = indurated whitish marl; CT = calcareous turbidite).

whitish marls in order to focus our attention on the long-term variations of the benthic assemblages (Guasti et al., 2004).

BENTHIC FORAMINIFERAL DATASET

P/B ratio

The percentage of planktonic foraminifera on the total assemblage (P/B ratio) was obtained plotting only the data from indurated yellow marl and indurated whitish marl samples (Fig. 3a). As shown in Fig. 3a the %P values prevalently range from 80% to 90%, with lower values occurring between 32 m and 38 m (values from 61% down to 35%).

BN >125 µm

The BN >125 µm curves obtained plotting separately the whole dataset (Fig. 3b) and only the data from indurated yellow marl and indurated whitish marl samples (Fig. 3c) show a slight decreasing-upwards trend with average values ranging from 100 to 300.

Species distribution patterns

Benthic foraminiferal assemblages are represented by 49 species, referred to the genera *Anomalinoidea*, *Astronion*, *Bigenerina*, *Bolivina*, *Bulimina*, *Cassidulina*, *Chilostomella*, *Cibicidoides*, *Ehrenbergina*, *Epistominella*, *Eponides*, *Globobulimina*, *Globocassidulina*, *Hanzawaia*, *Karreriella*, *Martinottiella*, *Melonis*, *Neoeponides*, *Oridorsalis*, *Pleurostomella*, *Pullenia*, *Sigmoilopsis*, *Siphonina*, *Sphaeroidina*, *Spiroplectammina*, *Spiroplectinella*, *Textularia*, *Uvigerina*, *Vulvulina*, and by other five taxonomic units, such as *Cibicides lobatulus*/cf. *refulgens* (see Appendix), *Cibicidoides dutemplei/subhaidingerii* (see Appendix), *Gyroidina* spp., *Lenticulina* spp., *Nodosariidae*.

The distribution patterns of the most abundant and/or paleoecologically significant taxa, selected from the whole dataset, are described below (Fig. 4). *Cibicidoides pachyderma*, *Uvigerina semiornata*, and *U. striatissima*, together with *Bolivina reticulata*, *C. lobatulus*/cf. *refulgens*, *C. dutemplei/subhaidingerii*, *Gyroidina* spp., *Lenticulina* spp., *Siphonina reticulata* are present throughout the section. *C. pachyderma*, *U. semiornata*, and *U. striatissima* show the same long-term trend, gradually increasing from 8 m up to 37-38 m (percentage values respectively up to 28%, 25%, and 18%) and decreasing in the uppermost part of the section (percentage values 5-15% for *C. pachyderma*, and down to 1% for both *Uvigerinas*). The patterns of *C. dutemplei/subhaidingerii*, *Lenticulina* spp. and *S. reticulata* do not show remarkable variations in abundance. *B. reticulata* shows a light decreasing trend up to 38 m, followed by an increasing trend with percentage values prevalently ranging from 2 to 9%. The *C. lobatulus*/cf. *refulgens* distribution pattern shows a weak decreasing-upwards trend with percentage values mainly ranging from 1 to 9%; however, four acme intervals (2-6 m, 12-19 m, 29-33 m, 38-42 m) separated by intervals with minor percentages are recognizable. *Bulimina costata*, *Hanzawaia boueana*, *Melonis barleeaanum*, and *Gyroidina* spp. are more common (percentage values up to 20%, 19%, 18% and 16%, respectively) in the lower

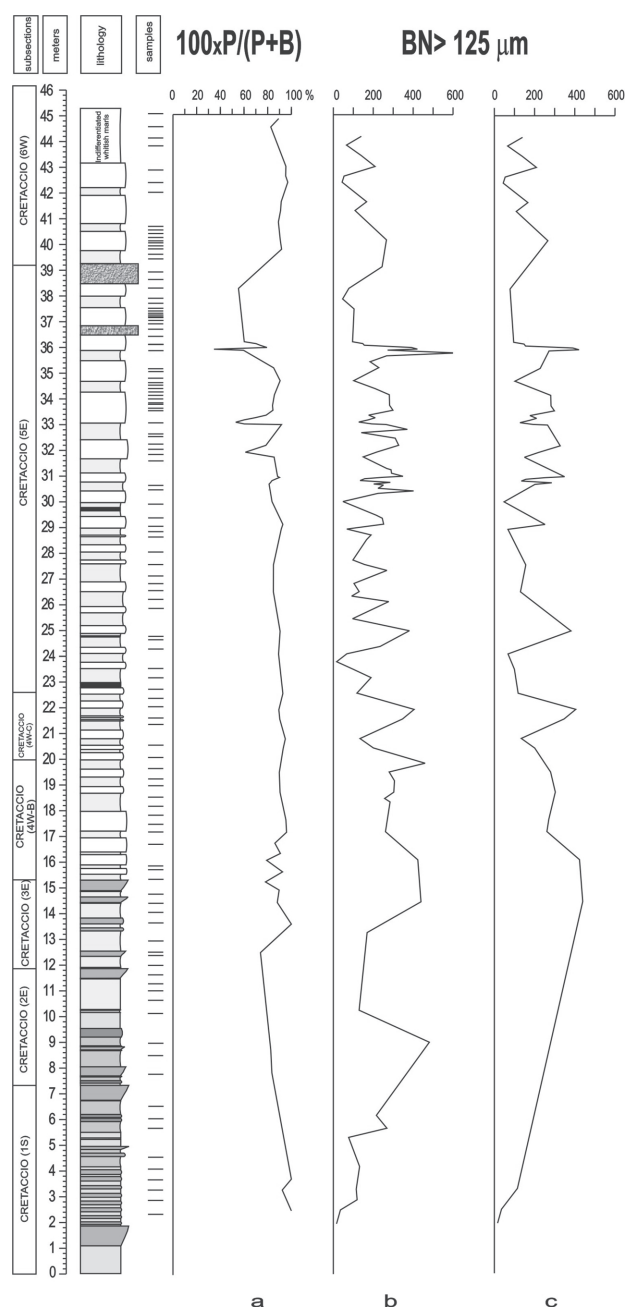


Fig. 3 - a) P/B ratio curve along the Cretaccio composite section, plotted by data from indurated marl samples, following the formula of Van der Zwaan et al. (1990); b-c) Benthic number (BN > 125 µm): b = curve obtained by the whole dataset from marl and indurated marl samples, c = curve obtained exclusively by data from indurated marl samples.

part of the section up to 16 m and strongly decrease above. *Cibicidoides wuellerstorfi* shows a discontinuous and rare distribution through the entire succession occurring with percentage values never exceeding the 3-4%. It is noteworthy that *C. wuellerstorfi* is more represented above 16 m where *Bulimina costata*, *Hanzawaia boueana*, and *Melonis barleeaanum* are almost absent and *Gyroidina* spp. strongly decrease.

Short-term distributions of the same taxa are described below analyzing separately their patterns in indurated marls and marls (Fig. 5a). *Gyroidina* spp.,

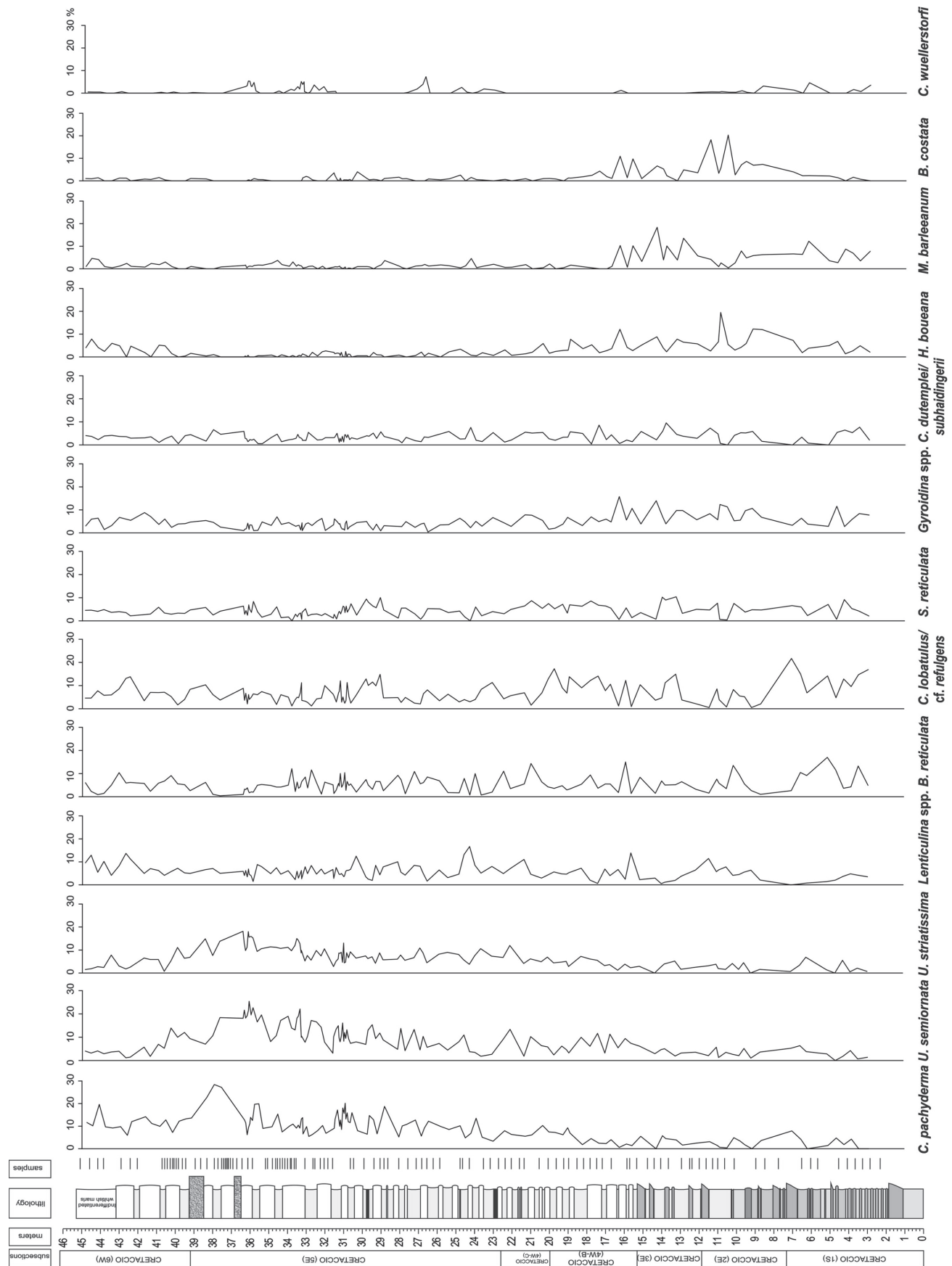


Fig. 4 - Vertical distribution patterns of significant taxa occurring along the Cretaccio composite section obtained by the whole dataset from marl and indurated marl samples.

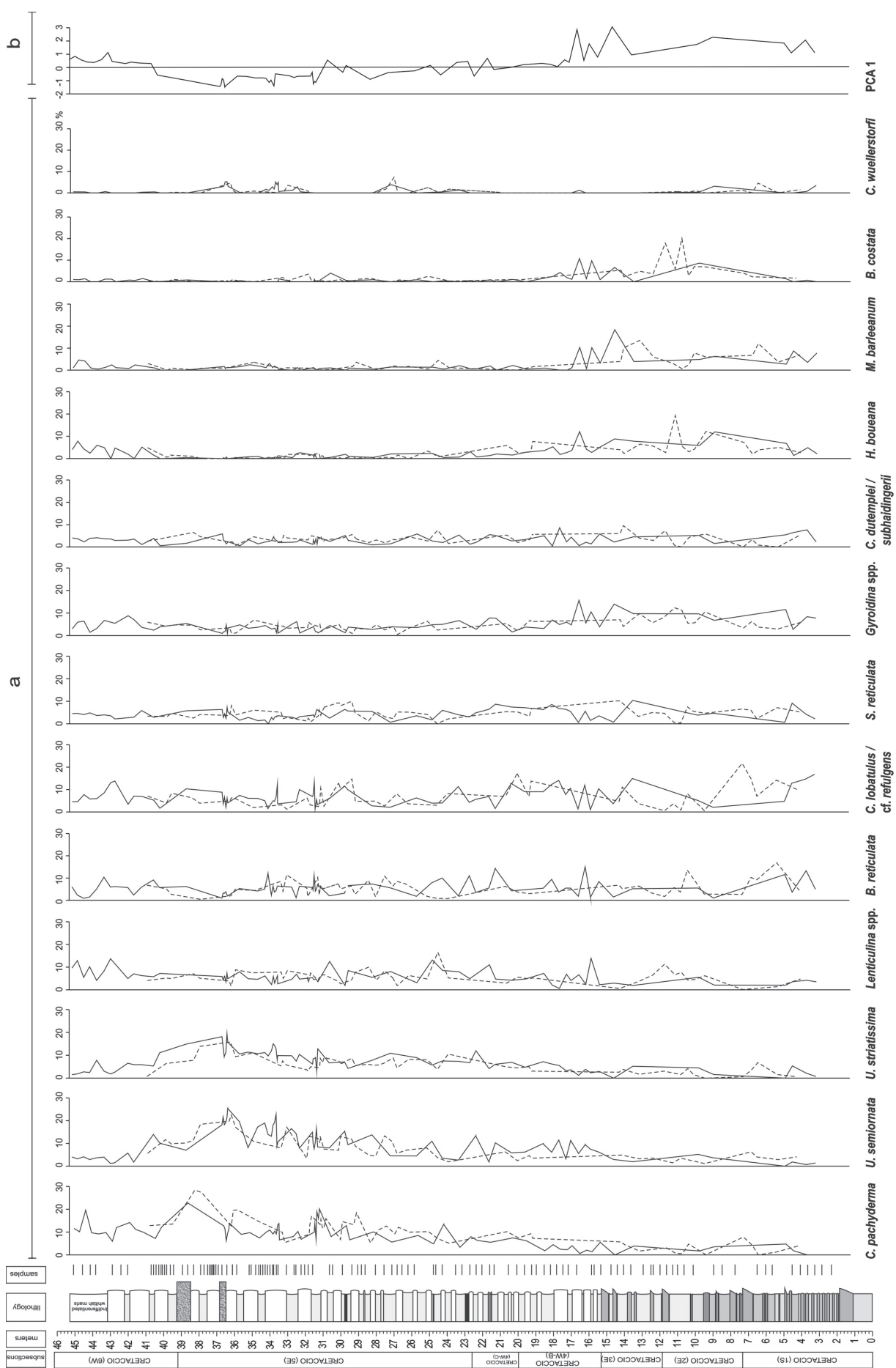


Fig. 5 - a) Vertical distribution patterns of significant taxa occurring along the Cretaccio composite section obtained by data from indurated marl samples only (continuous line), compared with curves obtained by data from marl samples only (dashed line); b) sample score pattern on the first principal component (PCA 1) obtained exclusively by data from indurated marl samples.

U. semiornata, and *U. striatissima*, as well as *C. lobatulus*/cf. *refulgens*, *C. dutemplei/subhaidingerii*, *C. pachyderma*, *C. wuellerstorfi*, *H. boueana*, *Lenticulina* spp. show positive peaks in both lithologies, but the first three species reach the highest value in the indurated marls, while the others show the highest value in the marls. The abundance of *S. reticulata* does not exhibit remarkable difference in both lithologies. *M. barleeianum* generally shows higher abundances in the indurated marls than in the marls, while *B. reticulata* has higher abundances in the marls than in the indurated marls. *B. costata* shows the highest values in the marls.

Percentage of oxic species

The oxygenation state of the bottom waters has been estimated using the percentages of the oxic species with respect to the total of oxic and suboxic ones. The oxic and suboxic species classified mainly following Kaiho (1994) are listed in Tab. 2. *C. pachyderma* has not been included in the group of oxic species because its pattern mirrors that of *U. semiornata* and *U. striatissima*, typical suboxic species (see Appendix). *B. reticulata* and *O. umbonatus*, as well as *H. boueana* and *S. reticulata*, showing a different pattern from both Uvigerinas, have been considered oxic species following the interpretation of Van der Zwaan (1982). In Fig. 6 we plotted separately the curve of the oxic species from the whole dataset (Fig. 6a) and that calculated only from indurated marl samples (Fig. 6b). The two curves show the same pattern: decreasing trend (from 62% down to 24%) from the base up to 37 m and increasing trend (up to 60%) in the uppermost part of the section. The lowest values occur at 15 m (16%) in correspondence of the lithological colour change and between 33 m and 37 m where the oxic species range from 24% to 32%.

STATISTICAL ANALYSES

Statistical analyses were performed only on indurated marls dataset (72 out of 125 samples). The dataset, originally containing 55 taxa, was condensed to 26 taxa considering only those with percentages >4% to perform principal component (PCA) and hierarchical cluster

Oxic species	Suboxic species
<i>Bolivina reticulata</i>	<i>Bulimina costata</i>
<i>Cibicides lobatulus</i>	<i>Cassidulina laevigata</i>
<i>Cibicides cf. refulgens</i>	<i>Gyroidina</i> spp.
<i>Cibicidoides bradyi</i>	<i>Lenticulina</i> spp.
<i>Cibicidoides cicatricosus</i>	<i>Melonis barleeianum</i>
<i>Cibicidoides dutemplei/subhaidingerii</i>	<i>Pullenia multilobata</i>
<i>Cibicidoides ungerianus</i>	<i>Pullenia quadriloba</i>
<i>Cibicidoides wuellerstorfi</i>	<i>Pullenia quinqueloba</i>
<i>Cibicidoides</i> sp.	<i>Pullenia salisburyi</i>
<i>Hanzawaia boueana</i>	<i>Uvigerina barbatula</i>
<i>Oridorsalis umbonatus</i>	<i>Uvigerina cf. cocoaensis hantkeni</i>
<i>Siphonina reticulata</i>	<i>Uvigerina rutila</i>
	<i>Uvigerina semiornata</i>
	<i>Uvigerina striatissima</i>

Tab. 2 - List of oxic and suboxic species (see the text for details).

analyses, using standard SPSS statistical software (version 11.0).

Principal component analysis (Davis, 1973) was applied in order to evaluate the major changes in the benthic foraminiferal trends during the analyzed time interval. Unrotated factor scores of the first axis were considered.

The first axis (PCA 1) explains 21.9 % of the total variance (Tab. 3). Taxa with positive loading, such as *Bulimina costata*, *Cibicides lobatulus*, *Cibicidoides cicatricosus*, *C. dutemplei/subhaidingerii*, *Epistominella lecalvezi*, *Gyroidina* spp., *Hanzawaia*

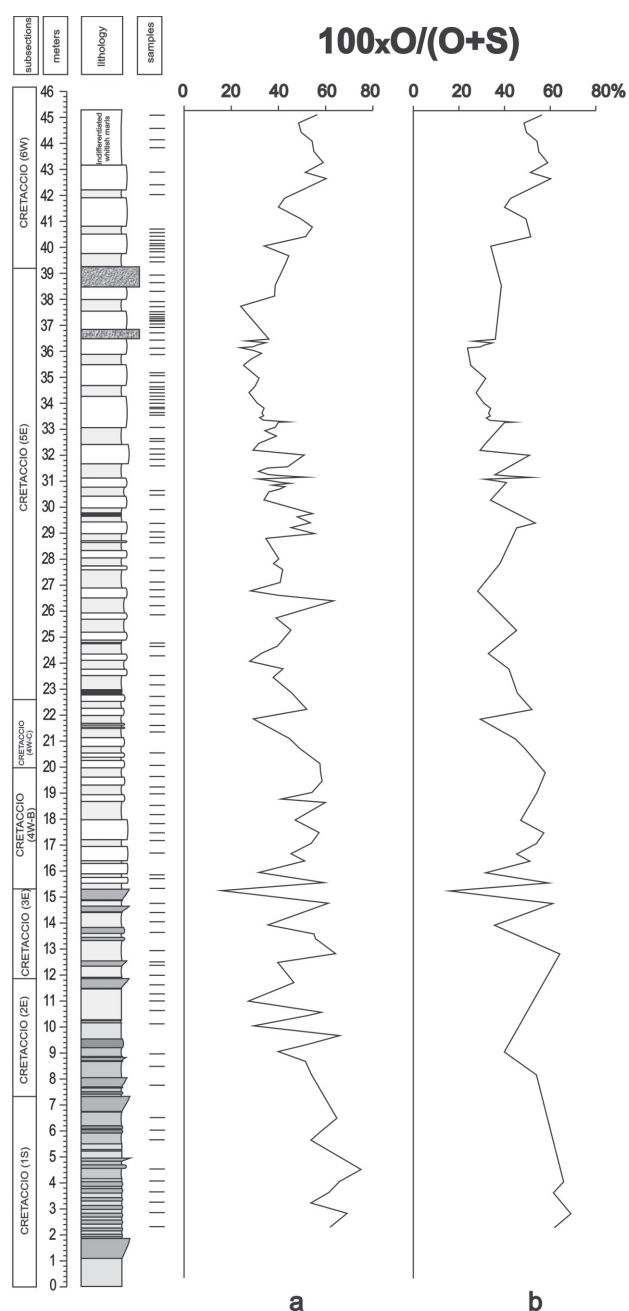


Fig. 6 - Curves of the oxic species along the Cretaccio composite section. a) Curve obtained by the whole dataset from marl and indurated marl samples; b) curve obtained exclusively by data from indurated marl samples.

Variables	PCA 1
<i>Bolivina reticulata</i>	0,050
<i>Bulimina costata</i>	0,663
<i>Cassidulina laevigata</i>	- 0,089
<i>Cibicides lobatulus</i>	0,238
<i>Cibicides cf. refulgens</i>	0,065
<i>Cibicidoides cicatricosus</i>	0,530
<i>Cibicidoides dutemplei/subhaidingerii</i>	0,180
<i>Cibicidoides pachyderma</i>	- 0,638
<i>Cibicidoides wuellerstorfi</i>	- 0,334
<i>Ehrenbergina bradyi</i>	- 0,323
<i>Ehrenbergina rugosa</i>	- 0,290
<i>Epistominella lecalvezi</i>	0,506
<i>Globocassidulina subglobosa</i>	- 0,028
<i>Gyroidina</i> spp.	0,774
<i>Hanzawaia boueana</i>	0,788
<i>Lenticulina</i> spp.	0,131
<i>Melonis barleeaanum</i>	0,691
<i>Nodosariidae</i>	0,541
<i>Oridorsalis umbonatus</i>	0,557
<i>Pullenia bulloides</i>	0,149
<i>Siphonina reticulata</i>	- 0,074
<i>Uvigerina barbatula</i>	0,303
<i>Uvigerina cf. cocoaensis hantkeni</i>	- 0,464
<i>Uvigerina rutila</i>	- 0,122
<i>Uvigerina semiornata</i>	- 0,733
<i>Uvigerina striatissima</i>	- 0,844
Variance	21,9

Tab. 3 - Principal component analysis results: loading of benthic foraminiferal taxa on the first principal component axis (PCA 1) and total variance explained by PCA 1.

boueana, *Lenticulina* spp., *Melonis barleeaanum*, *Nodosariidae*, *O. umbonatus*, *Pullenia bulloides*, *Uvigerina barbatula* (Tab. 3), generally show a decreasing trend starting from 16 m up to about 36 m (Fig. 5a). Taxa with negative loading, such as *Cibicidoides pachyderma*, *C. wuellerstorfi*, *Ehrenbergina bradyi*, *E. rugosa*, *Uvigerina cf. cocoaensis hantkeni*, *U. rutila*, *U. semiornata*, *U. striatissima* (Tab. 3), show an increasing trend from 8 m up to 37-38 m, and a decreasing-upwards trend to the top of the section (Fig. 5a).

The PCA 1 curve (Fig. 5b) shows a general trend from positive to negative values from the base up to about 40 m, followed in the last 5 m by positive values; transition from positive to negative values of PCA 1 scores occurs between 19 m and 25 m, while the change from negative to positive values is abruptly recorded at about 40 m (Fig. 5b).

The comparison with the curves of benthic taxa (Fig. 5a) shows that the lower part of PCA 1 curve is dominated by taxa with positive loading (e.g., *B. costata*, *C. lobatulus/cf. refulgens*, *Gyroidina* spp., *H. boueana*, and *M. barleeaanum*); from 25 m to 40 m the PCA 1 curve is dominated by taxa with negative loading

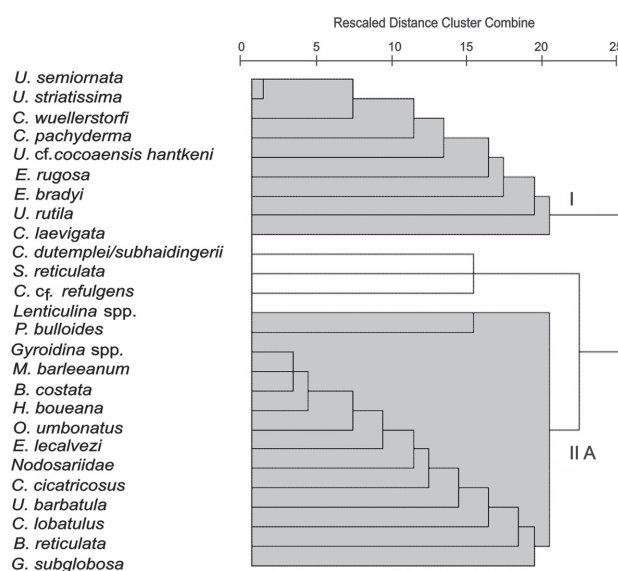


Fig. 7 - Dendrogram derived from hierarchical cluster analysis (within group, Pearson correlation) of relative frequency > 4% exclusively by data from indurated marl samples.

(e.g., *C. pachyderma*, *U. semiornata* and *U. striatissima*); the uppermost part of the PCA 1 curve is dominated again by *C. lobatulus/cf. refulgens*, *H. boueana* and *Gyroidina* spp. (Fig. 5b).

Hierarchical cluster analysis (within group, Pearson correlation) resulted in the dendrogram reported in Fig. 7, which divides species into two main groups, Cluster I and Cluster II. Cluster I groups taxa with negative loading on PCA 1 (e.g., *C. pachyderma*, *U. semiornata*, *U. striatissima*) showing an increasing trend from 8 m up to 37-38 m, and a decreasing-upwards trend to the top of the section. Within Cluster II, Subcluster IIA can be recognized. Subcluster II A groups taxa with positive loading on PCA 1 (e.g., *B. costata*, *Gyroidina* spp., *H. boueana*, *M. barleeaanum*) showing a decreasing-upwards trend starting from 16 m up to about 36 m, and an increasing trend in the uppermost part. The abundances of the species within Cluster I and Subcluster IIA have been summed and are graphically reported in Fig. 8.

The other subcluster of Cluster II observable in the dendrogram (Fig. 7) has not been interpreted since it only consists of species which group nowhere in the analysis and mostly have very low loadings on PCA 1.

DISCUSSION

Paleobathymetry

The values of the P/B ratio curve suggest an estimated paleodepth of about 800-1100 m for the Cretaccio composite section (Van der Zwaan et al., 1990). Nevertheless, we believe that the paleodepth is shallower, in agreement with the indications provided by the benthic foraminiferal assemblages recorded along the section. In fact, the co-occurrence of *U. semiornata*, a shelf-upper bathyal species, together with *U. striatissima*, a middle bathyal species, *B. reticulata* and *Cibicidoides ungerianus*, both typical upper bathyal species, and *C. lobatulus/cf. refulgens*, well represented

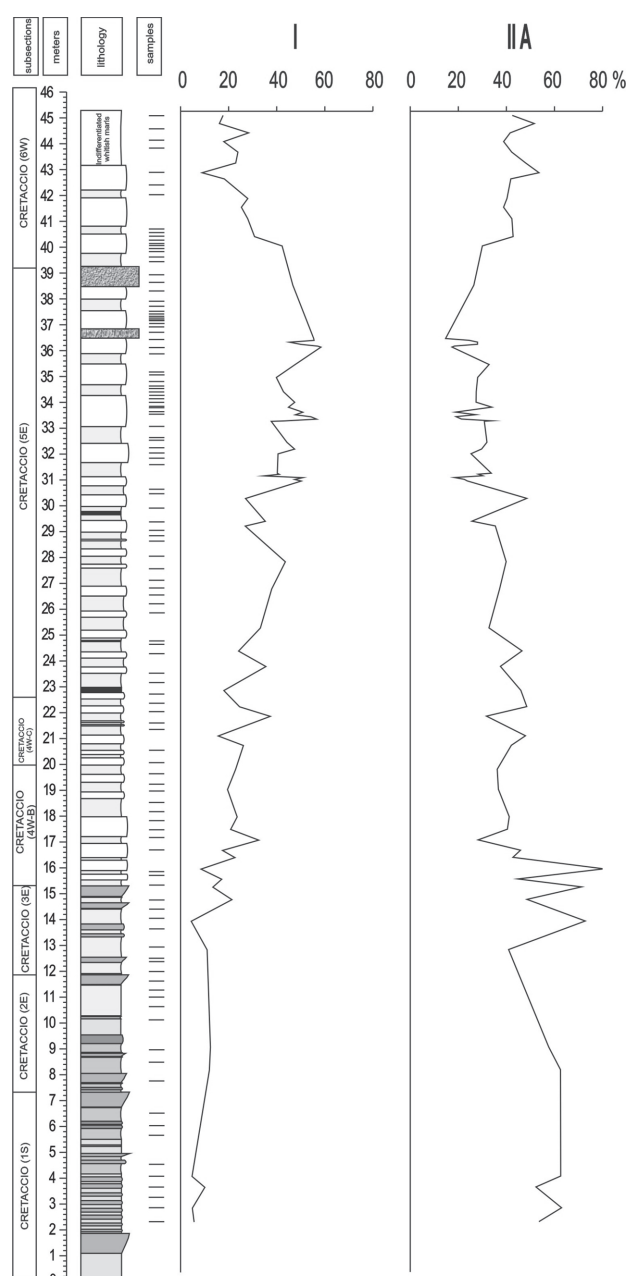


Fig. 8 - Summed relative frequencies of the species grouped in the Cluster I and Subcluster IIA.

from the shelf down to the upper bathyal zone, allow us to estimate a transitional paleodepth from the upper to the middle bathyal zone, which following van Morkhoven et al. (1986) occurs at 600 m. This hypothesis is in agreement with the distribution of *C. wuellerstorfi*, a typical lower bathyal species, whose upper water depth limit is recorded at about 500-600 m. The bathymetric/paleobathymetric meaning of the species is reported in the Appendix.

Paleoecological bottom conditions

The most remarkable changes recorded in the benthic foraminiferal assemblages concern the abundance patterns of *C. pachyderma*, *U. semiornata* and *U. striatissima*, those of *B. costata*, *Gyroidina* spp., *H. boueana* and *M. barleeianum*, and that of *C.*

wuellerstorfi (Fig. 5a). The ecological/paleoecological meaning of the species is reported in the Appendix.

The most significant results are summarized in Fig. 9. From 8 m up to 37-38 m, the abundance distribution of *U. semiornata* and *U. striatissima* (Fig. 9a) both tolerating only moderate oxygen deficiency, and the pattern of Cluster I (Fig. 9b), which includes the two species, jointly to the trend of the curve of the oxic species (Fig. 9c), indicate relatively well oxygenated conditions of bottom water masses with a weak gradual decline which culminates at about 37-38 m. Upwards to the top, the decreasing pattern of such species (Fig. 9a), the trends of Cluster I (Fig. 9b) and of the curve of the oxic species (Fig. 9c) seem to indicate an amelioration of the bottom conditions. *C. pachyderma*, showing the same long-term trend as *U. semiornata* and *U. striatissima* (Fig. 5a), also represented in Cluster I, should testify a moderate increase of food supply due to the increased mixing of bottom waters.

Other important changes concern the distribution of *B. costata*, *Gyroidina* spp., *H. boueana*, and *M. barleeianum* (Fig. 9d) which show a sharp decrease in abundance very close to the lithological colour change (15 m) from yellow to whitish/grey. Such a change, also detectable in the PCA 1 (Fig. 9e) and in Subcluster IIA (Fig. 9f) curves, may be interpreted as the response to a decrease in productivity. In fact, all the curves correlate well with the pattern of *B. costata* (Fig. 5a), a species relatively more abundant during periods of oxygen deficiency and nutrient abundance or typical of high productivity. The upwards decrease in productivity is also suggested by the pattern of the curve of BN (Fig. 3c), a parameter directly related to surface productivity by Herguera & Berger (1991) and Herguera (1992).

The discontinuous distribution of *C. wuellerstorfi* (Fig. 9g), a typical NADW (North Atlantic Deep Water) epifaunal species from elevated microhabitats indicating bottom water hydrodynamism, could suggest episodes of relatively active circulation of the bottom water masses in three different time intervals (5 m to 8 m, 23 m to 27 m, 31 m to 36 m). The most pronounced influx of *C. wuellerstorfi* occurs above 16 m where taxa indicative of major productivity (*Bulimina costata*, *Gyroidina* spp., *Hanzawaia boueana*, and *Melonis barleeianum*) are almost absent or strongly decrease.

The absence of *C. wuellerstorfi* (Fig. 9g), and the generally associated positive peaks of *S. reticulata* (Fig. 5a), an oxic species tolerating relatively low-oxygen bottom conditions, may be interpreted as the response to episodes of relatively sluggish bottom circulation associated with a moderate decrease of the bottom waters oxygen content.

The patterns of the most significant taxa in Cretaccio composite section indicate that the species do not show any significant relationship with the lithology, except for *B. costata*, which shows the highest values in the marls (Fig. 5a).

CONCLUSIONS

Based on the bathymetric/paleobathymetric meaning of the species, the Cretaccio composite section results

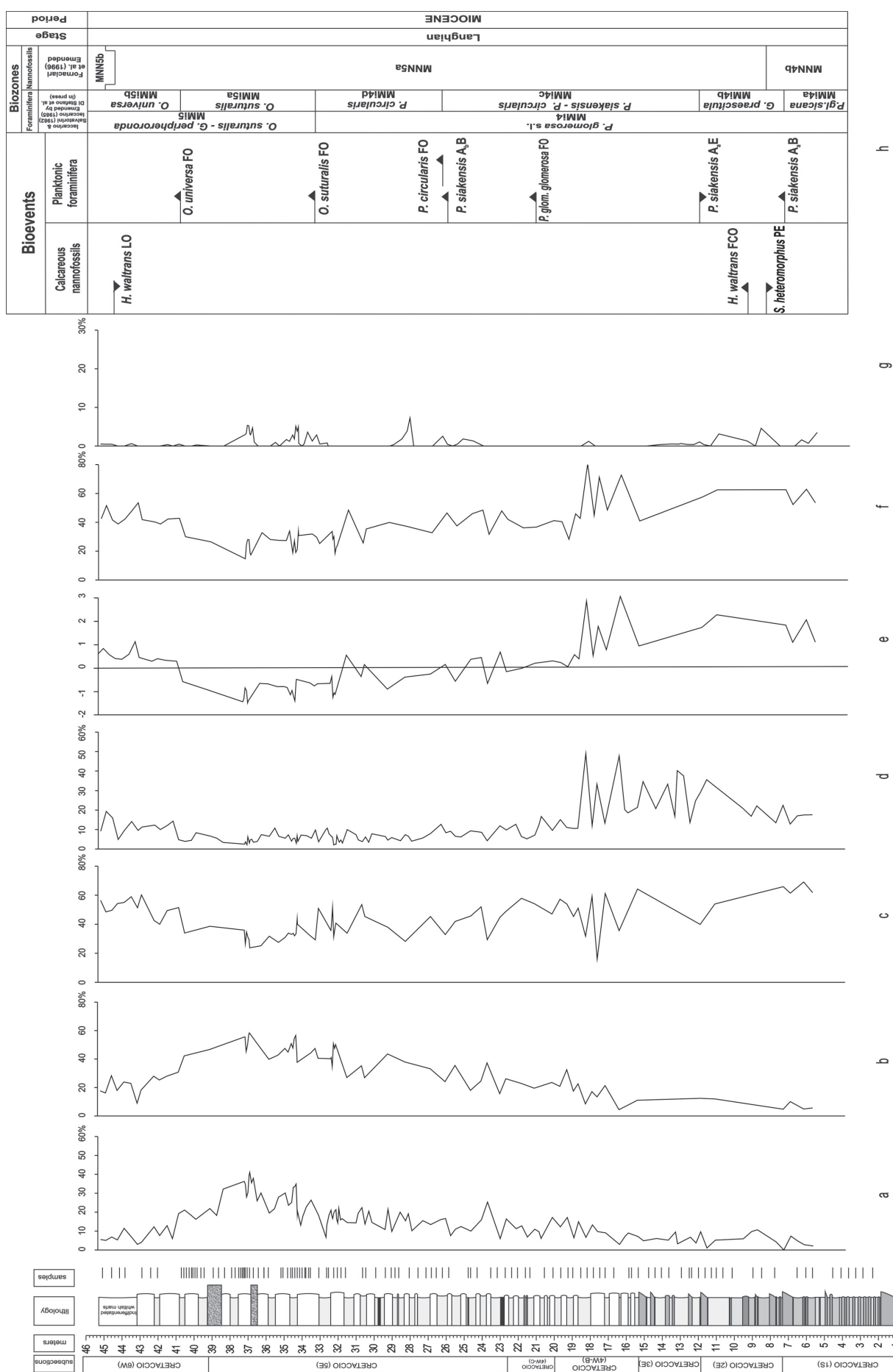


Fig. 9 - a) Distribution pattern of *U. semiornata* + *U. striatissima*; b) curve of oxyc species; d) distribution pattern of *B. costata* + *Gyroidina* spp. + *H. boueana* + *M. barleeuana*; e) curve of PCA 1; f) curve of Subcluster IIA; g) distribution pattern of *C. wuellerstorfi*; h) biostratigraphy of the investigated interval.

to be deposited at an estimated paleodepth corresponding to the transition from the upper to the middle bathyal zone (600 m).

The abundance curve of *B. costata* (Fig. 5a) suggests that the early Langhian between the PE of *S. heteromorphus* and the FO of *P. glomerosa glomerosa* (Fig. 9h) was characterized by a relatively high productivity.

Two remarkable variations in the benthic foraminiferal assemblages are recorded in the investigated section: at about 15 m and between 8 m and 37-38 m respectively.

At about 15 m (Figs. 9d, e), in correspondence with the lithological colour change predating the FO of *P. glomerosa glomerosa* (Fig. 9h), the assemblage composition is characterized by a sharp decrease of the taxa representative of productivity which could be related to the maximum phase of the Langhian transgression, which culminated with the glacial/interglacial time at about 15.6 Ma according to Shackleton & Raffi (2002).

The second change is more gradual and culminates at 37-38 m within Subzone MMi5a, above the FO of *O. suturalis* and below the FO of *O. universa* (Di Stefano et al., in press) (Fig. 9h). It is characterized by a flexion of the oxic species (Fig. 9c), and by an increase of *U. semiornata* and *U. striatissima* (Fig. 9a) as confirmed by the curves of Cluster 1 (Fig. 9b) and PCA 1 (Fig. 9e). We argue that the increasing restriction in the Tethyan/Indo-Pacific water exchanges could be responsible of the gradual development of relatively less oxygenated bottom water masses.

The presence/absence of *C. wuellerstorfi* recorded along the section could be explained with a major/minor inflow of Atlantic deep waters. The same interpretation was suggested by Dall'Antonia (2003; in press) through the ostracod assemblages recorded in the Cretaccio section. The episodic influences of cold Atlantic waters into the Mediterranean are already documented by Gebhardt (1999), who developed a circulation model for the Middle to Late Miocene western Mediterranean suggesting a low position of the "Gibraltar sill" and an estuarine circulation during the Langhian (interval from the M5a to the M5b Subzones of Berggren et al., 1995, and from Subzones MMi4b to MMi5b according to Di Stefano et al., in press). An estuarine circulation in the central Mediterranean since the early Langhian is also described by Dall'Antonia et al. (2001) in the Hyblean Plateau (SE Sicily) as testified by the occurrence of the ostracod psychrospheric species *Agrenocythere hazelae* in the same time interval (upper part of the *P. glomerosa sicana* Subzone; middle part of the MNN5a Subzone). We do not exclude that the inflow of *C. wuellerstorfi* in the early Langhian might have come from Indo-Pacific deep water masses. In fact, the same authors recorded that typical psychrospheric conditions were probably reached only in the late Langhian (interval from the upper part of the MMi5a Subzone to the lower part of the MMi5b Subzone). They finally hypothesized that both the western connections to the Atlantic Ocean and the African-Sicilian threshold must have been "deep enough" to allow the entry of the psychrosphere into the Hyblean Basin.

Concluding, the main variations detected in the benthic foraminiferal assemblages are a combination

of different causes: the incoming changes in the bottom water masses related to the closure processes of the eastern connections between Tethyan and Indo-Pacific realms, which culminated in the Middle Miocene at about 14 Ma, and the episodic inflow of Atlantic (or possibly Indo-Pacific) deep waters.

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APPENDIX

ECOLOGICAL AND PALEOECOLOGICAL NOTES

The notes concerning the taxa described below are based mainly on the papers of Van der Zwaan (1982), Murray (1991), Kaiho (1994), Kouwenhoven (2000), and selected papers (cited).

Genus *Bolivina*

According to Murray (1991), the genus *Bolivina* is infaunal-epifaunal, free, cold to warm and occurs in the muddy substrates of the inner shelf-bathyal.

According to Kaiho (1994), the genus *Bolivina* is a dysoxic indicator.

Bolivina reticulata Hantken

Bolivina reticulata Hantken, 1875.

Paleobathymetry

- from the upper bathyal down to the middle bathyal zones, but well represented only in the upper bathyal zone in some Late Miocene sections (Kouwenhoven, 2000);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Paleoecology

- open marine mud-dweller species indicative of stable marine conditions, with no tolerance for increased salinities or for oxygen deficiency (Van der Zwaan, 1982).

Genus *Bulimina*

According to Murray (1991), the genus *Bulimina* is ?infaunal, free, cold-temperate and occurs in the mud to fine sand of the inner shelf-bathyal.

According to Kaiho (1994), the genus *Bulimina* includes both suboxic and dysoxic indicators.

Bulimina costata d'Orbigny

Bulimina costata d'Orbigny, 1826.

Paleobathymetry

- from the circalittoral zone (upper water depth limit: 70 m) down to bathyal zone, but more abundant in the bathyal zone in Recent sediments of the Gulf of Salerno, in the southern Tyrrhenian Sea (Sgarrella & Barra, 1984);
- upper depth limit at about 200 m in Cenozoic deep sea sediments (van Morkhoven et al., 1986);
- from 95-2500 m depth range in Recent sediments (Murray, 1991), as additional common species of the *Uvigerina mediterranea* association in the Adriatic Sea (Jorissen, 1988) and eastern Mediterranean (Parker, 1958);
- from 355-868 m and 350-850 m depth ranges in Recent sediments (Murray, 1991), as characteristic species respectively of a minor and a major association of the Adriatic Sea (Jorissen, 1988);
- from 1000-1600 m depth range in Recent sediments (Murray, 1991), as occurring species with percentage values >10 % on muddy substrates off Provence and Corsica (Bizon & Bizon, 1984);
- from 100 m down to 1000 m in the Gulf of Naples, and from 100 m down to water depths deeper than 1000 m in the other sectors of the Mediterranean Sea in Recent sediments (Sgarrella & Moncharmont Zei, 1993), more abundant from 100-500 m depth range in both the Gulf of Naples and the other zones of Mediterranean Sea;
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002).

Paleoecology

- mud-dweller species with but a slight tolerance to increased salinities, relatively most abundant during periods of oxygen deficiency and nutrient abundance (Van der Zwaan, 1982);
- tolerant species to low oxygen conditions (Jonkers, 1984);
- related to high productivity Monterey global event (Bellanca et al., 2002)

Genus *Cibicides*

According to Murray (1991), the genus *Cibicides* is epifaunal, attached, cold-warm and occurs in the hard substrates from 0 to >2000 m of lagoon and shelf-bathyal.

According to Kaiho (1994), the genus *Cibicides* includes oxic indicators.

Cibicides lobatulus (Walker & Jacob)/cf. *refulgens*

Nautilus lobatulus Walker & Jacob, 1798.

C. lobatulus/cf. *refulgens* corresponds in this paper to *C. lobatulus sensu* Van der Zwaan (1982). According to this author *C. lobatulus* is a variable group in which two "varieties" can be

distinguished: the first is the typical *C. lobatulus*, which is irregular in shape and coarsely perforated, the second resembles *C. refulgens* de Montfort, 1808, and is more regularly shaped and finely perforated. We have lumped together these two "varieties" to perform the quantitative analyses, while we reported them separately as *C. lobatulus* and *C. cf. refulgens* only to carry out statistical analyses.

Paleobathymetry

C. lobatulus and *C. refulgens*, both typical shelf species, are also well represented at water depths lower than 200 m in Recent sediments (Murray, 1991). In detail:

C. lobatulus

- from 50-485 m depth range and at 2695 m (living) in Recent western North Atlantic sediments (Atlantic seaboard of North America), as additional common species;
- from 100-2500 m and 177 - 3299 m depth ranges, and from 0-900 m depth range in Recent eastern North and South Atlantic sediments (Atlantic seaboard of Europe and Africa), respectively as additional common species, and as dominant species (*C. lobatulus* association);
- from 100-500 m depth range in Recent sediments of the eastern margin of the Pacific Ocean;
- from 164-3770 m and 136-950 m depth ranges in Recent sediments of Southern Ocean, as additional common species;

C. refulgens

- from 0-900 m and 128-801 m depth ranges, in Recent eastern North and South Atlantic sediments (Atlantic seaboard of Europe and Africa), as additional common species;
- from 50-4800 m and 136-950 m depth ranges in Recent sediments of Southern Ocean, respectively as additional common species, and as dominant species (*C. refulgens* association).

C. lobatulus is also reported from the infralittoral down to the upper circalittoral zones in the Gulf of Naples and in the other sectors of Mediterranean Sea in Recent sediments (Sgarrella & Moncharmont Zei, 1993).

C. lobatulus and *C. refulgens* are reported from shelf to upper bathyal environments, but well represented only in the upper bathyal zone in some Late Miocene sections (Kouwenhoven, 2000).

C. lobatulus/refulgens is reported from 1000-1200 m depth range in the Late Miocene *Monte del Casino* section (northern Italy) (Kouwenhoven, 2000).

Paleoecology

- epiphyte species with a tolerance to increased salinities (Van der Zwaan, 1982).

Genus *Cibicidoides*

According to Murray (1991), the genus *Cibicidoides* is epifaunal, clinging, cold and occurs in the hard substrates of shelf-bathyal.

According to Kaiho (1994), the genus *Cibicidoides* includes oxic indicators.

Cibicidoides dutemplei (d'Orbigny)/*subhaidingerii* (Parr)

Rotalina dutemplei d'Orbigny, 1846.

Cibicides subhaidingerii Parr, 1950.

According to Van der Zwaan (1982) specimens referred to *Cibicides dutemplei* show some variation in the height of the dorsal side; in particular most of them are biconvex, but some others are planoconvex. Such variants intergrade with types belonging to *Cibicidoides subhaidingerii*, reported as *Cibicides ungerianus* by Van der Zwaan (1982). Also van Morkhoven et al. (1986) point out a general similarity between *Cibicidoides dutemplei* and *C. subhaidingerii*.

In this paper we lumped together these two species as *C. dutemplei/subhaidingerii*, because we found difficult to separate clearly the biconvex (*C. subhaidingerii*) from the planoconvex (*C. dutemplei*) forms, which are the most abundant.

Paleobathymetry

- from outer neritic and upper bathyal depths (*C. dutemplei*), and from neritic down to abyssal depths (*C. subhaidingerii*) in Neogene deposits of western Europe, Mediterranean and North Africa (van Morkhoven et al., 1986);

- from the upper bathyal down to the middle bathyal zones, but more abundant in the upper bathyal zone (*Cibicides dutemplei*) in some Late Miocene sections (Kouwenhoven, 2000)

Paleoecology

- mud-dweller species, with little tolerance for oxygen deficiency or increased salinities according to Hageman (1979), Van der Zwaan (1982) and Jonkers (1984);
- indicative species of oxic bottom conditions, as epifaunal taxa belonging to the genus *Cibicoides* (Corliss, 1991; Kaiho, 1994, among other authors).

Cibicoides pachyderma (Rzehak)

Truncatulina pachyderma, Rzehak 1886.

Paleobathymetry

- from the upper bathyal zone, but also at shelf paleo-depths and at 3615 m (Berggren & Haq, 1976), in Cenozoic deep sea sediments (van Morkhoven et al., 1986);
- from 73 m downwards but frequent deeper than 110 m in the Gulf of Naples, from 50-70 m downwards but frequent in the bathyal muds in the Gulfs of Salerno and Policastro, and from the epibathyal zone in the Balearic area and in the Gulf of Taranto, in Recent sediments (Sgarrella & Moncharmont Zei, 1993);
- from the middle to lower bathyal zones in some Late Miocene sections (Kouwenhoven, 2000).

Paleoecology

- epifaunal and oxic species (Corliss, 1985; Corliss & Chen, 1988);
- abundant species in the Wurmian Mediterranean sediments, indicative of well oxygenated bottom waters, with relative increase of food supply due to the increased mixing of bottom waters during cold periods (Blanc-Vernet et al., 1983; Sgarrella, 1988);
- occurring species in the Recent South China Sea sediments, in concomitance of an increased oxygen bottom content and a decreased organic matter bottom content (Miao & Thunell, 1993).

Cibicoides ungerianus (d'Orbigny)

Rotalina ungeriana d'Orbigny, 1846.

Paleobathymetry

- from the shelf down to the middle bathyal zone, but well represented only in the upper bathyal zone in some Late Miocene sections (Kouwenhoven, 2000, reported as *Cibicides ungerianus*);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Paleoecology

- open marine mud-dweller species, with no tolerance to oxygen deficiency or to increased salinities (Van der Zwaan, 1982);
- epifaunal and oxic species (Corliss, 1985; Corliss & Chen, 1988);
- a good tracer of regular influxes of the Middle Miocene central Mediterranean intermediate water mass (Bellanca et al., 2002).

Cibicoides wuellerstorfi (Schwager)

Anomalina wuellerstorfi Schwager, 1866.

Paleobathymetry

- from the bathyal zone at water depths lower than 1000 m in Recent sediments (Murray, 1991), as characteristic species (reported as *Fontbotia wuellerstorfi*). In detail:
- from 2500-3800 m (North Atlantic Deep Water "NADW") and 3800-5128 m (Antarctic Bottom Water "AABW") depth ranges in Recent western North Atlantic sediments (Atlantic seaboard of North America), as additional common species;
- from 598-3614 m depth range and at water depths lower than about 1900 m in Recent sediments of the Gulf of Mexico and Caribbean Sea, respectively as additional common species, and as dominant species (*F. wuellerstorfi* association);
- from 3815-4833 m and 2145-3700 m depth ranges in Recent western South Atlantic sediments (Atlantic seaboard of South America), respectively as additional common species, and as dominant species (*F. wuellerstorfi* association);
- from 100-7500 m and 1360-4280 m depth ranges in Recent eastern North and South Atlantic sediments (Atlantic seaboard

- of Europe and Africa), respectively as additional common species, and as dominant species (*F. wuellerstorfi* association);
- from 2897-4700 m and 2187-3781 m depth ranges in Recent sediments of Indian Ocean, respectively as additional common species, and as dominant species (*F. wuellerstorfi* association);
- at about 200 m in Recent sediments of Drake Passage area of Southern Ocean, as occurring species according to Herb (1971);
- from 1537-2424 m depth range in Recent sediments of the Arctic Ocean, as additional common species;
- from 500-3000 m and lower bathyal-abyssal depth ranges in Cenozoic deep-sea sediments (van Morkhoven et al., 1986), respectively as rare occurring species (Bandy & Chierici, 1966), and as dominant planulid (Berggren, et al., 1976). In detail:
- at water depths lower than 3000 m in Recent sediments of the Gulf of California and Gulf of Mexico, as dominant species according to Bandy & Echols (1964);
- upper depth limit at about 1800-1900 m and its greatest abundance below about 2500 m in Recent sediments of the North-eastern United States continental margin, according to Miller & Lohmann (1982);
- from 980-4700 m depth range in Recent North Atlantic sediments, occurring with percentage values ranging about from 1 to 4%, according to Schnitker (personal communication);
- from the middle to the lower bathyal zones, but well represented only in the lower bathyal zone in some Late Miocene sections (Kouwenhoven, 2000, reported as *Cibicides wuellerstorfi*);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Paleoecology

- well adapted species to low annual flux rates of organic carbon in Atlantic Ocean (Altenbach, 1988);
- true NADW species in Atlantic and Indian oceans (Murray, 1991). Far more abundant in the Norwegian Sea than elsewhere and not depth dependent in Atlantic Ocean (Murray 1991);
- epifaunal species from elevated microhabitats, indicative of lateral bottom currents and bottom hydrodynamism (Altenbach & Sarnthein, 1989; Lutze & Thiel, 1989; Linke & Lutze, 1993).

Genus Gyroidina

According to Murray (1991), the genus *Gyroidina* is epifaunal, free, cold and occurs in the mud substrates of shelf-bathyal.

According to Kaiho (1994), the genus *Gyroidina* includes suboxic indicators.

Gyroidina spp.

Paleobathymetry

- from shelf-bathyal paleodepths in Recent sediments (Murray, 1991);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Genus Hanzawaia

According to Murray (1991), the genus *Hanzawaia* is epifaunal, clinging, temperate-warm and occurs in the hard substrates of the inner shelf (down to 100 m).

Hanzawaia boueana (d'Orbigny)

Truncatulina boueana d'Orbigny, 1846.

Paleobathymetry

- from the upper to the middle bathyal zones in some Late Miocene sections (Kouwenhoven, 2000);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Paleoecology

- species with a rather great tolerance to increased salinities, but with no such tolerance to oxygen deficiency (Van der Zwaan, 1982).

Genus *Lenticulina*

According to Murray (1991), the genus *Lenticulina* is epifaunal, free, cold and occurs in the mud substrates of the outer shelf and bathyal.

According to Kaiho (1994), the genus *Lenticulina* includes suboxic indicators.

Lenticulina spp.Paleobathymetry

- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Genus *Melonis*

According to Murray (1991), the genus *Melonis* is infaunal, free and occurs in the mud and silt substrates of shelf-bathyal.

According to Kaiho (1994), the genus *Melonis* includes suboxic indicators.

Melonis barleeana (Williamson)

Nonionina barleeana Williamson, 1858.

Paleobathymetry

- ubiquitous, but more abundant from the circalittoral zone down to bathyal zone in Recent sediments of the Gulf of Salerno, in the southern Tyrrhenian Sea (Sgarrella & Barra, 1984);
- from 40-1000 m depth range and at water depths lower than 1000 m in Recent sediments respectively of the Gulf of Naples (southern Tyrrhenian Sea) and of other sectors of Mediterranean Sea (Sgarrella & Moncharmont Zei, 1993);
- from the middle down to the lower bathyal zones in some Late Miocene sections (Kouwenhoven, 2000).

Genus *Siphonina**Siphonina reticulata* (Czjzek)

Rotalina reticulata Czjzek, 1848.

Paleobathymetry

- from 104-1016 m depth range in Recent sediments of the eastern Mediterranean Sea (Parker, 1958);
- from 81-1000 m depth range in Recent sediments of North western Mediterranean Sea (Bizon & Bizon, 1984);
- upper depth limit at 600 m in Cenozoic deep sea sediments (van Morkhoven et al., 1986);
- at water depths lower than 22 m and from the infralittoral zone down to bathyal zone in Recent sediments respectively of the Gulf of Naples (southern Tyrrhenian Sea) and of other sectors of Mediterranean Sea (Sgarrella & Moncharmont Zei, 1993);
- from the middle down to the lower bathyal zones, but well represented only in the lower bathyal zone, in some Late Miocene sections (Kouwenhoven, 2000);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Paleoecology

- open marine species without notable tolerance to salinity and oxygen fluctuations (Van der Zwaan, 1982);
- dominant species of the "non-sapropel" assemblage from Early Pliocene eastern Mediterranean sediments (Katz & Thunell, 1984);
- occurring species in the Recent sediments of the Gulf of Salerno (southern Tyrrhenian Sea) only on the *Posidonia* substrates (Sgarrella & Barra, 1984);
- very abundant species of Pliocene Mediterranean hypersaline bottom water masses from 150-1000 m depth range (Hasegawa et al., 1990);

- epifaunal to transitional species recorded in areas with oxygen bottom content of 1.5 ml/l (Rathburn & Corliss, 1994; Rathburn & Miao, 1995), corresponding to the transition from low oxic bottom conditions to suboxic bottom conditions *sensu* Kaiho (1994);
- species tolerant of relatively low oxygen bottom content, but able to live in an oxic environment (Sgarrella et al., 1999).

Genus *Uvigerina*

According to Murray (1991), the genus *Uvigerina* is mainly infaunal, sometimes epifaunal, free, cold, occurring on the muddy substrates of the shelf-bathyal (depth range: 100->4500 m).

According to Kaiho (1994), the genus *Uvigerina* includes suboxic indicators.

Uvigerina semiornata group

According to Borsetti et al. (1986) and Van der Zwaan et al. (1986) these following three species belong to *U. semiornata* group:

Uvigerina rutila Cushman & Todd

Uvigerina rutila Cushman & Todd, 1941.

Paleobathymetry

- from the bathyal zone in Tertiary carbonate-rich marls with abundant planktonic foraminifera (Boersma, 1984);
- from the upper bathyal zone down to the middle bathyal zone, but well represented only in the middle bathyal zone, in some Late Miocene sections (Kouwenhoven, 2000);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002, reported as *U. rutila-barbatula* group);
- from an estimated paleobathymetry of about 1000 m in Serravallian Tremiti Islands sediments (Russo et al., 2002).

Paleoecology

- well represented species under well oxygenated bottom conditions (Boersma, 1984);
- species tolerating only moderate oxygen deficiency (Borsetti et al., 1986).

Uvigerina semiornata d'Orbigny

Uvigerina semiornata d'Orbigny, 1846.

Paleobathymetry

- from shelf depths to the upper bathyal zone in Tertiary deposits of central and northern Europe and similarly shallow water sediments under the West African upwelling (Boersma, 1984);

Paleoecology

- occurring species in Europe from shallowing sequences of the para-Tethys, some of which are interpreted to represent higher than normal salinities, and off western Africa in a high productivity area, characterized by warm, saline and stratified surface waters and by low oxygen content at the bottom with tendency towards dysoxia (Boersma, 1984);
- species tolerating only moderate oxygen deficiency, as well as *U. rutila*.

Uvigerina striatissima Perconig

Uvigerina striatissima Perconig, 1955.

Paleobathymetry

- only from the middle bathyal zone in some Late Miocene sections (Kouwenhoven, 2000);
- from an estimated paleobathymetry of about 500-600 m in Middle Miocene Malta sediments (Bellanca et al., 2002, reported as *U. rutila-barbatula* group);

Paleoecology

- species tolerating only moderate oxygen deficiency, as well as *U. rutila*.