

Palaeoenvironmental Investigation of Sapropelic Sediments from the Marmara Sea: A Biostratigraphic Approach to Palaeoceanographic History During the Last Glacial–Holocene

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Abstract: High-resolution micropalaeontological examination of two cores recovered from the Central Basin of the Marmara Sea distinguishes seven biostratigraphical zones within pre-sapropelic (Pr1 & 2 zones), sapropelic (Sap1 & 2 zones) and post-sapropelic (Po1-2-3 zones) sediments. The pre-sapropelic sediments at the basal section of the cores reflect the lake stage of the Marmara Sea when it was isolated both from the Black and Mediterranean seas. First colonization of foraminifers at about 11–10.4 ky BP indicate the beginning of marine conditions following the entry of Mediterranean waters through the Çanakkale Strait. Sapropelic sediments deposited at about 10.3–6.2 ky BP were associated with enhanced productivity of the surface waters, as inferred from the confined abundance of *Globigerina bulloides* in sapropelic zones. The first stage of the sapropelic deposition started under anoxic-close to anoxic bottom water conditions and continued in dysoxic-suboxic conditions, as deduced from benthic foraminiferal assemblages. Towards the end of the sapropelic deposition, suboxic conditions dominated. The most enriched $\delta^{18}\text{O}$ values occur within the sapropelic sediments suggesting that a relative freshening of the surface water must have occurred after deposition of the sapropelic sediments; this observation casts doubt on the postulated strong Black Sea outflow during their formation.

Post-sapropelic sediments deposited during the last 6 ky BP have been divided into three intervals by distinct distribution patterns of foraminiferal fauna, possibly indicating relative changes in the Marmara Sea during the Late Holocene. The benthic foraminiferal assemblages in these intervals show that suboxic bottom conditions continued from the last stage of the sapropelic deposition up to the present day.

Key Words: benthic foraminifera, planktic foraminifera, biostratigraphy, sapropel, stable isotopes, palaeoceanography, last glacial–Holocene, Marmara Sea

Marmara Denizi Sapropelik Sedimentlerinin Ortamsal İncelemesi: Son Buzullaşma–Holosen Paleosinografisine Biyostratigrafik Bir Yaklaşım

Özet: Marmara Denizi'nin Orta Havzası'ndan alınmış olan iki karotun yüksek ayrımlı mikropaleontolojik incelemesi; sapropelik çökeltim öncesi (Pr1 & 2 zonları), sapropelik (Sap 1 & 2 zonları) ve sapropelik çökeltim sonrası (Po1-2-3 zonları) sedimentler içerisinde yedi biyostratigrafik zon ayırt etmeye olanak sağlamıştır. Karotların tabanında yer alan sapropelik çökeltim öncesi sedimentler, Marmara Denizi'nin Akdeniz ve Karadeniz'den izole olduğu göl safhasını yansıtmaktadır. Günümüzden yaklaşık 11000–10400 yıl önce başlayan ilk foraminifer yerleşimi, Çanakkale Boğazı yolu ile giren Akdeniz suları ile denizel koşulların oluşmaya başlamasını gösterir. Günümüzden 10300–6200 yıl öncesi zaman aralığında sapropelik sedimentler çökelmiştir. *Globigerina bulloides*'in sadece Sapropel zonlarında yer alan yüksek bolluğu, bu sedimentlerin çökeltiminin yüzey sularında artan birincil üretim ile ilişkili olduğunu ortaya koymaktadır. Sapropelik sedimentlerin benthik foraminifer toplulukları, sapropelik çökeltimin ilk aşamasının anoksik-anoksiğe yakın dip suyu koşulları altında başladığını ve disoksik-suboksik koşullarda devam ettiğini gösterir. Sapropelik çökeltimin sonlarına doğru suboksik koşullar hakimdir. $\delta^{18}\text{O}$ 'ce en zengin değerlerin sapropelik

sedimentler içerisinde yer alışı, göreceli yüzey suyu tatlılaşmasının sapropelik sedimentlerin çökeliminden sonra gerçekleştiğini ve çökelimleri esnasında Karadeniz'den güçlü su akışı olduğu görüşünü şüpheye düşürmektedir.

Son 6000 yıl esnasında çökelmiş olan sapropelik çökelim sonrası sedimentler, foraminiferal faunadaki belirgin dağılım şekillerine göre üç zona ayrılmıştır. Bu zonlar, muhtemelen Geç Holosen esnasında Marmara Denizi'nde göreceli değişikliklere işaret etmekte ve sapropelik çökelinin son safhasından günümüze kadar suboksik koşulların hakim olduğunu göstermektedir.

Anahtar Sözcükler: Bentik foraminifer, planktik foraminifer, biyostratigrafi, sapropel, duraylı izotop, paleoşinografi, Son buzullaşma-Holosen, Marmara Denizi

Introduction

Palaeoceanographic significance of sapropel formations has been well-documented from Middle Miocene to Late glacial–Holocene deposits in the Mediterranean Sea (Vergnaud-Graezini *et al.* 1977; Kidd *et al.* 1978; and also see papers in Cita *et al.* 1991 and Rohling & Thunell 1999) and in Holocene deposits from the Black Sea (Strakhov 1971; Ross & Degens 1974; Calvert *et al.* 1987; Calvert 1990). The formation of such organic-rich deposits is often attributed to increased primary production, to changes in stratification and/or to the chemistry of the water column leading to anoxia in bottom waters. Sapropel deposition correlates with variations in the Earth's orbital parameters which control the strength of seasonal monsoon conditions in the North African region (Rossignol-Strick *et al.* 1982; Rossignol-Strick 1983, 1985; Rohling & Hilgen 1991; Lourens *et al.* 2001). Strong inflows of the less saline nutrient-rich Black Sea waters via the Marmara Sea and its straits were also shown to be an important factor in formation of the eastern Mediterranean sapropel layers (Ryan 1972; Stanley 1978; Thunell & Lohman 1979; Aksu *et al.* 1995, 1999), whilst a closer freshwater source from the North African region (the Nile River) as a cause of deposition of S1 sapropel has also been considered (Rossignol-Strick 1999; Krom *et al.* 2002).

Sapropelic layers in the Marmara Sea were first recognized on the southern shelf (Çağatay *et al.* 1999) and later in the deep basin (Çağatay *et al.* 2000; Aksu *et al.* 2002a). Radiocarbon ages (^{14}C) for the upper and lower sapropelic layers range from 4.75–3.2, and 10.6–6.4 ky BP, respectively. The lower sapropelic layer is therefore synchronous with the youngest sapropel (S1 sapropel) of the Mediterranean Sea. Aksu *et al.* (2002a) identified two sapropel layers in the deep basin: the sapropel M1 corresponding to the lower sapropelic layer in Çağatay *et al.* (2000) and the sapropel M2 deposited between 29.5 and 23.5 ky BP. Formation of the

sapropelic layers in the Marmara Sea is considered to be closely related to nutrient-rich and strong fresh water input from the Black Sea at about 11–10 ky BP, which resulted in a high organic flux to the sea floor and consequently a strong water stratification (Çağatay *et al.* 1999, 2000). These results are supported by additional multi-proxy palaeoceanographic data (Aksu *et al.* 2002a, b; Kaminski *et al.* 2002; Abrajano *et al.* 2002; Hiscott & Aksu 2002; Hiscott *et al.* 2002). However, these interpretations related to sea-level changes and associated water exchanges between the Black and Mediterranean seas clash with the *Flood Hypothesis* introduced by Ryan *et al.* (1997, 2003). An abrupt Mediterranean transgression at about 7.15 ky or 8.4 ky BP catastrophically submerged the low-sea level (lower than – 100 m) shelf area of the Black Sea via the İstanbul Strait, decreasing the persistent outflow of the Black Sea beginning at about 11–10 ky BP through the İstanbul Strait. In addition, heavy $\delta^{18}\text{O}$ values and high salinities at the sea surface indicate that low salinity surface water from the Black Sea was absent during deposition of the sapropelic sediments in the Marmara Sea, as reported in a further study by Sperling *et al.* (2003).

Previous studies related to the foraminiferal fauna of the Marmara Sea sediments are few (Alavi 1988; Hakyemez & Toker 1997; Meriç & Sakıncı 1990; Meriç *et al.* 1995; Çağatay *et al.* 1999, 2000; Aksu *et al.* 2002a; Sperling *et al.* 2003). Planktic foraminiferal (Aksu *et al.* 2002a; Sperling *et al.* 2003) and benthic foraminiferal assemblages in the sapropels (Çağatay *et al.* 1999, 2000; Kaminski *et al.* 2002) were studied. Although Kaminski *et al.* (2002) investigated benthic foraminifers in the sapropels (core MAR98 –12; from Central Basin of the Marmara Sea), no detailed quantitative data were given. Oxygen isotopic composition of foraminiferal tests were given only in two studies (Aksu *et al.* 2002a; Sperling *et al.* 2003), but led to completely opposite interpretations. Aksu *et al.* (2002a) identified strong Black Sea outflow

during deposition of sapropelic layers on the basis of depleted oxygen isotopes values. In contrast, Sperling *et al.* (2003) found enriched oxygen isotopes values within the sapropel and interpreted them in terms of the absence of Black Sea water during deposition.

In this paper we present high-resolution micropalaeontological (foraminifera, ostracoda and calcareous nannofossil) data together with oxygen isotopes from two cores, including sapropelic sediments and located in the Central Basin of the Marmara Sea with the aim of establishing for the first time a local biostratigraphical scheme from quantitative analysis of the benthic and planktic foraminiferal assemblages through the cores. This biostratigraphical scheme and oxygen isotope data are addressed to contribute new data to the palaeoceanographic conditions of the Marmara Sea during the Last glacial–Holocene interval, with particular attention to the controversial water exchanges between the Black Sea and Mediterranean Sea.

Study Area

The Marmara Sea is a land-locked sea located between the Thrace and Anatolia peninsulas and constitutes an oceanographic link between two large semi-enclosed basins, the Mediterranean Sea and Black Sea (Figure 1a). It is connected to brackish waters (18–22 psu) Black Sea via the İstanbul Strait (the Bosphorus) and to normal marine waters (37.5–38.5 psu) of the Mediterranean Sea via the Çanakkale Strait (Dardanelles). Black Sea waters flowing through the İstanbul Strait enter the Marmara Sea as a surface current, whereas Mediterranean Sea flows through the Çanakkale Strait as an undercurrent. These two water bodies cause permanent two-layered water stratification (Ünlüata *et al.* 1990) at about 25 m depth and form a major feature of the present-day oceanography of the Marmara Sea. As a result of this water stratification and limited vertical mixing of the two water masses, the dissolved oxygen content of the lower layer is depleted and decreases from the Çanakkale Strait (7–10 mg/l) to the İstanbul Strait (2.5 to 5.0 mg/l) (Ünlüata *et al.* 1990). The lower layer is relatively poor in organic substances compared with the upper layer. The Black Sea originating as the upper layer transports 1.5×10^6 ton/y of organic carbon to the Marmara Sea. This is four times higher than that of the lower layer (Polat & Tuğrul 1995). Production and accumulation of organic

matter in the Marmara Sea are mainly influenced by the organic-rich upper layer, by the riverine input from south and, to a lesser extent, by the lower layer.

The sea floor of the Marmara Sea presents a complicated morphological system, including shelves, slopes, ridges and deep basins (Figure 1b). The northern and southern shelves extend to 100 m water depth where they are limited by a shelf break. Relatively steep slopes (gradients higher than 7°) are mainly formed at the shelf break-basin transition in the northern part, whereas gentle slopes (gradients between 4 and 6°) are characteristic of ridge-basin and shelf-ridge transitional zones in the southern part (Gazioğlu *et al.* 2002). The four basins, namely Çınarcık (1270 m), Silivri (820 m), Central (1268 m) and Tekirdağ (1133 m) are separated by ridges, occurring at water depths between 360 and 650 m. Submarine canyons and landslides occur locally across the slopes of the Marmara Sea (Gazioğlu *et al.* 2002). Topographical restrictions (sills) in both straits control the present bottom water circulation and they played important roles during the Late Quaternary sea level variations. In the İstanbul Strait there are two sills: one is located off the northern entrance at about 60 m depth, and the other is off the southern entrance at about 30 m of depth. The sill depth of the Çanakkale Strait is about 70 m deep. These sills prevented water exchanges between the Black Sea and Mediterranean Sea when the global sea level was at low stands during glacial periods, until the sea level rising during the interglacial periods.

Material and Methods

Gravity core DM18 and piston core KL40 were collected from the Central Basin of the Marmara Sea during a cruise of the R/V MTA *Sismik-1* in 1998 and M44/1 cruise of the R/V *Meteor* in 1999, respectively (Figure 1c & Table 1). The cores were lithologically described and systematically sub-sampled at 2 cm intervals (KL40, Kuhn *et al.* 2000; DM18, Başaran 2002).

Dates for the cores are based on the accelerator mass spectrometry (AMS) ¹⁴C dating method performed at the NSF Arizona AMS Laboratory of Arizona University with a precision of ±41 to ±50 years standard deviation (Table 2). A Tephra layer, dated 22 ky BP cal (uncalibrated age: 18.05–18.88 ky BP, Pichler & Friedrich 1976; Eriksen *et al.* 1990 in Wulf *et al.* 2002) from the Cape Riva Eruption of Santorini was used as a further time marker

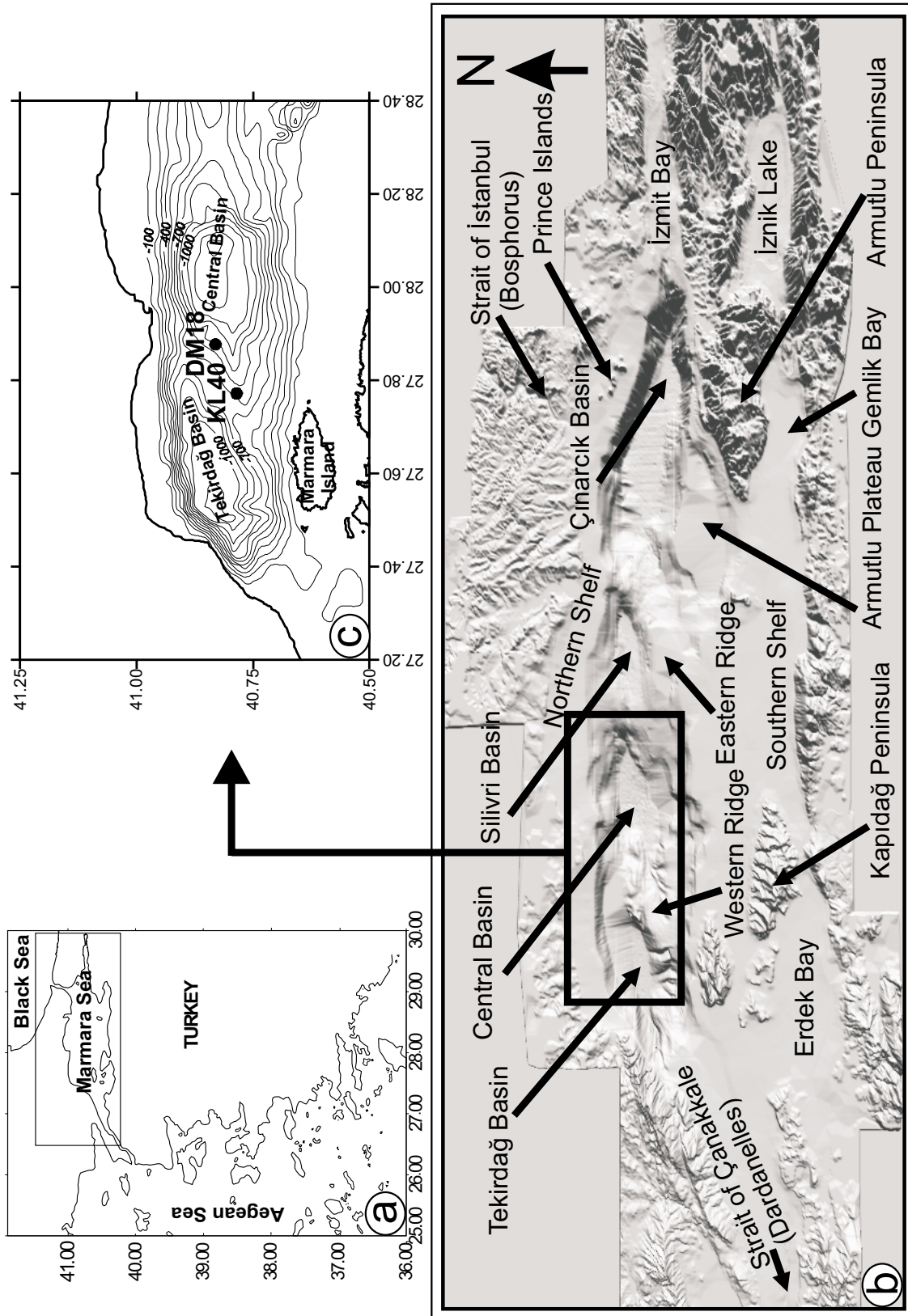


Figure 1. (a) Location map of the Marmara Sea. (b) Sub-bottom morphological image of the Marmara Sea (from Gazioglu *et al.* 2002). The study area is enclosed within a rectangle. (c) Location of the studied cores (bathymetry map from MTA 2004).

Table 1. Location, water depth and length of the studied cores.

Core number	Latitude (N)	Longitude (E)	Water depth (m)	Core length (cm)
DM18	40°49.845'	27°52.626'	895	424
KL40	40°47.12'	27°46.31'	703	901

Table 2. Radiocarbon ages of selected levels in the Marmara Sea cores based on uncalibrated AMS ¹⁴C measurements (*: from Caner 2005).

Core	Depth (cm)	Dated material	Laboratory number	¹⁴ C date (yr BP)
DM18	46-48	<i>U. mediterranea</i> + <i>B. striata</i>		1893 ± 37*
DM18	198-200	Planktic foraminifera (mix)	AA59214	5096 ± 41
DM18	314-316	<i>G. bulloides</i>	AA59215	9277 ± 49
KL40	98-100	Bulk carbonate	AA59216	7716 ± 46
KL40	131-133	Bulk carbonate	AA59217	9160 ± 50

in core KL40. The radiocarbon dates in this study are expressed as uncalibrated to compare them with uncalibrated ages published in previous studies (Çağatay *et al.* 2000; Aksu *et al.* 2002a, b; Kaminski *et al.* 2002; Hiscott & Aksu 2002; Hiscott *et al.* 2002) in the study area.

Total carbonate and organic carbon (C_{org}) contents of the sediment samples in core KL40 were determined by a gasometric-volumetric method (Loring & Rantala 1992) and the Walkley-Blake method (Gaudette *et al.* 1974; Loring & Rantala 1992). The total carbonate and C_{org} values of core DM18 came from Başaran (2002).

Foraminiferal analyses were performed at about 10 cm intervals in each core. Sapropelic layer in core DM18 was studied at about 2–6 cm intervals for foraminiferal analysis. 10 g of sub-sampled dried sediments were soaked in 10% H_2O_2 and then washed on a 0.063 mm sieve. The residue was dried in air and later sieved on a 0.125 mm sieve. All the residue of planktonic and benthic foraminiferal specimens were identified and counted in each fraction coarser than 0.125 mm. The results are given as percentages in the graphical illustrations, and as numbers of specimens per sample in the appendices. The lower interval (350–901 cm) of core KL40 is not shown in the graphical illustrations and appendix due to absence of a foraminiferal fauna. Direct comparisons of taxa were made using a planktonic foraminiferal collection from the Eastern Atlantic (Pflaumann & Krasheninnikov 1978) in Kiel University and a benthic foraminiferal collection from NW Africa (Lutze 1980) at Munich Ludwig-Maximilians

University (LMU). Taxonomic concepts of Parker (1962), Bolli & Saunders (1985), Hemleben *et al.* (1989), Cimerman & Langer (1991), Sgarrella & Moncharmont-Zei (1993), Jones (1994), Loeblich & Tappan (1994), Yassini & Jones (1995), Loeblich & Tappan (1998) and Meriç *et al.* (2004) were mainly followed for identification of species. Selected specimens were photographed using a Leitz-1200 scanning electron microscope at LMU, Munich. Ostracodan fauna were also picked out and identified at the same samples in the lower parts of the both cores (between 375 and 400 cms in DM18; between 190 and 890 cms in KL40) where a foraminiferal fauna is absent. Calcareous nannofossil examination was performed on 16 samples between 53 and 871 cms of core KL40. For microscopic determination of nannofossils smear-slides were prepared as outlined in Perch-Nielsen (1985a). Dried sediment samples were scrapped onto a glass slide by a needle or razor and diluted with distilled water to spread onto a lam, then covered by a lamella, using Canada balsam. Nannofossil assemblages were identified under a Nikon polarizing microscope with a Sony camera using the taxonomic description of Perch-Nielsen (1985a, b) and Martini (1971).

Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopic measurements were carried out on the planktonic foraminifera *Turborotalita quinqueloba* in core DM18 at the Isotope Geochemistry Laboratory of the LMU, Munich. Sediment samples were soaked in water and washed through a 0.063 mm sieve. About 100–195

individuals of the species were selected from the dry sieved grain size fraction of 0.125 to 0.250 mm for measurements. The results were referred to the international Vienna-Pee Dee Belemnite standard as ‰ deviation.

Results

Lithology and Chronology

The sediments of the studied cores are composed predominantly of muddy sediments (Figure 2). The uppermost 70 cm of core DM18 consists of brownish

grey-green mud. Greyish-green mud predominates between 70 and 250 cm. Dark olive green mud interbedded with a light greyish-green mud layer occurs between 250 and 342 cm. The lower parts of the core are composed mainly of light greyish-green mud with intervening yellowish-brown mud.

The uppermost 410 cms of core KL40 are composed of dark olive to olive grey mud with occasional dark coloured stains and spots (Figure 2). The interval between 410 and 540 cms is represented by a dark grey-blackish grey mud, bounded with a coarse-grained thin layer (8 cm thick). The lower parts of the cores show

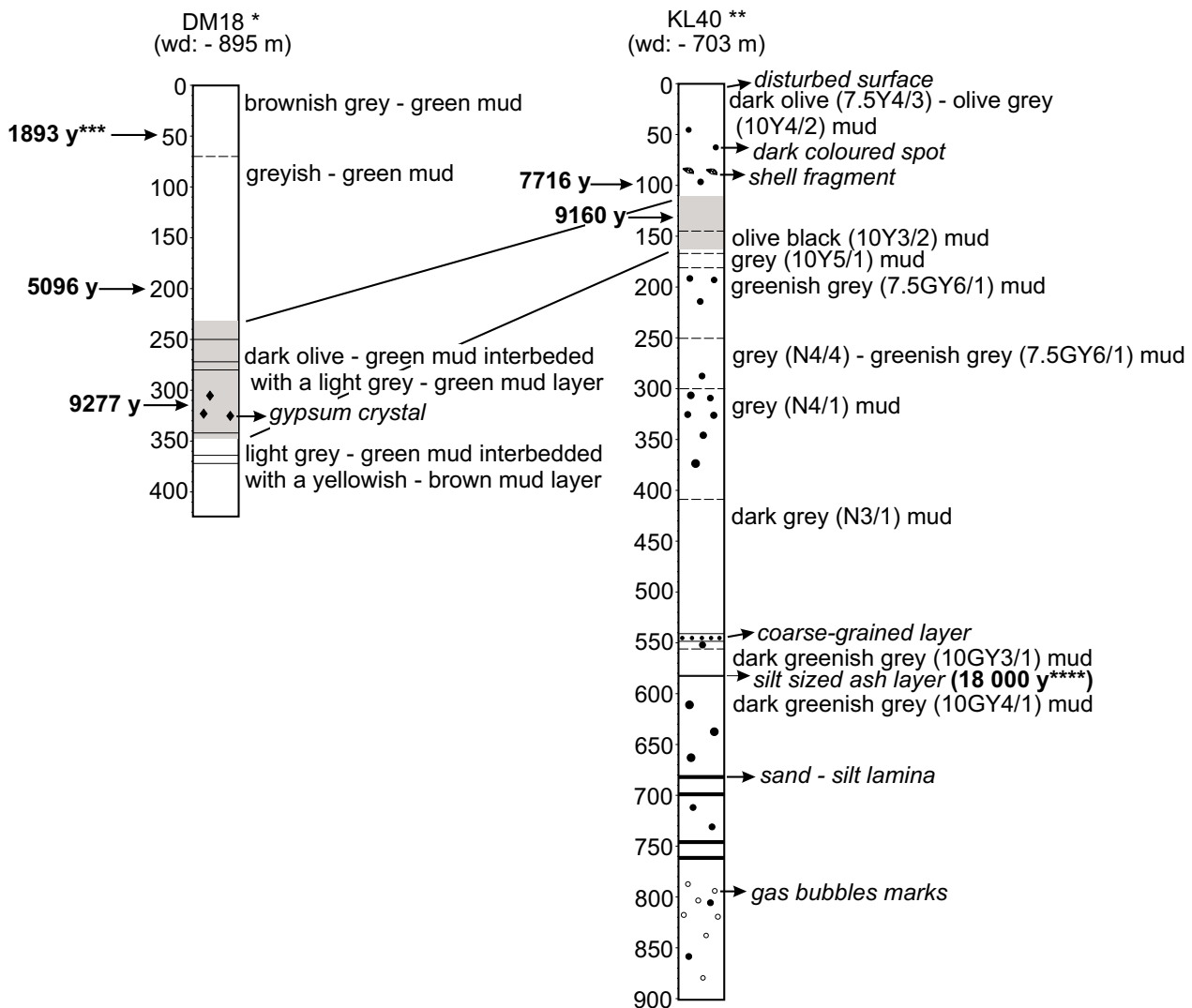


Figure 2. Lithological features of the Marmara Sea cores (*: from Bařaran 2002; **: from Kuhn *et al.* 2000) and uncalibrated AMS ¹⁴C dates (***: from Caner 2005) in the cores. ****: uncalibrated date for ash layer was used from Wulf *et al.* (2002). The shaded intervals indicate the sapropelic layer.

mainly different tones of green and grey. The ash layer linked to the Cape Riva event was found (Wulf *et al.* 2002) between 582 and 583 cms in this core.

A sapropelic layer occurs between 232 and 345 cms in core DM18 and between 111 and 163 cms in core KL40. The lower boundaries of the sapropelic layer of both cores are highlighted by lithological sign, whereas the upper boundaries do not show any lithological sign. The discrimination is based on C_{org} content $> 1.5\%$. A total of 5 age determinations both from foraminiferal calcite and bulk carbonate were obtained in two cores (Table 2). Linear interpolated AMS ^{14}C ages obtained from foraminiferal calcite in core DM18 suggest that sapropelic sediments were deposited between 10.3 and 6.2 ky BP, whereas dates from bulk carbonate in core KL40 suggest that sapropelic sediments were deposited between 10 and 8.3 ky BP (Tables 2 & 3). Radiocarbon dates from KL40 are in agreement with the lower limit of the sapropelic sediments in DM18, but gave slightly older age for the upper limit, probably due to reworked older carbonate. Therefore, DM18 age dates have been considered for the chronology. The age of the sapropelic layer obtained in this study is in agreement with the previous findings as shown in the comparison of Table 3.

Total Carbonate and Organic Carbon Contents of the Core Sediments

The total carbonate and C_{org} contents of the core samples vary between 2.0 and 37.0% and between 0.2 and 3.6%, respectively (Figure 3). The carbonate distribution of core DM18 is practically homogeneous (9.0–13.0%) and displays a peak only in the lower part of the core with the highest values ranging from 23.0 to 35.0%. In core KL40, the highest carbonate values (26.0–37.0%) are found between 191 and 212 cms. The lowest value (2.0%) occurs within the ash layer. The rest of this core

has intermediate carbonate values ranging from 7.0 to 14.0%.

A sapropelic layer containing 1.5–3.6% and 1.5–2.9% C_{org} occurs at 232–345 cms in core DM18, and at 111–163 cms in core KL40, respectively. This sapropelic layer in terms of age and C_{org} content corresponds to a previously defined sapropelic layer (see Çağatay *et al.* 2000: Lower sapropelic layer; Aksu *et al.* 2002a: sapropel M1; Sperling *et al.* 2003: S1_{Marmara}; Table 3). The lowest C_{org} values are observed in sediments deposited below the sapropelic layer, whereas intermediate values occur in sediments overlying the sapropelic layer. The maximum carbonate values of both of the cores correspond to the level just below the sapropelic layer.

Local Biostratigraphical Division

Throughout the cores, the benthic foraminiferal fauna display high diversity compared with the planktonic fauna and is represented by predominantly calcareous forms. However, most of the species have low abundances and sporadic occurrences. Planktonic foraminifera are abundant in spite of low diversity. *Neogloboquadrina pachyderma*, *Globigerina bulloides*, *Globigerinoides ruber* and *Turborotalita quinqueloba* show significant abundances, whereas the other planktonic foraminiferal species are represented only by sporadic occurrences. The ostracoda fauna exhibits low diversity and abundance in the lower parts of the cores where a foraminiferal fauna is absent. The down-core distribution of microfauna shows distinct quantitative patterns and assemblages (Figures 4–10) and hence allows subdivision of the biostratigraphical zones into three sections: (i) pre-sapropelic sediments (Pr; Pr1-2), (ii) sapropelic sediments (Sap; Sap1-2), (iii) post-sapropelic sediments (Po; Po1-3).

Table 3. Comparison of radiocarbon ages calculated for the sapropelic levels found in previous studies.

Çağatay <i>et al.</i> (1999)	Çağatay <i>et al.</i> (2000)	Aksu <i>et al.</i> (2002)	Sperling <i>et al.</i> (2003)	This study
4750–3500 y	Upper sapropel	Sapropel M1	S1 _{Marmara}	10 300–6200 y
	4750–3200 y	10 500–6000 y	11 000–7000 y cal	
	Lower sapropel	Sapropel M2		
	10 600–6400 y	29 500–23 500 y		

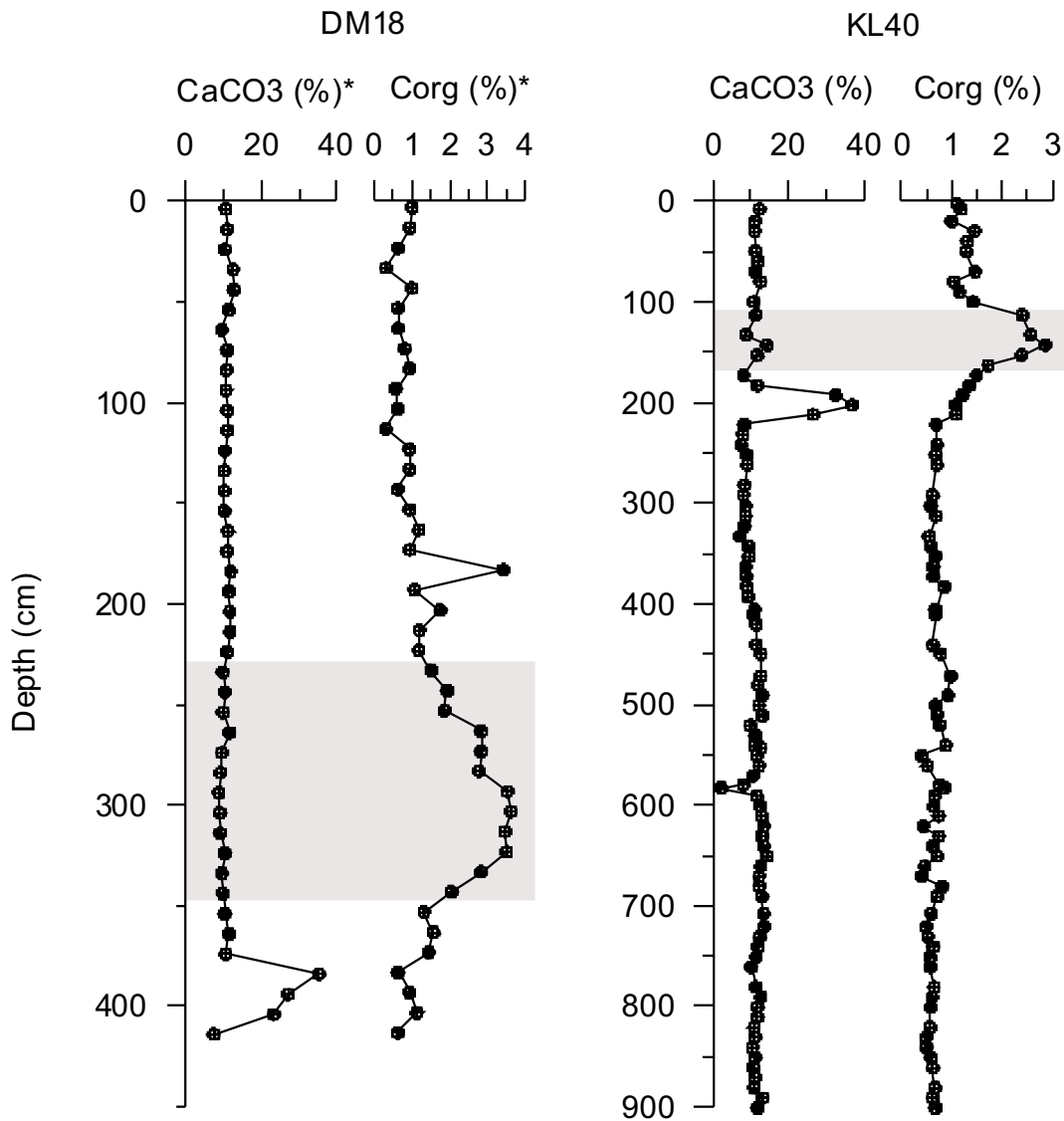


Figure 3. Downcore distribution of total carbonate and organic carbon contents of the cores (*: from Bařaran 2002). The shaded intervals indicate the sapropelic layer.

Pre-sapropelic Sediments (Pr). (Pr) sediments below the sapropelic sediments in both cores are characterized by very rare occurrence of foraminifera (Figures 4–10, Appendices 2 & 3) and by the presence of ostracoda. They are divided into two zones based on the appearance of foraminifera. The (Pr1) zone is practically barren of benthic and planktonic foraminifera, whereas significant numbers of *Bulimina aculeata*, *B. elongata*, *B. marginata* and *Turborotalita quinqueloba* occur in the (Pr2) zone in core DM18. This thin (Pr2) zone was not observed in the

upper part of the (Pr) sediments of core KL40 (Figures 7, 8 & 10). The nannofossil assemblages of the (Pr1) zone in KL40 (Table 4) includes completely reworked forms of Late Maastrichtian, Early Paleocene, Late Eocene, Early Miocene and Mio–Pliocene age, such as *Chiasmolithus solitus*, *Criboecium reticulatum*, *Florisphaera profunda*, *Gephyrocapsa cf. caribbeanica*, *Helicosphaera euphratis*, *Isthmolithus recurvus*, *Lithraphidites quadratus*, *Micula mura*, *Pseudoemiliana lacunosa*, *Semihololithus priscus* and *Zygrhablithus bijugatus*.

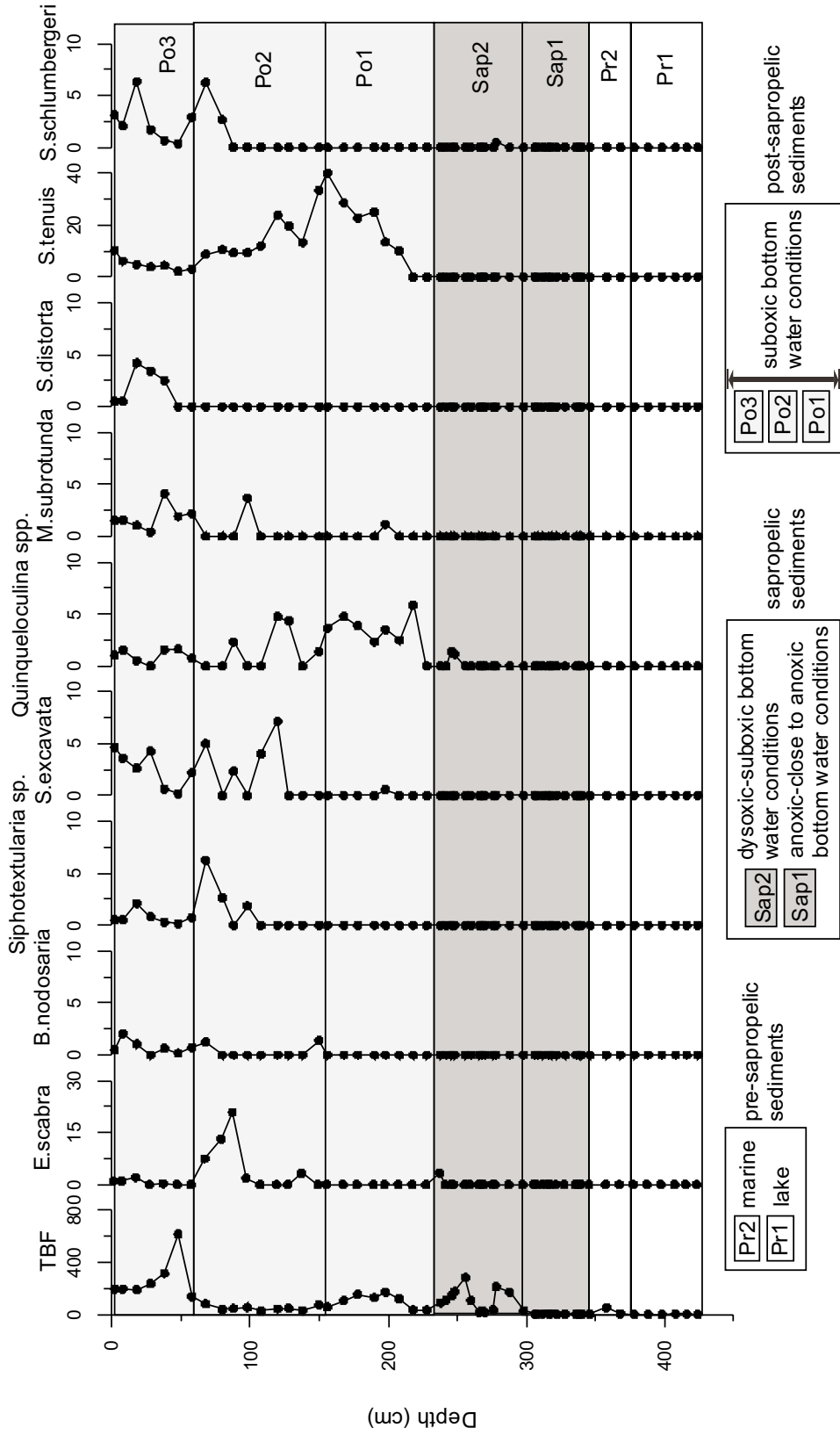


Figure 4. Downcore abundance of dominant benthic foraminiferal species in core DM18. TBF: Total benthic foraminifera presented as numbers/10 g dry sediment. Species frequencies are in percent of total.

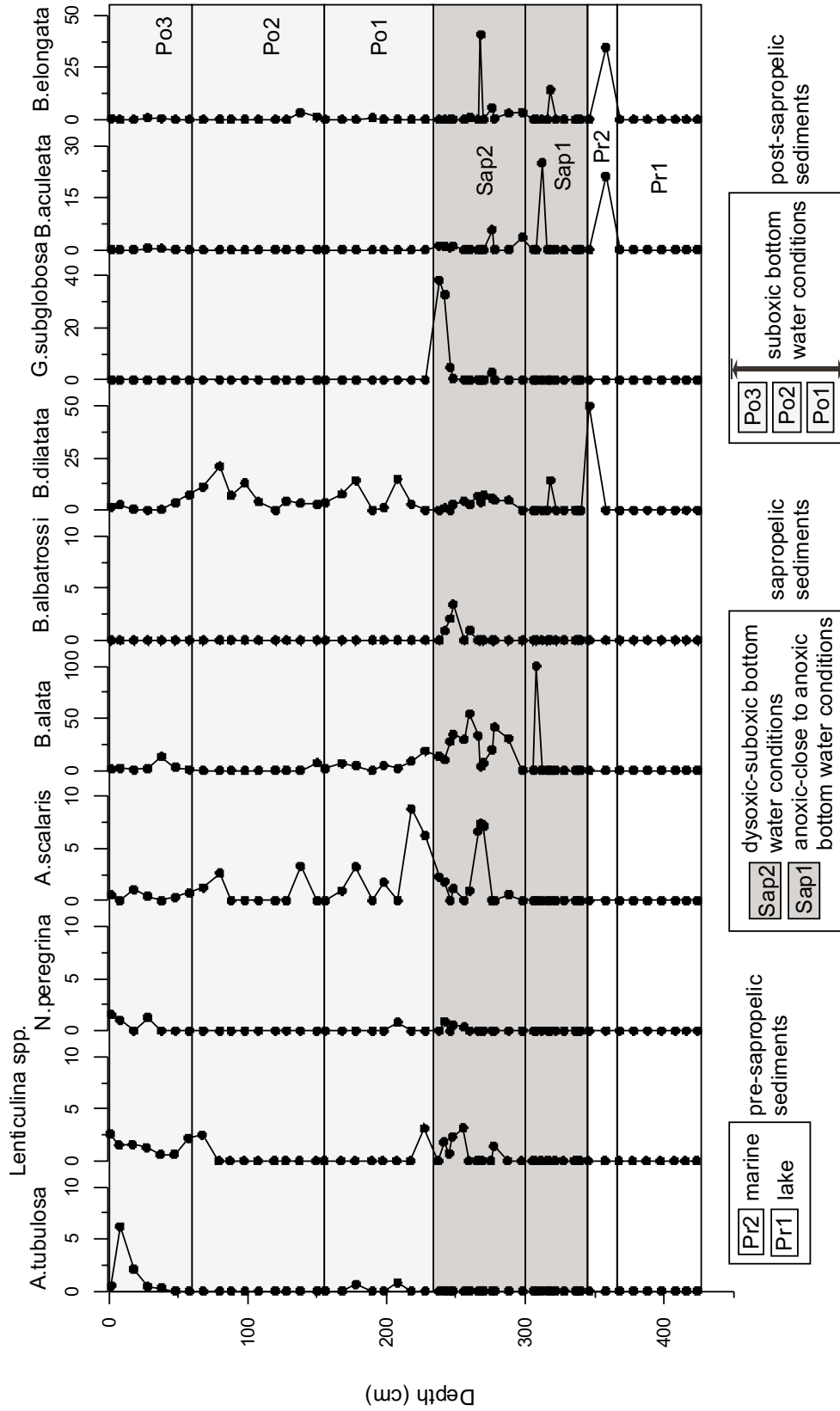


Figure 5. Downcore abundance of dominant benthic foraminiferal species in core DM18. Species frequencies are in percent of total.

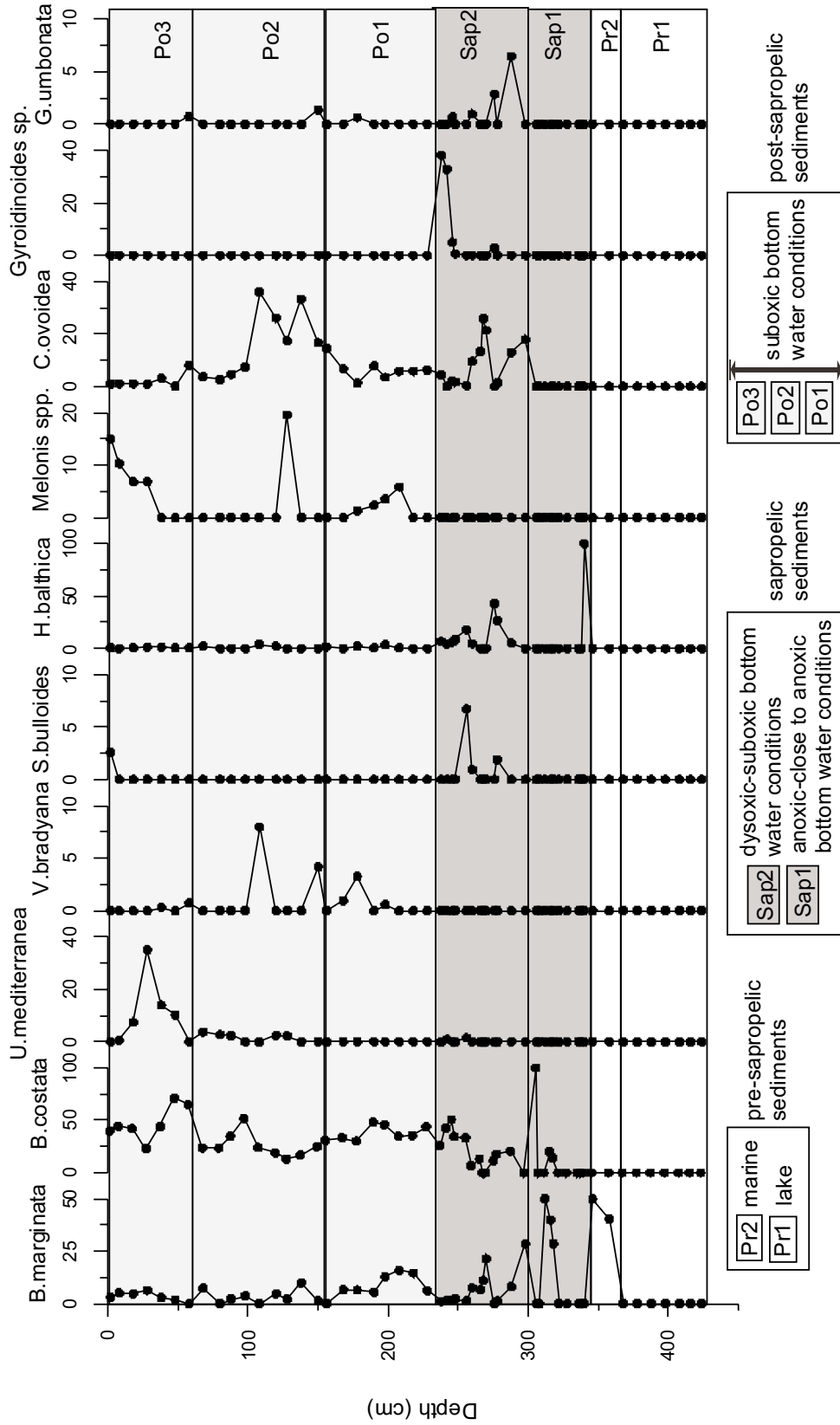


Figure 6. Downcore abundance of dominant benthic foraminiferal species in core DM18. Species frequencies are in percentage of the total.

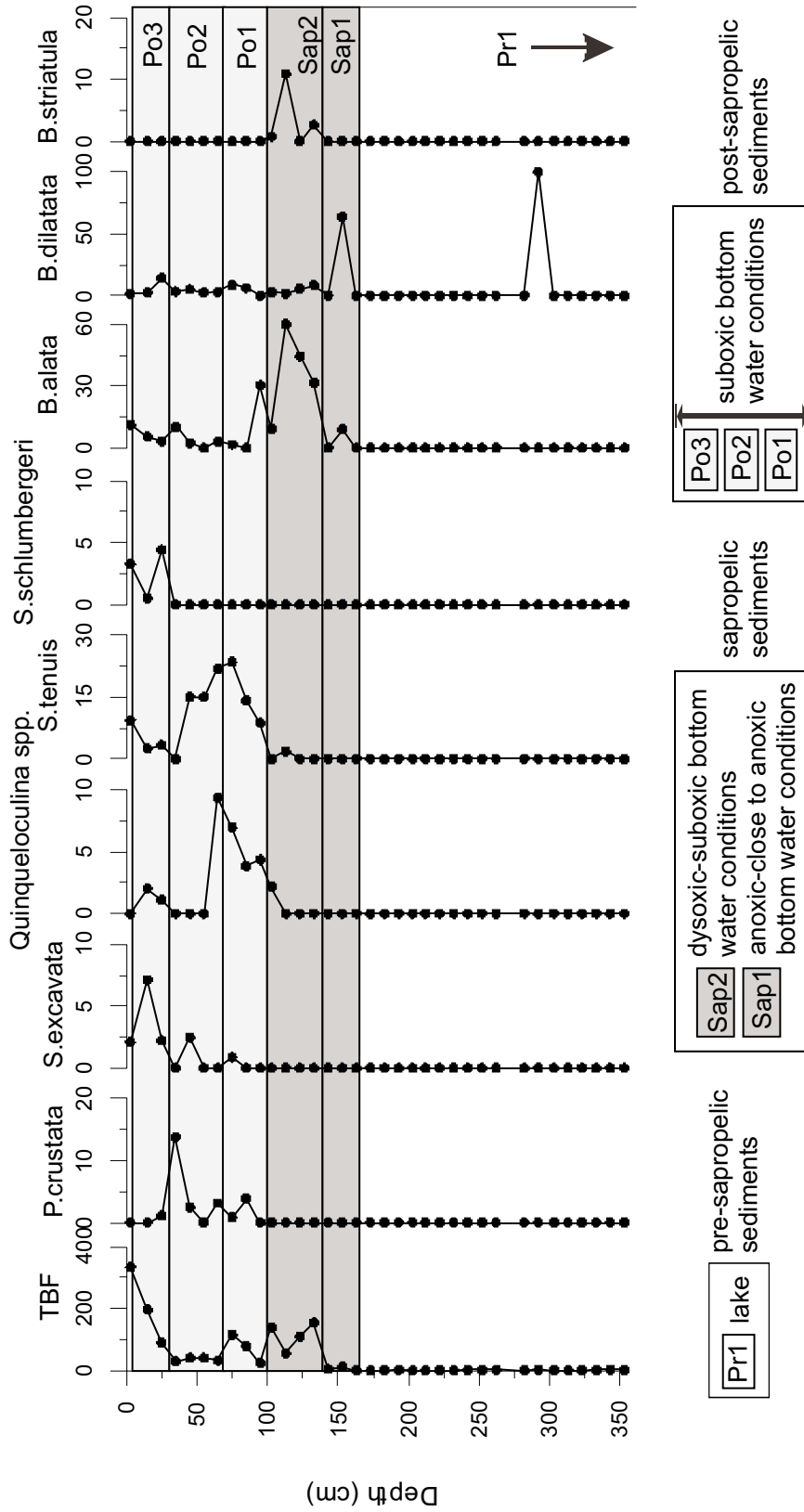


Figure 7. Downcore abundance of dominant benthic foraminiferal species in core KL40. TBF: Total benthic foraminifera presented as numbers/10 g dry sediment. Species frequencies are in percent of total. The lower interval (350–901 cm) of the core is not shown due to absence of a foraminiferal fauna.

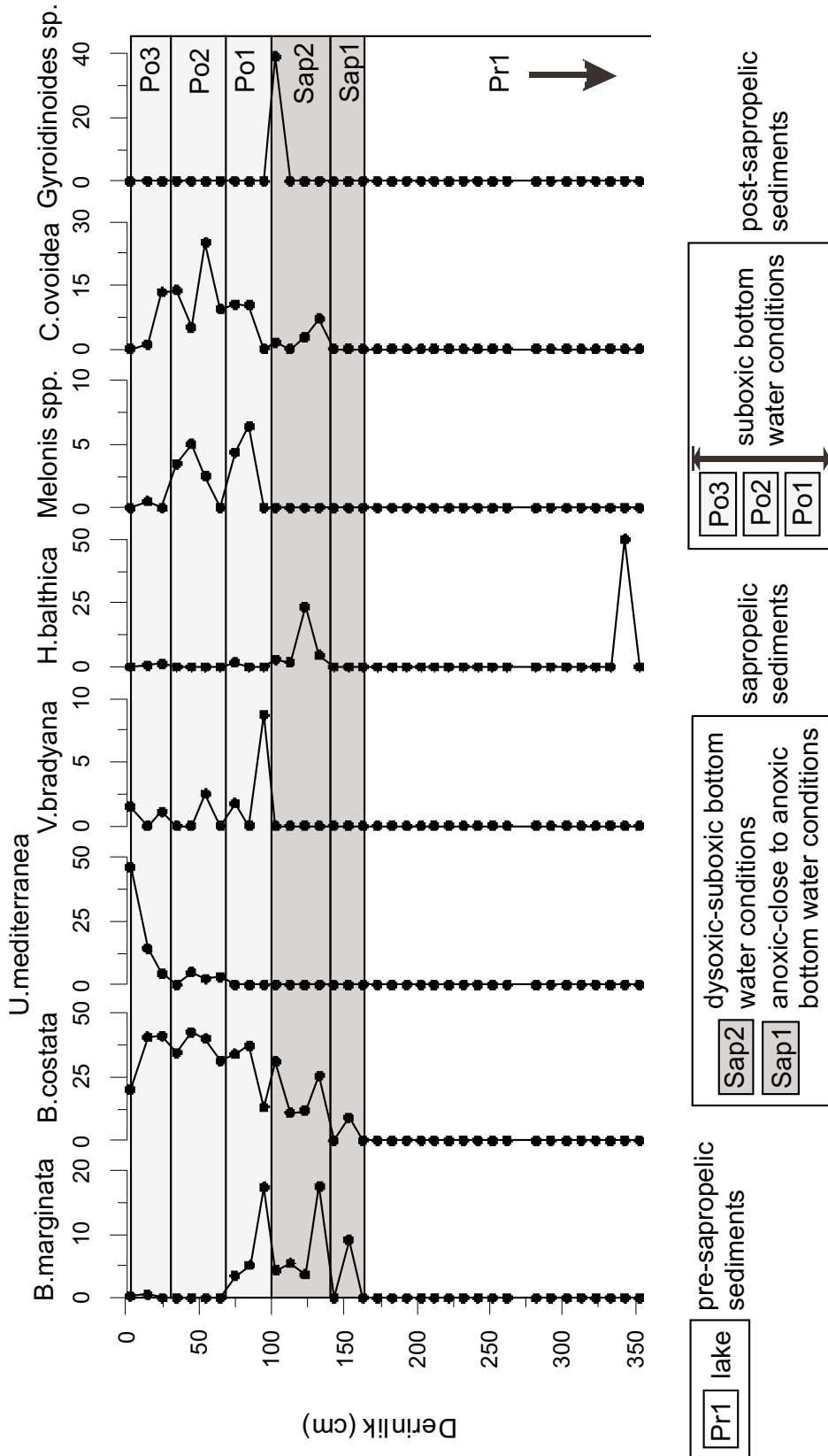


Figure 8. Downcore abundance of dominant benthic foraminiferal species in core KL40. Species frequencies are in percent of total. The lower interval (350–901 cm) of the core is not shown due to absence of a foraminiferal fauna.

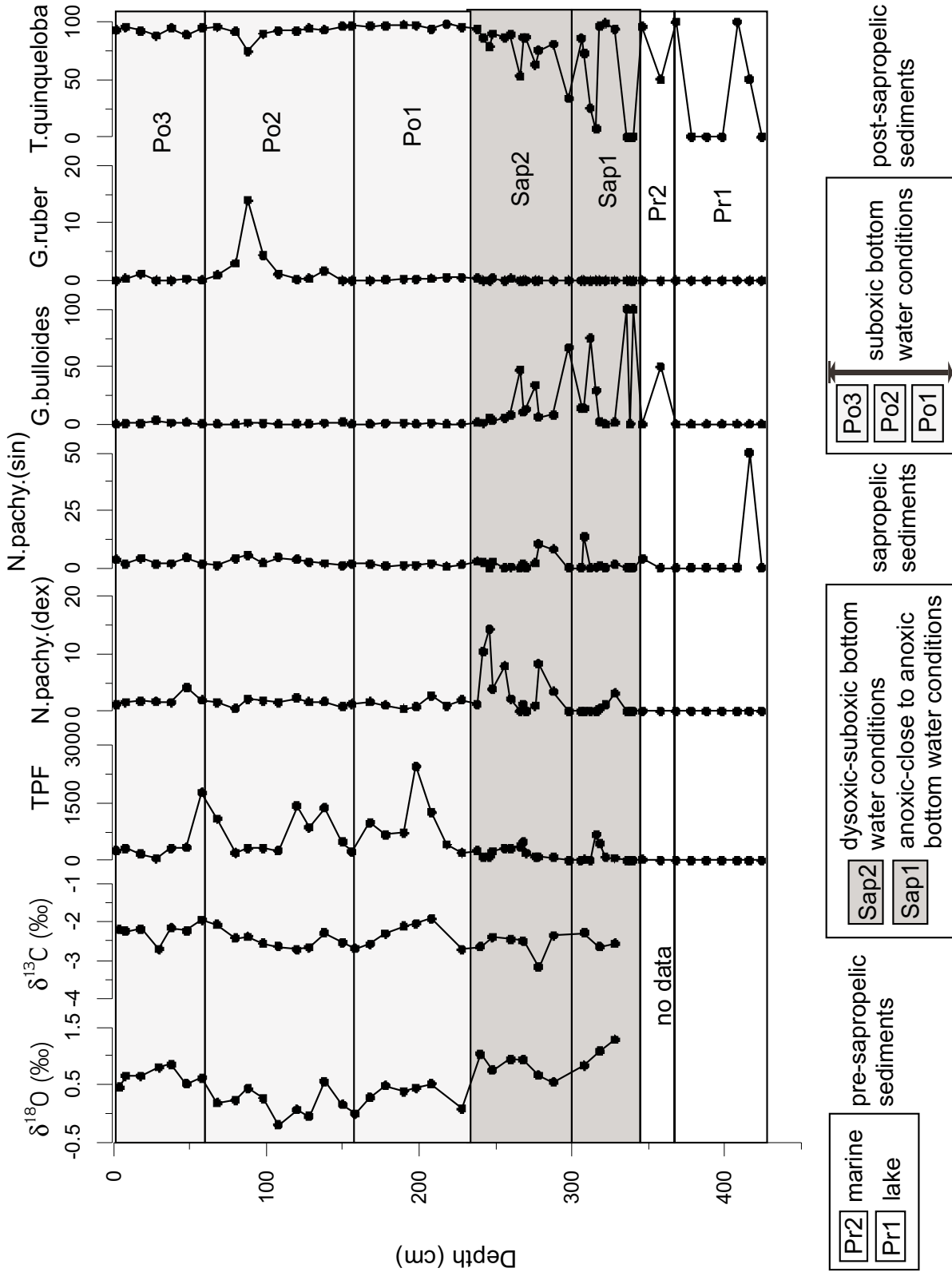


Figure 9. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records of planktic foraminifera *Turborotalita quinqueloba* and abundances of dominant planktic foraminiferal species in core DM18. TPF: Total planktonic foraminifera presented as numbers/10 g dry sediment. Species frequencies are in percent of the total.

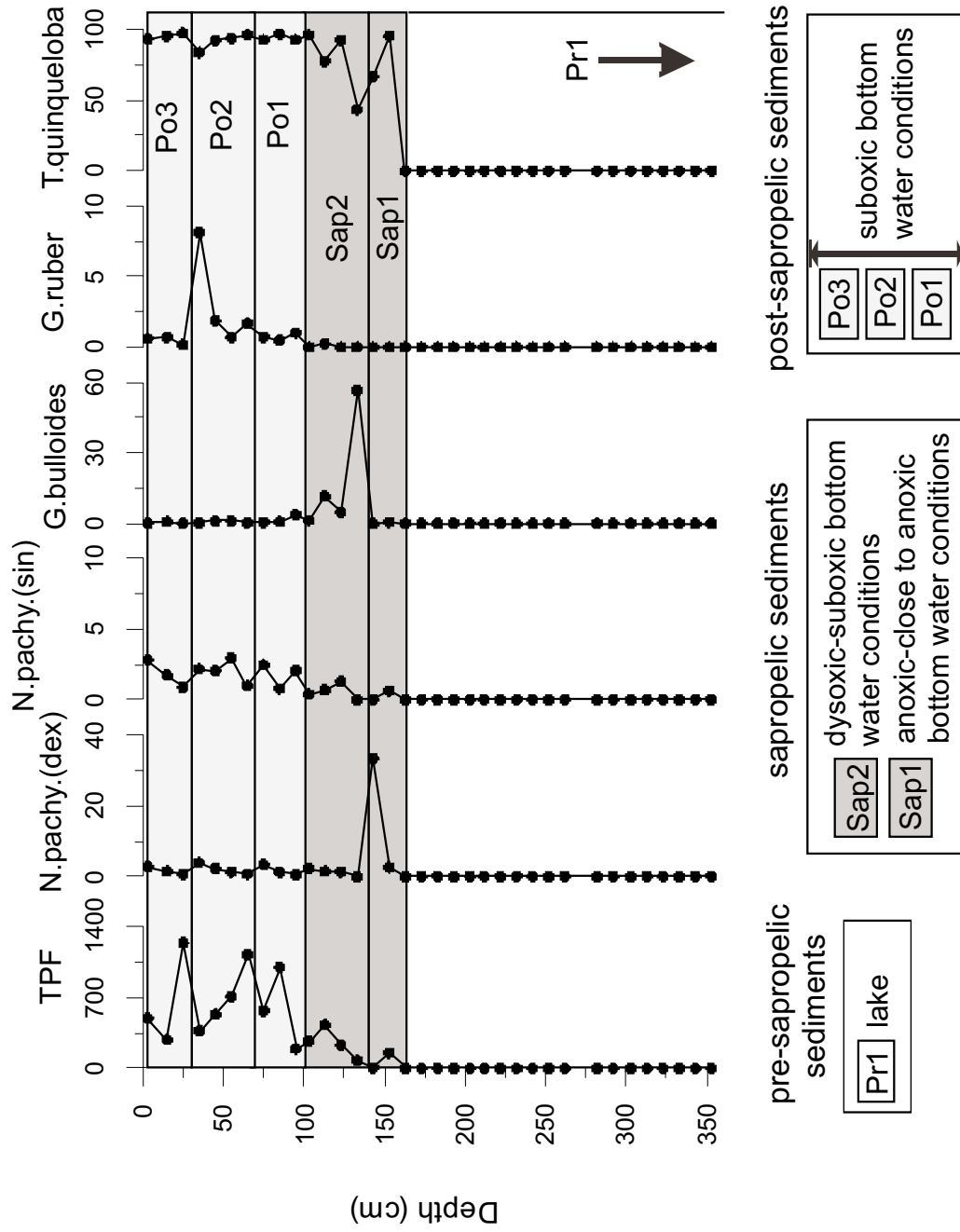


Figure 10. Downcore abundance of dominant planktic foraminiferal species in core KL40. TPF: Total planktic foraminifera presented as numbers/10 g dry sediment. Species frequencies are in percent of total. The lower interval (350–901 cm) of the core is not shown due to absence of foraminiferal fauna.

Table 4. General characteristics of the nannofossils assemblages in the studied levels of core KL40.

NANNOFOSSILS	Depth (cm)															
	53-55	73-75	83-85	93-95	101-103	191-193	311-313	391-393	403-406	519-521	549-551	569-591	629-631	809-811	829-831	869-871
<i>Braarudosphaera bigelowii</i> (Gran & Braarud)	rR	RF	FC	FC	R											
<i>Calcidiscus leptoporus</i> (Murray & Blackman)	-	r	-	-	r											
<i>Calciosolenia murrayi</i> Gran	-	-	-	-	r											
<i>Coronosphaera mediterranea</i> (Lohmann)	RF	F	FC	F	RF											
<i>Coccolithus pelagicus</i> (Wallich)	RF	RF	F	RF	RF											
<i>Crenalithus dornicoides</i> (Black & Barnes)	r	-	r	-	r											
<i>Dictyococcites antarcticus</i> Haq	RF	rR	R	R	r											
<i>Dictyococcites productus</i> (Kamptner)	RF	R	RF	R	F											
<i>Emiliana huxleyi</i> (Lohmann)	FC	FC	C	FC	C											
<i>Gephyrocapsa ericsonii</i> McIntyre & Bé	FC	FC	FC	FC	F											
<i>Gephyrocapsa muelleri</i> Bréhéret	R	R	r	rR	rR											
<i>Gephyrocapsa oceanica</i> Kamptner	-	-	r	r	R											
<i>Helicosphaera carteri</i> (Wallich)	R	r	R	F	RF											
<i>Helicosphaera hyalina</i> (Gaarder)	RF	R	F	F	F											
<i>Helicosphaera wallichii</i> (Lohmann)	RF	R	F	F	F											
<i>Syracosphaera pulchra</i> Lohmann	r	R	R	RF	r											
<i>Thoracosphaera</i> spp.	RF	R	r	rR	R											
<i>Umbellosphaera irregularis</i> Paasche	-	-	r	-	r											
<i>Umbilicosphaera sibogae</i> (Weber-van Bosse)	r	r	-	r	r											
+																
Reworked Nannofossils (ratio in the samples)	35%	20%	30%	30%	35%											
BIOZONE	NN21 <i>E. huxleyi</i> Zone															

Explanation:
 r 1 specimen in per 100 area
 rR 2 specimen in per 100 area
 R 3 - 5 specimen in per 100 area
 RF 6 - 9 specimen in per 100 area
 F 10 - 15 specimen in per 100 area
 FC 16 - 50 specimen in per 100 area
 C 51 - 100 specimen in per 100 area

However, typical marine Late Pleistocene records were not observed. The ostracoda fauna in this zone includes species with thin and fragile carapaces such as *Candona candida*, *Candona* sp., *Darwinula* sp. and *Leptocythere lacertosa* in DM18 and *Callistocythere littoralis*, *Callistocythere* sp., *Candona candida*, *Candona* sp., *Candona (Pseudocandona)* sp., *Heterocypris* sp., *Leptocythere castanea*, *L. lacertosa*, *L. psammophila*, *Loxoconcha rhomboidea* and *Tyrrhenocythere amnicola* in KL40. The most common and dominant species is *Candona candida*. This species is one of the best-known benthic freshwater cypridoids. The maximum tolerated salinity for *Candona candida* reported in the literature is 5.77‰ (Meisch 2000). Other ostracod species, such as *Callistocythere littoralis*, *Callistocythere* sp., *Darwinula* sp., *Heterocypris* sp., *Leptocythere castanea*, *L. lacertosa*, *L. psammophila*, *Loxoconcha rhomboidea* and *Tyrrhenocythere amnicola* have sporadic occurrences; at present they generally live in oligohaline (0.5–5‰) and mesohaline (5–18‰) environments (van Morkhoven 1963; Guillaume *et al.* 1985; Besonen 1997).

Sapropelic Sediments (Sap). (Sap) sediments, defined by the C_{org} value >1.5% (Figure 3) include two zones, based on abundance and distribution pattern of foraminiferal fauna (Figures 4–10, Appendices 2 & 3). The lower parts of the (Sap) contain only a few benthic species (Sap1 zone). The (Sap2) zone is characterized by relatively abundant benthic foraminiferal assemblages, dominated by infaunal life-style-taxa, such as *Brizalina alata*, *B. dilatata*, *Bulimina costata*, *B. marginata*, *Hyalinea balthica* and *Chilostomella ovoidea*. The transition from the (Sap) sediments to the (Po) sediments is characterized by a sharp decrease in total benthic foraminifera (TBF) (Figures 4 & 7). The planktonic foraminiferal fauna of the (Sap) sediments are dominated by cold-water assemblages, including abundantly shallow-dwellers *Turborotalita quinqueloba* (Bé 1977; Hemleben *et al.* 1989; Ottens 1992; Stangeew 2001), *Globigerina bulloides* and subordinately specimen of *Neogloboquadrina pachyderma* (Figures 9 & 10). The (Sap1) zone includes low TPF consisting mainly of *Globigerina bulloides* and *Turborotalita quinqueloba*. In

the (Sap2) zone the occurrence of *Neogloboquadrina pachyderma* increases according to the TPF value. The highest abundance of *Globigerina bulloides* is observed only in the (Sap) layer.

Post-sapropelic Sediments (Po). Due to the different sedimentation rates the thicknesses of the (Po) interval are ~230 cms in core DM18 and ~100 cms in core KL40. The (Po) sediments are characterized by high abundance of TPF which displays some maxima, up to 2500 specimen/10 g (Figures 9 & 10). Considering both the TBF and TPF distributions, three zones can be identified (Po1, Po2, Po3; Figures 4–10). The TBF and the species richness start to increase in (Po1); the assemblage is represented mainly by *Sigmoilinita tenuis*, *Brizalina dilatata*, *Bulimina costata*, *B. marginata*, and by minor numbers of *Quinqueloculina* spp., *Spiroloculina excavata*, *Neolenticulina peregrina*, *Amphicoryna scalaris*, *Melonis* spp. and *Chilostomella ovoidea* (Figures 4–8). TBF decreases in the (Po2) zone, but diversity remains nearly the same (average number of species in the Po1 zone= 14; average number of species in the Po2 zone= 12). The occurrences of *Sigmoilinita tenuis*, *Brizalina dilatata*, *Bulimina costata* and *B. marginata* decrease, while *Chilostomella ovoidea* and other benthic species continue to occur sporadically with low abundance. The (Po3) zone includes the top parts of the cores; it shows the highest TBF and the most diverse benthic foraminiferal fauna (27 species, Figures 4–8). The most dominant taxa are *Bulimina costata* and *Uvigerina mediterranea* together with subordinate numbers of *Spiroloculina excavata*, *Quinqueloculina* spp., *Miliolinella subrotunda*, *Sigmoilinita tenuis*, *Sigmoilopsis schlumbergeri*, *Lenticulina* sp., *Brizalina alata*, *B. dilatata*, *Bulimina marginata*, *Melonis* spp., *Chilostomella ovoidea* and some agglutinated forms such as *Eggerella scabra*, *Bigenerina nodosaria*, *Pseudoclavulina crustata*, *Sigmoilopsis schlumbergeri*, *Siphotextularia* sp. and *Textularia* spp.

Regarding the planktonic foraminifera, the TPF value starts to increase within the (Po1) zone and the fauna include predominantly *Turborotalita quinqueloba* and *Neogloboquadrina pachyderma* (Figures 9 & 10). Abundant *Globigerinoides ruber* defines zone (Po2). TPF starts to decrease in the (Po3) zone and is represented by *Turborotalita quinqueloba*, with lesser numbers of *Neogloboquadrina pachyderma* (both dextral and sinistral morphotypes).

(Po) sediments also include nannofossils. NN21 *Emiliana huxleyi* Interval Zone (Martini 1971) were identified (Table 4 & Plate I). *Emiliana huxleyi* is accompanied by *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Coronosphaera mediterranea*, *Dictyococcites antarcticus*, *D. productus*, *Gephyrocapsa ericsonii*, *G. muelleriae*, *G. oceanica*, *Helicosphaera carteri*, *H. hyalina*, *H. wallichii*, *Syracosphaera pulchra*, *Thoracosphaera* spp. and *Umbilicosphaera sibogae*. However, the presence of *Braarudosphaera bigelowii*, *Helicosphaera carteri*, *H. hyalina* and *H. wallichii* within the zone is conspicuous. In addition, approximately 20–35% of reworked forms consisting of Cretaceous, Early or Late Tertiary species occur at this level of the core. The abundance of *Emiliana huxleyi* and the absence of *Pontosphaera indoceanica* indicate that these levels were deposited during the Holocene.

Stable Isotope Records

The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ records of planktonic foraminifera *Turborotalita quinqueloba* in core DM18 extend from the top to 328 cms (within the [Sap] layer). The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values range from -3.18 to -1.92‰ and from 1.28 to -0.20‰, respectively (Figure 9). The higher $\delta^{18}\text{O}$ values (between 1.28 and 0.54‰) occur within the (Sap) layer. The transition from the (Sap) sediments to the (Po) sediments is marked by a sharp decrease in $\delta^{18}\text{O}$ values with 0.95‰ depletion. The most depleted values are observed within the (Po) sediments, where it is possible to distinguish three patterns towards the top of the core: (i) between 226 and 158 cms, $\delta^{18}\text{O}$ value increases from 0.08‰ to 0.51‰; (ii) between 158 and 58 cms, $\delta^{18}\text{O}$ values display fluctuations from -0.20 to 0.55‰; (iii) in the uppermost part of the core, $\delta^{18}\text{O}$ values fluctuate between 0.45 and 0.85 ‰. Although there is no statistically strong correlation between isotopes and TBF; TPF values along the core and the biostratigraphic zone boundaries correspond to major changes in isotope distributions (Figure 9).

Discussion

Lake Stage and Initial Colonisation–Pre-sapropelic Deposition

Cores DM18 and KL40 recovered from the Central Basin of the Marmara Sea record the last lowstand stage of the Marmara Sea. The lower parts of the cores (Pr1 zone,

Figures 4–10) are nearly totally barren of benthic and planktonic foraminifera. The (Pr1) zone between 170 and 901 cms in KL40 includes mixed/old nannofossils although characteristic Late Pleistocene forms were not observed (Table 4). Very rare occurrences of marine fauna and flora and the presence of fresh-brackish water ostracods in the (Pr1) zone denote the lake stage of the Marmara Sea when it was isolated from the Black Sea and the Aegean Sea during Last-glacial time when sea level was below the sill depth of the Çanakkale Strait. These results are in agreement with Stanley & Blanpied (1980), Çağatay *et al.* (2000), Aksu *et al.* (2002a) and Kaminski *et al.* (2002). The salinity of the Marmara Lake must have been much lower than that of the Mediterranean waters, as inferred from oligohaline and mesohaline ostracoda species recorded in the (Pr1) zone. Thus sudden water stratification is likely expected to occur during the invasion of Mediterranean waters. The first colonization of foraminiferal species such as *Bulimina aculeata*, *B. elongata*, *B. marginata* and *Turborotalita quinqueloba* occurs at about 11–10.4 ky BP in core DM18 based on the interpolated ^{14}C ages (Pr2 zone: from 345 to 370 cms, Figures 5, 6 & 9). These assemblages denote the start of marine conditions and record saline Mediterranean Sea water inflow through the Çanakkale Strait before the sapropelic deposition. The Mediterranean influence at shallower sites (~550 and 110 m water depths) is recorded by *Turborotalita quinqueloba*, *Fursenkoina* together with subordinate numbers of *Brizalina* and *Bulimina* species and *Aubignyna perlucida*, *Cassidulina carinata*, *Fursenkoina acuta* and *Haynesina depressula*, respectively (Aksu *et al.* 2002a; Kaminski *et al.* 2002).

Sapropelic Deposition

The benthic foraminiferal assemblage of the (Sap) interval allows determination of the oxygen level of bottom water during deposition of the sapropelic sediments in the Marmara Sea. The lower part of the sapropelic layer (Sap1 zone) is almost barren of benthic foraminifera indicating that the first stage of sapropelic deposition started under anoxic-close to anoxic bottom water conditions (Figures 4–8). The first appearance of species such as *Brizalina alata*, *B. dilatata*, *Bulimina costata*, *B. marginata*, *Hyalinea balthica* and *Chilostomella ovoidea* in the (Sap2) zone is indicative of dysoxic and suboxic environments. On the basis of test morphology

(Kaiho 1991, 1994), the genera *Brizalina* and *Chilostomella* are considered dysoxic indicators and some species of the genera *Bulimina* are suboxic indicators (Aksu *et al.* 2002a). Considering the microhabitat, *Brizalina alata*, *B. dilatata* and *Chilostomella ovoidea* are deep infaunal species (Jorissen 1999a; Kitazato *et al.* 2000), whereas *Bulimina costata*, *B. marginata* and *Hyalinea balthica* are infaunal, shallow-deep infaunal and shallow infaunal, respectively (Rathburn *et al.* 1996; Jorissen *et al.* 1998; Jorissen 1999a, b; Schmiel *et al.* 2000). Selected species of deep-infaunal taxa can live down to 10 cms depth in sediments (Jorissen 1999b) and can tolerate very low oxygen conditions (Jorissen 1999a). In this case, it is likely that the deep infaunal taxa are more resistant to low oxygen conditions compared to shallow-infaunal taxa because of the decreasing dissolved-oxygen content downward in sediments resulting from organic degradation. Combining the test morphology and microhabitat, we assume that *Brizalina alata*, *B. dilatata*, *Bulimina marginata* and *Chilostomella ovoidea* are dysoxic indicators, whereas *Bulimina costata* and *Hyalinea balthica* are suboxic indicators. These assemblages in (Sap2) zone show that anoxic-close to anoxic bottom water conditions in the initial stage of the sapropelic deposition must have changed to dysoxic-suboxic conditions in the (Sap2) zone (Figures 4–8). Near the top of the (Sap2) zone, the maximum abundance of *Gyroidinoides*, which is an indicator of suboxic conditions (Kaiho 1994), clearly indicates establishment of suboxic conditions in the bottom waters (Figures 6 & 8). At the same level, the frequency of dysoxic species becomes less abundant. This might be related to the decreasing organic matter input as indicated by the decreasing C_{org} content (Figure 3). Some benthic foraminifera are highly responsive to organic flux changes and cannot survive under constantly reduced food availability (Altenbach & Sarnthein 1989; Gupta 1999; Jian *et al.* 1999; De Rijk *et al.* 2000; Kitazato *et al.* 2000; Wollenburg & Kuhnt 2000).

The significant occurrence of *Globigerina bulloides* in the (Sap1-2) zones can testify to enhanced productivity in the surface waters of the Marmara Sea during sapropelic deposition as previously shown by Rohling *et al.* (1997) and Sperling *et al.* (2003). Its absence and/or presence with <20 specimens in sediments above the (Sap) section suggests that primary production may have reduced after termination of sapropelic deposition (Figures 9 & 10). The maximum abundance of *Globigerina bulloides* within

the sapropel interval was also reported by Aksu *et al.* (2002a) and Sperling *et al.* (2003), but not interpreted as a sign of enhanced productivity during deposition of the sapropel by Aksu *et al.* (2002a).

The $\delta^{18}\text{O}$ records of *Turborotalita quinqueloba* display the most enriched $\delta^{18}\text{O}$ values ranging from 1.28 to 0.54‰ and occur within the (Sap1-2) zones in core DM18 (Figure 9). The $\delta^{18}\text{O}$ value sharply decreases at the boundary between the (Sap) and (Po) sediments. This trend suggests that a relative freshening of the surface waters occurred after deposition of the (Sap) sediments. If Black Sea waters had strongly outflowed into the Marmara Sea at about 11–10 ky BP the $\delta^{18}\text{O}$ values within the sapropelic layer should be depleted. However, the sapropelic layer displays the most enriched $\delta^{18}\text{O}$ values. The distribution patterns of $\delta^{18}\text{O}$ and C_{org} contents between the (Sap) and (Po) sediments suggest that the surface waters of the Marmara Sea were relatively saline during deposition of the sapropelic sediments and there must have been a relative freshening after the sapropelic deposition. *Turborotalita quinqueloba* lives mostly in the photic zone and bears symbionts (Hemleben *et al.* 1989). On the other hand, considering that the habitat of this species reflects the deeper layer, but not the surface water layer (Carstens *et al.* 1997; Niebler *et al.* 1999), it is possible that a relatively thin surface layer with brackish water from the Black Sea might have existed. However abruptly depleted $\delta^{18}\text{O}$ values of this species at the end of the sapropelic deposition clearly indicate the increasing brackish water inflow after deposition of the sapropelic sediments. This view contrasts with previous conclusions concerning formation of the sapropelic layers in the Marmara Sea (Çağatay *et al.* 2000; Aksu *et al.* 2002a). Multi-proxy data from core sediments in the Marmara Sea and Black Sea shelf areas indicate that the Black Sea strongly outflowed into the Marmara Sea at about 11–10 ky BP causing a strong water stratification that initiated sapropelic deposition (Aksu *et al.* 2002a, b). In addition, the formation of a delta located at the southern exit of the İstanbul Strait has been related to the presence of strong and persistent outflow of the Black Sea (Aksu *et al.* 2002a; Hiscott *et al.* 2002; Kaminski *et al.* 2002).

In these studies, depleted $\delta^{18}\text{O}$ from the planktic foraminiferal tests and the planktonic foraminiferal transfer functions have been considered as signatures of a significantly reduced surface water salinity and

temperature during the sapropel deposition interval. Although the same planktonic foraminifera have been used in our study, an opposite isotopic data trend was found. This contradiction remains partially unexplained. On the other hand, deltaic deposition at the southern exit of the İstanbul Strait was evidently linked to local river activity (the Kurbağalı stream) with east–west-prograding parasequences located on the eastern side of the İstanbul Strait and not to the strong outflow of the Black Sea (Göktaşan *et al.* 2005).

On the other hand, our isotopic data support the results of Sperling *et al.* (2003). These latter authors pointed out that the Black Sea is not a major factor for the formation of organic-rich sediments in the Marmara Sea on the basis of the heavy $\delta^{18}\text{O}$ values recorded on *T. quinqueloba* of the sapropelic sediments. Consequently; absence or presence (regarding the habitat of *T. quinqueloba*) of thin Black Sea-originating low salinity surface waters declining with strong Black Sea outflow at about 11–10 ky BP. The main conditions for sapropelic deposition must be the enhanced productivity at the surface waters as shown by high abundances of *Globigerina bulloides*. Water stratification and/or bottom water anoxia for preserving the sapropelic sediments might be produced by stratification between saline Mediterranean waters and Marmara Lake waters following the connection with the Mediterranean Sea via the Çanakkale Strait.

Post-sapropelic Deposition

The (Po) sediments reflect depositional conditions during the last ~6 ky BP in the Marmara Sea. The benthic foraminiferal assemblages of the (Po1-3) zones show that suboxic bottom conditions continued from the last stage of sapropelic deposition up to the present day. Although Miliolids are generally considered indicators of oxic conditions (Kaiho 1994), their occurrences are limited only to small forms (<350 μm) within the (Po) sediments. Considering the fact that the deep bottom waters of the Marmara Sea are oxygen-depleted at the present time, oxic bottom conditions in the basinal area are not expected. Depleted $\delta^{18}\text{O}$ values and significant abundance of *Turborotalita quinqueloba* in the (Po1) zone suggest that surface waters were cold and became relatively less saline just after the end of sapropelic deposition. This likely indicates the development of a Black Sea surface current, probably similar to the

present-day. At present-day condition, nutrient-rich, brackish Black Sea waters constitute the upper layer of the Marmara Sea. However, sapropelic sediments do not occur and the enhanced food dependent species *Globigerina bulloides* occurs in only minor amounts, which weakens the low-salinity, nutrient rich water-source view of sapropelic deposition. *Globigerinoides ruber*, indicating warm waters, occurs in maximum abundance only in the (Po2) zone and disappears in the upper parts of the cores, indicating an intermittent short term change. Planktonic foraminifera generally decrease in the (Po3) zone in the uppermost part of the cores. Biostratigraphical zones in post-sapropelic sediments probably reflect variations in sea level and/or local climatic conditions.

Conclusions

The core sediments from the Marmara Sea include various biostratigraphical zones that are characterized by their TBF, TPF and distinct assemblages in each depositional section. The pre-sapropelic sediments reflect the lake stage of an isolated Marmara Sea and also the beginning of marine conditions through the Çanakkale Strait at about 11 ky BP. Benthic foraminiferal assemblages of the sapropelic sediments show that the initial stage of the sapropelic sedimentation occurred under anoxic-close to anoxic bottom water conditions at 10.3 ky BP and continued into dysoxic-suboxic conditions. The leading conditions for sapropelic deposition inferred from the confined abundance of *Globigerina bulloides* within the sapropelic sediments were enhanced by primary productivity of the surface waters of the Marmara Sea. The most enriched $\delta^{18}\text{O}$ values within the sapropelic sediments and the most

depleted values within the post sapropelic sediments suggest that relative freshening of the surface waters must have occurred after deposition of the sapropelic sediments, but not during their deposition in the Marmara Sea. This finding implies the presence of only a thin Black Sea flow into the Marmara Sea during sapropelic deposition. Termination of sapropelic deposition at about 6.2 ky BP together with the most depleted isotope signals in post-sapropelic sediments suggest that a Black Sea outflow, probably similar to the present-day, had been established. Benthic foraminiferal assemblages within the (Po1-3) zones show that suboxic bottom conditions continued from the last stage of the sapropelic layer up to the present. Three zones in post-sapropelic sediments imply small variations during the establishment of present-day oceanographical conditions. Further studies will be necessary for a better understanding of these changes.

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Appendix 1. Taxonomy (in alphabetical order)

- Amphicoryna scalaris* (Batsch 1791)-Plate II, Figure 11**
 1791 *Nautilus (Ortoceras) scalaris* n. sp.-Batsch: p. 1, pl. 2, fig. 4
 1991 *Amphicoryna scalaris* (Batsch 1791)-Cimerman & Langer: p. 52, pl. 54, figs. 1-9
 1993 *Amphicoryna scalaris* (Batsch 1791)-Sgarrella & Moncharmont-Zei: p. 191, pl. 11, figs. 2-3
 2002 *Lagena striata* (d'Orbigny 1839a)-Kaminski *et al.*: pl. 2, fig. 4
- Articulina tubulosa* (Seguenza 1862b)**
 1862a *Quinqueloculina tubulosa* n. sp.-Seguenza: p. 119, pl. 2, fig. 8
 1993 *Articulina tubulosa* (Seguenza 1862b)-Sgarrella & Moncharmont-Zei: p. 190, pl. 10, fig. 10
- Asterigerinata mamilla* (Williamson 1858)**
 1858 *Rosalina mamilla* n. sp.-Williamson: p. 54, pl. 4, figs. 109-111
 2004 *Asterigerinata mamilla* (Williamson 1858)-Meriç *et al.*: p. 189, pl. 29, figs. 5-6
- Astrononion tumidum* Cushman & Edwards 1937**
 1937 *Astrononion tumidum* n. sp.-Cushman & Edwards: p. 33, pl. 3, fig. 17
 1993 *Astrononion tumidum* Cushman & Edwards 1937-Sgarrella & Moncharmont-Zei: p. 238, pl. 24, fig. 7
- Aubignyna perlucida* (Heron-Allen & Earland 1913)**
 1913 *Rotalia perlucida* n. sp.-Heron-Allen & Earland: p. 139, pl. 13, figs. 7-9
 2002 *Aubignyna perlucida* (Heron-Allen & Earland 1913)-Kaminski *et al.*: pl. 4, figs. 8-10
- Bigenerina nodosaria* d'Orbigny 1826-Plate II, Figure 2**
 1826 *Bigenerina nodosaria* n. sp.-d'Orbigny: p. 261, pl. 11, figs. 9-12
 1993 *Bigenerina nodosaria* d'Orbigny 1826-Sgarrella & Moncharmont-Zei: p. 164, pl. 4, fig. 12
- Biloculinella inflata* (Wright 1902)**
 1993 *Biloculinella inflata* (Wright 1902)-Sgarrella & Moncharmont-Zei: p. 188, pl. 10, fig. 12
- Brizalina alata* (Seguenza 1862a)-Plate II, Figures 13–14**
 1862 *Vulvulina alata* n. sp.-Seguenza: p. 115, pl. 2, fig. 5
 1991 *Brizalina alata* (Seguenza 1862a)-Cimerman & Langer: p. 59, pl. 61, figs. 12-14
 1993 *Bolivina alata* (Seguenza 1862a)-Sgarrella & Moncharmont-Zei: p. 207, pl. 14, fig. 8
 2002 *Brizalina alata* (Seguenza 1862a): Kaminski *et al.*: pl. 2, fig. 12
- Brizalina albatrossi* (Cushman 1922a)-Plate II, Figure 12**
 1922a *Bolivina albatrossi* n. sp.-Cushman: p. 311, pl. 6, fig. 4
 1993 *Bolivina albatrossi* Cushman 1922a-Sgarrella & Moncharmont-Zei: p. 207, pl. 14, fig. 7
- Brizalina difformis* (Williamson 1858)**
 1858 *Textularia variabilis* var. *difformis*-Williamson: p. 77, pl. 6, figs. 166-167
 1991 *Brizalina difformis* (Williamson 1858)-Cimerman & Langer: p. 59, pl. 61, figs. 9-11
- Brizalina dilatata* (Reuss 1850)-Plate II, Figure 15**
 1850 *Bolivina dilatata* n. sp.-Reuss: p. 381, pl. 48, fig. 15
 1991 *Brizalina dilatata* (Reuss 1850)-Cimerman & Langer: p. 59, pl. 62, fig. 2
- Brizalina pseudoplicata* (Heron-Allen & Earland 1930)**
 1930 *Bolivina pseudoplicata* n. sp.-Heron-Allen & Earland: p. 81, pl. 3, figs. 36-40
 1991 *Bolivina pseudoplicata* Heron-Allen & Earland 1930-Cimerman & Langer: p. 58, pl. 61, figs. 1-3
- Brizalina striatula* (Cushman 1922b)-Plate II, Figure 16**
 1922b *Bolivina striatula* n. sp.-Cushman: p. 27, pl. 3, fig. 10
 1991 *Brizalina striatula* (Cushman 1922b)-Cimerman & Langer: p. 60, pl. 62, figs. 6-9
 1993 *Bolivina striatula* Cushman 1922b-Sgarrella & Moncharmont-Zei: p. 210, pl. 14, fig. 16
 2002 *Brizalina striatula* (Cushman 1922b)-Kaminski *et al.*: pl. 2, fig. 10
- Brizalina subspinescens* (Cushman 1922b)**
 1922b *Bolivina subspinescens* n. sp.-Cushman: p. 48, pl. 7, fig. 5
 1993 *Bolivina subspinescens* Cushman 1922b-Sgarrella & Moncharmont-Zei: p. 210, pl. 14, figs. 12-13
 1994 *Brizalina subspinescens* (Cushman 1922b)-Jones: p. 57, pl. 52, figs. 24-25
- Bulimina aculeata* d'Orbigny 1826**
 1826 *Bulimina aculeata* n. sp.-d'Orbigny: p. 269
 1993 *Bulimina aculeata* d'Orbigny 1826-Sgarrella & Moncharmont-Zei: p. 211, pl. 15, fig. 1
- Bulimina costata* d'Orbigny 1852-Plate II, Figures 19–20**
 1852 *Bulimina costata* n. sp.-d'Orbigny: p. 194
 1993 *Bulimina costata* d'Orbigny 1852-Sgarrella & Moncharmont-Zei: p. 211, pl. 15, fig. 3

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- Bulimina elongata* d'Orbigny 1846-Plate II, Figure 17
 1846 *Bulimina elongata* n. sp.-d'Orbigny: p. 187, pl. 11, figs. 19-20
 2002 *Bulimina elongata* d'Orbigny 1846-Kaminski *et al.*: pl. 3, fig. 4
- Bulimina marginata* d'Orbigny 1826-Plate II, Figure 18
 1826 *Bulimina marginata* n. sp.-d'Orbigny: p. 269, pl. 12, figs. 10-12
 1993 *Bulimina marginata* d'Orbigny 1826-Sgarrella & Moncharmont-Zei: p. 212, pl. 15, figs. 5-7
- Cassidulina crassa* d'Orbigny 1839b
 1839c *Cassidulina crassa* n. sp.-d'Orbigny: p. 56, pl. 7, figs. 18-20
 1993 *Cassidulina crassa* d'Orbigny 1839b-Sgarrella & Moncharmont-Zei: p. 236, pl. 23, figs. 10-11
 1994 *Cassidulina crassa* d'Orbigny 1839b-Jones: p. 60, pl. 54, fig. 4
- Cassidulina laevigata* d'Orbigny 1826
 1826 *Cassidulina laevigata* n. sp.-d'Orbigny: p. 282, pl. 15, figs. 4-5
 1991 *Cassidulina laevigata* d'Orbigny 1839b-Cimerman & Langer: p. 61, pl. 63, figs. 1-3
- Chilostomella ovoidea* Reuss 1850-Plate II, Figure 25
 1850 *Chilostomella ovoidea* n. sp.-Reuss: p. 380, pl. 48, fig. 12
 1994 *Chilostomella ovoidea* Reuss 1850-Loeblich & Tappan: p. 160, pl. 350, figs. 1-3
- Dentalina communis* (d'Orbigny 1826)
 1826 *Nodosaria communis* n. sp.-d'Orbigny: p. 254
 1993 *Dentalina communis* (d'Orbigny 1826)-Sgarrella & Moncharmont-Zei: p. 192, pl. 11, fig. 6
- Discorbinella bertheloti* (d'Orbigny 1839a)
 1839b *Rosalina bertheloti* n. sp.-d'Orbigny: p. 135, pl. 1, figs. 28-30
 1993 *Discorbinella bertheloti* (d'Orbigny 1839a)-Sgarrella & Moncharmont-Zei: p. 216, pl. 16, figs. 11-12
- Eggerella scabra* (Williamson 1858)-Plate II, Figure 1
 1858 *Bulimina scabra* n. sp.-Williamson: p. 65, pl. 5, figs. 136-137
 1993 *Eggerella scabra* (Williamson 1858)-Sgarrella & Moncharmont-Zei: p. 162, pl. 4, fig. 9
- Elphidium aculeatum* (d'Orbigny 1846)
 1846 *Polystomella aculeata* n. sp.-d'Orbigny: p. 131, pl. 6, figs. 1-4
 1991 *Elphidium aculeatum* (d'Orbigny 1846)-Cimerman & Langer: p. 77, pl. 89, figs. 1-4
- Elphidium granosum* (d'Orbigny 1846)
 1846 *Nonionina granosa* n. sp.-d'Orbigny: p. 110, pl. 5, figs. 19-20
 1993 *Elphidium granosum* (d'Orbigny 1846)-Sgarrella & Moncharmont-Zei: p. 229, pl. 21, figs. 1-2
- Elphidium macellum* (Fichtel & Moll 1798)
 1798 *Nautilus macellus* n. sp.-Fichtel & Moll: p. 66, pl. 10, figs. e-g, h-k
 1993 *Elphidium macellum* (Fichtel & Moll 1798)-Sgarrella & Moncharmont-Zei: p. 229, pl. 20, fig. 12
 2002 *Elphidium macellum* (Fichtel & Moll 1798)-Kaminski *et al.*: pl. 5, fig. 11
- Favulina hexagona* (Williamson 1848)
 1848 *Entosolenia squamosa* (Montagu) var. *hexagona*-Williamson: p. 20, pl. 2, fig. 23
 1991 *Favulina hexagona* (Montagu 1803)-Cimerman & Langer: p. 55, pl. 58, figs. 8-9
- Fursenkoina acuta* (d'Orbigny 1846)
 1846 *Polymorphina acuta* n. sp. d'Orbigny: p. 234, pl. 13, figs. 4-5, pl. 14, figs. 5-7
 1993 *Fursenkoina acuta* (d'Orbigny 1846)-Sgarrella & Moncharmont-Zei: p. 235, pl. 23, fig. 7
- Globobulimina affinis* (d'Orbigny 1839b)
 1839a *Bulimina affinis* n. sp.-d'Orbigny: p. 105, pl. 2, figs. 25-26
 1993 *Globobulimina affinis* d'Orbigny 1839b-Sgarrella & Moncharmont-Zei: p. 212, pl. 15, figs. 8-9
- Globobulimina pseudospinescens* (Emiliani 1949)
 1949 *Bulimina pyrula* d'Orbigny var. *pseudospinescens*-Emiliani: p. 9, pl. 2, figs. 24-25
 1993 *Globobulimina pseudospinescens* (Emiliani 1949)-Sgarrella & Moncharmont-Zei: p. 212, pl. 15, fig. 12
- Globocassidulina subglobosa* (Brady 1881)
 1884 *Cassidulina subglobosa* n. sp.-Brady: p. 60
 1991 *Globocassidulina subglobosa* (Brady 1884)-Cimerman & Langer: p. 61, pl. 63, figs. 4-6
 1993 *Globocassidulina subglobosa* (Brady 1881)-Sgarrella & Moncharmont-Zei: p. 236, pl. 24, figs. 1-2
- Gyroidina umbonata* (Silvestri 1898)
 1898 *Rotalia soldanii* d'Orbigny var. *umbonata*-Silvestri: p. 329, pl. 6, fig. 14
 1993 *Gyroidina umbonata* (Silvestri 1898)-Sgarrella & Moncharmont-Zei: p. 241, pl. 25, figs. 1-2
- Gyroidinoides neosoldanii* (Brotzen 1936)
 1936 *Gyroidina neosoldanii* n. sp.-Brotzen: p. 158
 1994 *Gyroidina neosoldanii* Brotzen 1936-Loeblich & Tappan: p. 163, pl. 361, figs. 13-15, pl. 362, figs. 1-7

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- Gyroidinoides soldanii* (d'Orbigny 1826)**
 1826 *Gyroidina soldanii* n. sp.-d'Orbigny: p. 276
 1991 *Gyroidinoides soldanii* (d'Orbigny 1826)-Cimerman & Langer: p. 75, pl. 85, figs. 5-6
- Haynesina depressula* (Walker & Jacob 1798)**
 1798 *Nautilus depressulus* n.sp.-Walker & Jacob: p. 641, pl. 14, fig. 33
 1993 *Nonion depressulum* (Walker & Jacob 1798)-Sgarrella & Moncharmont-Zei: p. 238, pl. 24, figs. 3-4
 2002 *Haynesina depressula* (Walker & Jacob 1798)-Kaminski et al.: pl. 4, figs. 4-5
- Hyalinea balthica* (Schröter 1783)-Plate II, Figure 23**
 1783 *Nautilus balthicus* n. sp.-Schröter: p. 20, pl. 1, fig. 2
 1993 *Hyalinea baltica* (Schröter 1783)-Sgarrella & Moncharmont-Zei: p. 234, pl. 22, fig. 12
 2002 *Hyalinea baltica* (Schroeter)-Kaminski et al.: pl. 3, fig. 13
- Hyalinonetrion gracillimum* (Seguenza 1862a)**
 1862b *Amphorina gracillima* n. sp.-Seguenza: p. 51, pl. 1, fig. 37
 1991 *Hyalinonetrion gracillimum* (Seguenza 1862a)-Cimerman & Langer: p. 52, pl. 55, figs. 1-2
- Lagena nebulosa* Cushman 1923**
 1923 *Lagena laevis* (Montagu) var. *nebulosa*-Cushman: p. 29, pl. 5, figs. 4-5
 1993 *Lagena nebulosa* Cushman 1923-Sgarrella & Moncharmont-Zei: p. 198, pl. 11, fig. 18
- Lagena striata* (d'Orbigny 1839c)**
 1839b *Oolina striata* n. sp.-d'Orbigny: p. 21, pl. 5, fig. 12
 1991 *Lagena striata* (d'Orbigny 1839c)-Cimerman & Langer: p. 53, pl. 55, figs. 6-7
- Lenticulina gibba* (d'Orbigny 1826)**
 1826 *Cristellaria gibba* n. sp. d'Orbigny: p. 292
 1991 *Lenticulina gibba* (d'Orbigny 1826)-Cimerman & Langer: p. 51, pl. 53, figs. 7-11
- Lobatula lobatula* (Walker & Jacob 1798)**
 1798 *Nautilus lobatulus* n. sp.-Walker & Jacob: p. 642, pl. 14, fig. 36
 1991 *Lobatula lobatula* (Walker & Jacob 1798)-Cimerman & Langer: p. 71, pl. 75, figs. 1-4
- Marginulina glabra* d'Orbigny 1826**
 1826 *Marginulina glabra* n. sp.-d'Orbigny: p. 259
 1994 *Marginulina glabra* d'Orbigny 1826-Loeblich & Tappan: p. 73, pl. 129, figs. 13-16
- Marginulina gummi* Saidova 1975**
 1975 *Marginulina gummi* n. sp.-Saidova: p. 179, pl. 49, fig. 17
 1994 *Marginulina gummi* Saidova 1975-Loeblich & Tappan: p. 73, pl. 131, figs. 1-5
- Melonis barleeaenum* (Williamson 1858)-Plate II, Figures 24a-b**
 1858 *Nonionina barleeana* n. sp.-Williamson: p. 32, pl. 3, figs. 68-69
 1993 *Melonis barleeaenum* (Williamson 1858)-Sgarrella & Moncharmont-Zei: p. 242, pl. 26, figs. 1-2
- Melonis pompilioides* (Fichtel & Moll 1798)**
 1798 *Nautilus pompilioides* n. sp.-Fichtel & Moll: p. 31, pl. 2, figs. a-c
 1993 *Melonis pompilioides* (Fichtel & Moll 1798)-Sgarrella & Moncharmont-Zei: pl. 26, figs. 5-6
- Miliolinella elongata* Kruit 1955**
 1955 *Miliolinella circularis* (Bornemann) var. *elongata*-Kruit: p. 110, pl. 1, figs. 15a-b
 1991 *Miliolinella elongata* Kruit 1955-Cimerman & Langer: p. 41, pl. 37, fig. 8
- Miliolinella subrotunda* (Montagu 1803)**
 1803 *Vermiculum subrotundum* n. sp.-Montagu: p. 521
 1991 *Miliolinella subrotunda* (Montagu 1803)-Cimerman & Langer: p. 42, pl. 38, figs. 4-9
- Neolenticulina peregrina* (Schwager 1866)-Plate II, Figure 10**
 1866 *Cristellaria peregrina* n. sp.-Schwager: p. 245, pl. 7, fig. 89
 1993 *Neolenticulina peregrina* (Schwager 1866)-Sgarrella & Moncharmont-Zei: p. 195, pl. 12, fig. 4
- Nonion subturgidum* (Cushman 1924)**
 1924 *Nonionina subturgida* n. sp.-Cushman: p. 47, pl. 16, fig. 2
 1994 *Nonion subturgidum* (Cushman 1924)-Loeblich & Tappan: p. 158, pl. 343, figs. 1-9
- Nonionella turgida* (Williamson 1858)**
 1858 *Rotalina turgida* n. sp.-Williamson: p. 50, pl. 4, figs. 95-97
 1993 *Nonionella turgida* (Williamson 1858)-Sgarrella & Moncharmont-Zei: p. 240, pl. 24, fig. 5
- Nonionoides grateloupi* (d'Orbigny 1826)**
 1826 *Nonionina grateloupi* n. sp.-d'Orbigny: p. 294
 1994 *Nonionoides grateloupi* (d'Orbigny 1826)-Loeblich & Tappan: p. 158, pl. 342, figs. 1-5

Appendix 1. (Continued)

Nummuloculina irregularis* (d'Orbigny 1839c)**1839c *Biloculina irregularis* n. sp.-d'Orbigny: p. 67, pl. 8, figs. 20-211991 *Nummuloculina irregularis* (d'Orbigny 1839c)-Thies: p. 29, pl. 14, figs. 5a-c1994 *Pyrgoella irregularis* (d'Orbigny 1839c)-Jones: p. 18, pl. 1, figs. 17-18Pseudoclavulina crustata* Cushman 1936-Plate II, Figure 4**1936 *Pseudoclavulina crustata* n. sp.-Cushman: p. 19, pl. 3, figs. 12a-b1991 *Pseudoclavulina crustata* Cushman 1936-Cimerman & Langer: p. 23, pl. 11, figs. 9-10***Pseudotriloculina oblonga* (Montagu 1803)**1803 *Vermiculum oblongum* n. sp.-Montagu: p. 522, pl. 14, fig. 91991 *Pseudotriloculina oblonga* (Montagu, 1803)-Cimerman & Langer: p. 43, pl. 40, figs. 1-4***Pullenia quinqueloba* (Reuss 1851)**1851 *Nonionina quinqueloba* n. sp.-Reuss: p. 71, pl. 5, fig. 311993 *Pullenia quinqueloba* (Reuss 1851)-Sgarrella & Moncharmont-Zei: p. 240, pl. 24, figs. 8-9***Pyrgo anomala* (Schlumberger 1891)-Plate II, Figure 6**1891 *Biloculina anomala* n. sp.-Schlumberger: p. 569, pl. 11, figs. 84-86, pl. 12, fig. 101, text figs. 32-341993 *Pyrgo anomala* (d'Orbigny 1826)-Sgarrella & Moncharmont-Zei: p. 180, pl. 9, fig. 32004 *Pyrgo anomala* (Schlumberger 1891)-Meriç *et al.*: p. 95, pl. 13, fig. 13, pl. 14, figs. 1-2***Pyrgo elongata* (d'Orbigny 1826)**1826 *Biloculina elongata* n. sp.-d'Orbigny: p. 2981993 *Pyrgo elongata* (d'Orbigny 1826)-Sgarrella & Moncharmont-Zei: p. 182, pl. 9, fig. 12004 *Pyrgo elongata* (d'Orbigny 1826)-Meriç *et al.*: p. 96, pl. 14, figs. 3-5***Pyrgoella sphaera* (d'Orbigny 1839c)**1839b *Biloculina sphaera* n. sp.-d'Orbigny: p. 65, pl. 8, figs. 13-161991 *Pyrgoella sphaera* (d'Orbigny 1839c)-Cimerman & Langer: p. 45, pl. 41, figs. 1-22004 *Pyrgoella sphaera* (d'Orbigny 1839c)-Meriç *et al.*: p. 97, pl. 14, figs. 8-9***Rectuvigerina phlegeri* Le Calvez 1959**1959 *Rectuvigerina phlegeri* n. sp.-Berthois & Le Calvez: p. 363, pl. 1, fig. 111988 *Rectuvigerina phlegeri* Le Calvez 1959-Alavi: pl. 1, fig. 41993 *Rectuvigerina phlegeri* Le Calvez 1959-Sgarrella & Moncharmont-Zei: p. 215, pl. 16, figs. 3-4***Saidovina carreriana* (Brady 1881)**1881 *Bolivina carreriana* n. sp.-Brady: p. 581993 *Saidovina carreriana* (Brady 1881)-Sgarrella & Moncharmont-Zei: p. 211, pl. 14, fig. 141994 *Saidovina carreriana* (Brady 1881)-Loeblich & Tappan: p. 121, pl. 236, figs. 16-20***Sigmoilina distorta* Phleger & Parker 1951-Plate II, Figure 7**1951 *Sigmoilina distorta* n. sp.-Phleger & Parker: p. 8, pl. 4, figs. 3-51993 *Sigmoilina distorta* Phleger & Parker 1951-Sgarrella & Moncharmont-Zei: p. 184, pl. 9, fig. 5***Sigmoilinita tenuis* (Czjzek 1848)-Plate II, Figure 8**1848 *Quinqueloculina tenuis* n. sp.-Czjzek: p. 149, pl. 13, figs. 31-341988 *Sigmoilina tenuis* (Czjzek 1848)-Alavi: pl. 1, fig. 11988 *Sigmoilinita tenuis* (Czjzek 1848)-Loeblich & Tappan: p. 348, pl. 356, figs. 17-18***Sigmoilopsis schlumbergeri* (Silvestri 1904)-Plate II, Figure 9**1904 *Sigmoilina schlumbergeri* n. sp.-Silvestri: p. 2671991 *Sigmoilopsis schlumbergeri* (Silvestri 1904)-Cimerman & Langer: p. 48, pl. 46, figs. 10-14***Sphaeroidina bulloides* d'Orbigny 1826**1826 *Sphaeroidina bulloides* n. sp.-d'Orbigny: p. 2671988 *Sphaeroidina bulloides* d'Orbigny 1826-Loeblich & Tappan: p. 564, pl. 617, figs. 1-6***Spiroloculina depressa* d'Orbigny 1826**1826 *Spiroloculina depressa* n. sp.-d'Orbigny: p. 2981991 *Spiroloculina depressa* d'Orbigny 1826-Cimerman & Langer: p. 29, pl. 22, figs. 9-12***Spiroloculina excavata* d'Orbigny 1846-Plate II, Figure 5**1846 *Spiroloculina excavata* n. sp.-d'Orbigny: p. 271, pl. 16, figs. 19-211993 *Spiroloculina excavata* d'Orbigny 1846-Sgarrella & Moncharmont-Zei: p. 169, pl. 5, fig. 62002 *Spiroloculina excavata* d'Orbigny 1846-Kaminski *et al.*: pl. 1, fig. 11***Spiroplectinella wrightii* (Silvestri 1903)**1903 *Spiroplecta wrightii* n. sp.-Silvestri: p. 59, text-figs. 1-61993 *Spiroplectinella wrightii* (Silvestri 1903)-Sgarrella & Moncharmont-Zei: p. 161, pl. 3, fig. 13

Appendix 1. (Continued)

- Quinqueloculina padana** Perconig 1954
 1954 *Quinqueloculina padana* n. sp.-Perconig: p. 95, text-figs. 1, 1a-d, 2, 2a, 3-4
 1993 *Quinqueloculina padana* Perconig 1954-Sgarrella & Moncharmont-Zei: p. 172, pl. 7, fig. 1
- Quinqueloculina seminula** (Linné 1758)
 1758 *Serpula seminula* n. sp.-Linné: p. 786, pl. 2, figs. 1a-c
 1991 *Quinqueloculina seminula* (Linnaeus 1758)-Cimerman & Langer: p. 38, pl. 34, figs. 9-12
- Textularia bocki** Höglund 1947
 1947 *Textularia bocki* n. sp.-Höglund: p. 171, pl. 12, figs. 5-6
 1991 *Textularia bocki* Höglund 1947-Cimerman & Langer: p. 21, pl. 10, figs. 3-6
- Textularia conica** d'Orbigny 1839c
 1839a *Textularia conica* n. sp.-d'Orbigny: p. 143, pl. 1, figs. 19-20
 1991 *Textularia conica* d'Orbigny 1839c-Cimerman & Langer: p. 22, pl. 10, figs. 7-9
- Triloculina tricarinata** d'Orbigny 1826
 1826 *Triloculina tricarinata* n. sp.-d'Orbigny: p. 299
 1993 *Triloculina tricarinata* d'Orbigny 1826-Sgarrella & Moncharmont-Zei: p. 187, pl. 9, figs. 14-15
- Uvigerina mediterranea** Hofker 1932-Plate II, Figures 21–22
 1932 *Uvigerina mediterranea* n. sp.-Hofker: p. 118, fig. 32
 1988 *Uvigerina mediterranea* Hofker 1932-Alavi: pl. 2, fig. 1
 1993 *Uvigerina mediterranea* Hofker 1932-Sgarrella & Moncharmont-Zei: p. 214, pl. 16, figs. 1-2
- Valvulineria bradyana** (Fornasini 1900)
 1900 *Discorbina bradyana* n. sp.-Fornasini: p. 393, fig. 43
 1991 *Valvulineria bradyana* (Fornasini 1900)-Cimerman & Langer: p. 64, pl. 67, figs. 8-10
- Beella digitata** (Brady 1879)-Plate III, Figures 3–4
 1879 *Globigerina digitata* n. sp.-Brady: p. 286
 1985 *Beella digitata* (Brady 1879)-Bolli & Saunders: p. 254, figs. 44.1-4
- Globigerina bulloides** d'Orbigny 1826-Plate III, Figure 5
 1826 *Globigerina bulloides* n. sp.-d'Orbigny: p. 277
 1978 *Globigerina bulloides* d'Orbigny 1826-Pflaummann & Krasheninnikov: p. 888, pl. 1, figs. 8-10
 1989 *Globigerina bulloides* d'Orbigny 1826-Hemleben *et al.*: p. 10, figs. 2.1a-c
 1995 *Globigerina bulloides* d'Orbigny 1826-Yassini & Jones: p. 183, figs. 1078-1081
- Globigerinella calida** (Parker 1962)-Plate III, Figure 6
 1962 *Globigerina calida* n. sp.-Parker: p. 221, pl. 1, figs. 9-13, 15, pl. 14, fig. 3
 1989 *Globigerinella calida* (Parker 1962)-Hemleben *et al.*: p. 18, figs. 2.3.e-f
- Globigerinella glutinata** (Egger 1893)
 1893 *Globigerina glutinata* n. sp.-Egger: p. 371, pl. 13, figs. 19-21
 1962 *Globigerinella glutinata* (Egger 1893)-Parker: p. 246, pl. 9, figs. 1-16
- Globigerinoides ruber** (d'Orbigny 1839b)-Plate III, Figures 7a–b
 1839a *Globigerina rubra* n. sp.-d'Orbigny: p. 82, pl. 4, figs. 12-14
 1989 *Globigerinoides ruber* (d'Orbigny 1839b)-Hemleben *et al.*: p. 15, figs. 2.2.k-l
 1991 *Globigerinoides ruber* (d'Orbigny 1839b)-Cimerman & Langer: p. 58, pl. 60, fig. 9
- Globoturborotalita rubescens** (Hofker 1956)-Plate III, Figures 8a–b
 1956 *Globigerina rubescens* n. sp.-Hofker: p. 234, pl. 32, fig. 26, pl. 35, figs. 18-21
 1978 *Globigerina rubescens* Hofker 1956-Pflaummann & Krasheninnikov: p. 889, pl. 1, figs. 11-13
 1989 *Globoturborotalita rubescens* (Hofker 1956)-Hemleben *et al.*: p. 12, pl. 2.1.g-h
- Globoturborotalita tenella** (Parker 1958)-Plate III, Figures 9a–b
 1958 *Globigerinoides tenellus* n. sp.-Parker: p. 280, pl. 6, figs. 7-11
 1978 *Globigerinoides tenellus* Parker 1958-Pflaummann & Krasheninnikov: p. 890, pl. 4, figs. 1-3
 1989 *Globoturborotalita tenella* (Parker 1958)-Hemleben *et al.*: p. 12, figs. 2.1.i-k
- Neogloboquadrina pachyderma** (Ehrenberg 1861)-Plate III, Figures 1–2
 1861 *Aristerspira pachyderma* n. sp.-Ehrenberg: p. 276
 1978 *Globigerina pachyderma* (Ehrenberg 1861)-Pflaummann & Krasheninnikov: p. 889, pl. 8, figs. 10-12
 1989 *Neogloboquadrina pachyderma* (Ehrenberg 1861)-Hemleben *et al.*: p. 22, figs. 2.4.g-l
- Turborotalita quinqueloba** (Natland 1938)-Plate III, Figures 10a–b
 1938 *Globigerina quinqueloba* n. sp.-Natland: p. 149, pl. 6, fig. 7
 1978 *Globigerina quinqueloba* Natland 1938-Pflaummann & Krasheninnikov: p. 888, pl. 2, figs. 10-12
 1989 *Turborotalita quinqueloba* (Natland 1938)-Hemleben *et al.*: p. 13, figs. 2.2.a-f
- Orcadia riedeli** (Rögl & Bolli 1973)-Plate III, Figures 11a–b
 1973 *Hastigerinella riedeli* n. sp.-Rögl & Bolli: p. 567, pl. 4, figs. 1-5, pl. 14, figs. 1-3
 1989 *Orcadia riedeli* (Rögl & Bolli 1973)-Hemleben *et al.*: p. 19, figs. 2.3.l-m

Appendix 2. (Continued)

Core DM18 - Depth (cm)	<i>Fisurina</i> sp.	<i>Bolivina albatrossi</i>	<i>Brizalina alata</i>	<i>Brizalina difformis</i>	<i>Brizalina dilatata</i>	<i>Brizalina striatula</i>	<i>Brizalina subspinescens</i>	<i>Brizalina</i> sp.	<i>Cassidulina crassa</i>	<i>Cassidulina laevigata</i>	<i>Globocassidulina subglobosa</i>	<i>Saidovina karreriana</i>	<i>Bulimina aculeata</i>	<i>Bulimina costata</i>	<i>Bulimina elongata</i>	<i>Bulimina marginata</i>	<i>Bulimina striata</i>	<i>Bulimina</i> sp.	<i>Globobulimina affinis</i>	<i>Globobulimina pseudospinescens</i>	<i>Globobulimina</i> sp.	<i>Uvigerina mediterranea</i>	<i>Fursenkoina acuta</i>	<i>Valvulineria bradyana</i>	<i>Valvulineria</i> sp.	<i>Sphaeroidina bulloides</i>	<i>Siphonina</i> sp.	<i>Discorbinella bertheloti</i>	<i>Hyalinea balthica</i>	<i>Hyalinea</i> sp.	<i>Cibicides</i> sp.	<i>Astigerinata mamilla</i>	<i>Haynesina depressula</i>	<i>Nonionella turgida</i>	<i>Nonionoides grateoloupi</i>	<i>Astronion tumidum</i>	<i>Melonis barleanum</i>				
0-2		2	3										77	1	6	77	1	1							5														13		
6-8	2	4	5			1							86		10	86		1				1																	6		
16-18	1	1	1				1	1					80		9	80						14									2								5		
26-28		4											54	2	15	54						82						1		3									4		
36-38	1	42	1				2						139	2	9	139						44	1	1						4											
46-48		19	22				3						441		11	441						63					1		4												
56-58		1	10										89			89								1						1											
66-68			9										19		6	19			1			3								2											
78-80			8										9			9						1																			
86-88			3				1						15		1	15						1																			
96-98	1		7				1						28		2	28																									
106-108			1										6			6								2						1		1									
118-120													8		2	8						1		1						1											
126-128						2							6		1	6						1		2													1	1			
136-138						1		1					5	1	3	5								2													1				
148-150		5	2										18	1	1	18				1			3	1													1				
154-156		1	2										17			17																									
166-168		7	2	8									35		7	35							1																		
176-178		7	22										46		10	46							5																		
188-190						1							62	1	7	62																								1	
196-198		8	2	1		1		1					78		22	78								1						1									5		
206-208		2	18				1						42		19	42			1											1									3		
216-218		3	1	1									12		5	12																									
226-228		6											14		2	14		1																							
236-238		12	1										1	23	1	23	1																								
240-242	1	11		1									1	47	2	47							1																		
244-246	3	40		1									1	73	2	73																									
246-248	6	60	5	1				1					2	60	4	60			1																						
254-256		84	12										94		4	94							4																		
258-260	1	57	3	5	3								7	1	8	7																									
264-266		5	1	1		2							2		1	2																									
266-268		1	1											11	3								1																		
268-270		1	1												3		1	1				1																			
274-276		7	2										2	4	2		4																								
276-278		88	10		1								38	1	3	38																									
286-288		52	8	1	1			6					35	5	14	35																									
296-298								2					1		1	8		3		6																					
304-306													1				1																								
306-308		1																																							
310-312													1			2							1																		
314-316													1		2	1							1																		
316-318						1							1	1	2	1																									
320-322																																									
326-328																																									
334-336																																									
336-338																																									
338-340																																									
344-346						1										1							1																		
356-358													11		18	21																									
366-368								1									1																								
376-378																																									
386-388																																									
396-398																																									
406-408																																									
414-416																																									
422-424																																									

Appendix 2. (Continued)

Core DM18 - Depth (cm)	<i>Melonis pompilioides</i>	<i>Melonis</i> sp.	<i>Pullenia quinqueloba</i>	<i>Pullenia</i> sp.	<i>Chilostomella ovoidea</i>	<i>Chilostomella</i> sp.	<i>Gyroidinoides neosoldanii</i>	<i>Gyroidinoides soldanii</i>	<i>Gyroidinoides</i> sp.	<i>Gyroidina umbonata</i>	<i>Gyroidina</i> sp.	<i>Ammonia</i> sp.	<i>Elphidium aculeatum</i>	<i>Elphidium granosum</i>	<i>Elphidium</i> sp.	Total planktic foraminifera (TPF)	<i>Neogloboquadrina pachyderma</i> (d)	<i>Neogloboquadrina pachyderma</i> (s)	<i>Globigerinita glutinata</i>	<i>Beella digitata</i>	<i>Globigerina bulloides</i>	<i>Globigerinella calida</i>	<i>Globigerinoides ruber</i>	<i>Globobulborotalia rubescens</i>	<i>Turborotalita quinqueloba</i>	<i>Orcadia riedeli</i>
0-2	6	10			2										3	253	3	9	5					1	235	
6-8	4	10			2											317	5	5	1		2			1	303	
16-18	6	2	1		2											168	3	7			1		2		155	
26-28	5	7	1		2										1	59	1	1	1		2			2	52	
36-38					10								1		1	321	5	6	1		4				304	1
46-48					1	2										339	14	15		1	5	1	1	1	301	
56-58					11				1							1767	34	30		5	8	4	1	3	1680	2
66-68					3										1	1092	17	11		2	4		10	1	1046	1
78-80					1	1										200	1	8		2			6		183	
86-88					2										1	322	7	18	2	1	4		45	5	240	
96-98					4											322	6	7	1	2	2		14	1	289	
106-108					9										1	262	4	12		1			3		242	
118-120					11										2	1423	33	51	7	3	7	2	3	1	1314	2
126-128	2	6			8											864	14	21			4	4	3	1	817	
136-138					10											1375	23	27	1	2	14	5	23		1278	2
148-150					12				1							487	4	5		1	9				468	
154-156					8											231	3	4							223	
166-168					7											996	16	17	1	1	1				960	
176-178	1	1	1		2				1		1			2	669	7	5	3	1	6			1		646	
188-190	1	1			10									1	728	3	7			6			2	1	709	
196-198	1				6					1					2458	20	27	6	2	10		5			2388	
206-208	1	3			7								1		1266	34	24		4	14		4			1186	
216-218					2						1				421	4	2						2		413	
226-228					2					2					201	4	3				1		1		192	
236-238					4		14	2	18						251	3	7			4			1		236	
240-242					3				36						87	9	2				1				75	
244-246					3				7	1					98	14		2		5					77	
246-248					3		1			1			1	3	234	9	6			8			1		210	
254-256				2	1								1		317	25				18					274	
258-260					10					1				1	319	7	1			26			1		284	
264-266					2										358					169					189	
266-268					7					1					478	6	7	1		50					414	
268-270					3						1				198					26					172	
274-276								1	1						100	1	2			34					63	
276-278					3					1					97	8	10			6					73	
286-288					22					11	1	2		1	88	3	7			7					71	
296-298					5										3					2					1	
304-306															7					1					6	
306-308															22		3			3					16	
310-312															8					6					2	
314-316															683		2			633					48	
316-318															445	2	4			10					429	
320-322															87	1									86	
326-328															64	2	1			1					60	
334-336															1					1						
336-338																										
338-340															2					2						
344-346															26		1								25	
356-358															2				1						1	
366-368														1	1										1	
376-378																										
386-388																										
396-398																										
406-408											1				1										1	
414-416															2		1								1	
422-424																										

Appendix 3. Foraminiferal data of core KL40 (numbers of specimens per sample).

Core KL40 - Depth (cm)	Total benthic foraminifera (TBF)	<i>Eggerella scabra</i>	<i>Bigennerina nodosaria</i>	<i>Textularia</i> sp.	<i>Siphotextularia</i> sp.	<i>Pseudoclavulina crustata</i>	<i>Spiroloculina excavata</i>	<i>Quinqueloculina</i> sp.	<i>Quinqueloculina</i> spp.	<i>Miliolinella elongata</i>	<i>Miliolinella subrotunda</i>	<i>Pyrgo anomala</i>	<i>Pyrgo</i> sp.	<i>Sigmoilinita tenuis</i>	<i>Sigmoilopsis schlumbergeri</i>	<i>Articulina tubulosa</i>	<i>Dentalina</i> sp.	<i>Lenticulina gibba</i>	<i>Lenticulina</i> sp.	<i>Neolenticulina peregrina</i>	<i>Amphicoryna scalaris</i>	<i>Lagena nebulosa</i>	<i>Lagena striata</i>	<i>Bolivina albatrossi</i>	<i>Brizalina alata</i>	<i>Brizalina difformis</i>	<i>Brizalina dilatata</i>	<i>Brizalina striatula</i>	<i>Brizalina subspinescens</i>	<i>Brizalina</i> sp.	<i>Cassidulina laevigata</i>	<i>Cassidulina</i> sp.	<i>Bulimina costata</i>	<i>Bulimina elongata</i>	<i>Bulimina marginata</i>	<i>Globobulimina affinis</i>	<i>Globobulimina pseudospinescens</i>	<i>Globobulimina</i> sp.	<i>Uvigerina mediterranea</i>	<i>Valvulineria bradyana</i>		
1-3	332						7		1	5		1	31	11										38		5					67							154	5			
13-15	197	1				14	4		1				5	1										11	2	5					119			1	1			28				
23-25	90	1	3	3	1	2	1						3	4										3	13						37						4	1				
33-35	29	1	1			4						1						2		1				3	1					10												
43-45	40	2			1	1							6											1	2		1	1		17							2					
53-55	40			1									6											1	1				16		1						1	1				
63-65	32	2			1		3						7							2				1	1				10								1	1				
73-75	115				1	1	7			1			27		1							1		2	10				39			4						2				
83-85	78	1				3		3					11							2		3			5			1	29		4	1										
93-95	23					1							2						1	2				7				3		4	1								2			
101-103	138	1					3													1		1	2	13	4	1	2	43		6		1										
111-113	55		1										1											33	1	6	1	6		3	1	1										
121-123	110																	1						49	6			13		4												
131-133	154																							49	13	4		39		27								2				
141-143	4																						2																			
151-153	11																							1	7			1		1		1										
161-163																																										
171-173																																										
181-183																																										
191-193	1																																1									
201-203																																										
210-212																																										
220-222																																										
230-232																																										
240-242	1																1																									
250-252	1																																									
260-262	1																																									
280-282																																										
290-292	1																																									
301-303																																										
311-313																																										
321-323																																										
331-333	1																																									
341-343	2																																									

Appendix 3. (Continued)

Core KL40 - Depth (cm)	<i>Valvulineria</i> sp.	<i>Sphaeroidina bulloides</i>	<i>Hyalinea balthica</i>	<i>Lobanula lobatula</i>	<i>Asterigerinata mamilla</i>	<i>Nontionella turgida</i>	<i>Melonis barleanum</i>	<i>Melonis</i> sp.	<i>Chilostomella ovoidea</i>	<i>Gyroldinoidea</i> sp.	<i>Gyroldina umbonata</i>	<i>Elphidium macellum</i>	<i>Elphidium</i> sp.	Total planktic foraminifera (TPF)	<i>Neogloboquadrina pachyderma</i> (d)	<i>Neogloboquadrina pachyderma</i> (s)	<i>Globigerinata glutinata</i>	<i>Beella digitata</i>	<i>Globigerina bulloides</i>	<i>Globigerinella calida</i>	<i>Globigerinoides ruber</i>	<i>Globobulborotalita rubescens</i>	<i>Globobulborotalita tenella</i>	<i>Turborotalita quinqueloba</i>
1-3	1													497	14	14		1	1					464
13-15		1					1		2					283	4	5			2					270
23-25			1						12		1			1245	8	11	1	8	1	1	2			1213
33-35						1			4					369	14	8			1		30	2	4	310
43-45		2					2		2					534	12	11			6	1	10		1	493
53-55	1						1		10					710	9	21	1		8		5			666
63-65									3					1131	8	11		1	5		19			1087
73-75			2				2	3	12					569	19	14			3		4	1		528
83-85	1	1					5		8					1000	12	8			8		5			967
93-95														194	1	4			7		2			180
101-103			4						2	54				270	6	1			4					259
111-113			1											430	6	3			87		1			333
121-123		8	26						3					230	3	3			11					213
131-133			7	2					11					76					43					33
141-143					2									6	2									4
151-153														155	4	1	1		1					148
161-163																								
171-173																								
181-183																								
191-193																								
201-203																								
210-212																								
220-222																								
230-232																								
240-242																								
250-252												1												
260-262																								
280-282																								
290-292																								
301-303																								
311-313																								
321-323																								
331-333												1												
341-343		1																						

PLATE I

Nannofossils from core KL40 (PL. polarized light; XL. transmitted light; PC. phase contrast; QL. with quartz wedge; sample numbers right-above corners)

- 1 *Braarudosphaera bigelowii* (Gran & Braarud) (PL).
- 2 *Coronosphaera mediterranea* (Lohmann) (a) PL, (b) XL.
- 3 *Syracosphaera pulchra* Lohmann (a) PL, (b) XL.
- 4 *Emiliana huxleyi* (Lohmann) (a) PL, (b) PC, (c) QL.
- 5 *Helicosphaera carteri* (Wallich) (a) PL, (b) PC.
- 6 *Gephyrocapsa ericsonii* McIntyre & Bé (a) PL, (b) XL.
- 7 *Umbellosphaera irregularis* Paasche (PL).
- 8 *Helicosphaera wallichii* (Lohmann) (a) PL, (b) PC.
- 9 *Gephyrocapsa oceanica* Kamptner (a-b) PL.
- 10 *Umbilicosphaera sibogae* (Weber-van Bosse) (a) PL, (b) PC.
- 11 *Calciosolenia murrayi* Gran (a) PL, (b) PC.
- 12 *Gephyrocapsa muelleriae* Bréhérét (a) PL, (b) XL.
- 13 *Thoracosphaera* sp. (PL).
- 14 *Gephyrocapsa* cf. *caribbeanica* Boudreaux & Hay (PL).
- 15 *Lithraphidites quadratus* Bramlette & Martini (PL).
- 16 *Micula mura* (Martini) (PL).
- 17 *Semihololithus priscus* Perch-Nielsen (PL).
- 18 *Helicosphaera euphratis* Haq (PL).
- 19 *Umbilicosphaera sibogae* (Weber-van Bosse) (PL).
- 20 *Zygrhablithus bijugatus* (Deflandre) (PL).
- 21 *Isthmolithus recurvus* Deflandre (PL).
- 22 *Chiasmolithus solitus* (Bramlette & Sullivan) (PL).
- 23 *Cribocentrum reticulatum* (Gartner & Smith) (PL).
- 24 *Pseudoemiliana lacunosa* (Kamptner) (PL).

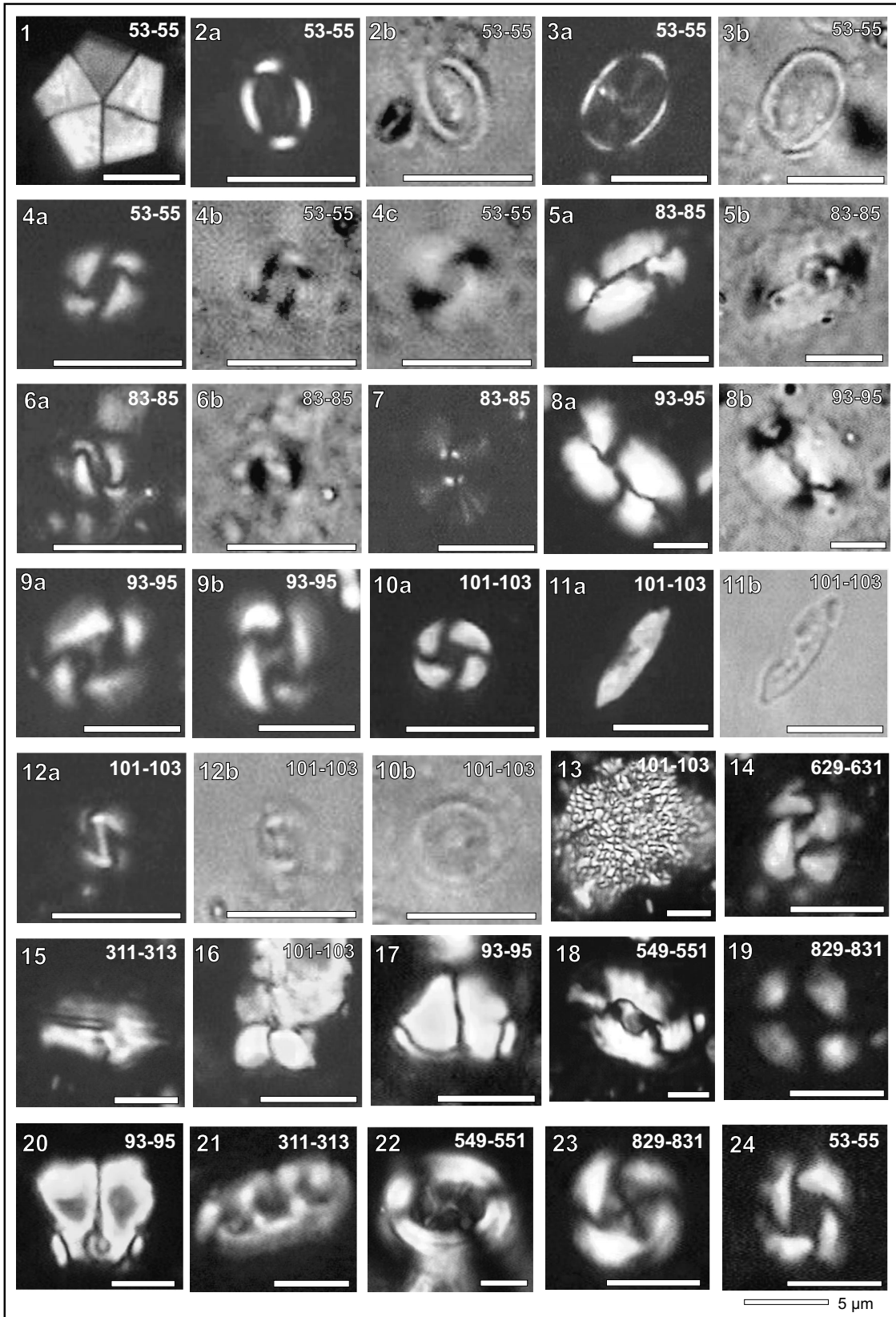


PLATE II

- 1 *Eggerella scabra* (Williamson, 1858), side view x100, core KL40, 43–45 cm.
- 2 *Bigennerina nodosaria* d'Orbigny, side view x100, core KL40, 13–15 cm.
- 3 *Siphotextularia* sp., side view x160, core DM18, 66–68 cm.
- 4 *Pseudoclavulina crustata* Cushman, side view x60, core DM18, 96–98 cm.
- 5 *Spiroloculina excavata* d'Orbigny, side view x66, core DM18, 36–38 cm.
- 6 *Pyrgo anomala* (Schlumberger), side view x55, core DM18, 26–28 cm.
- 7 *Sigmoilina distorta* Phleger & Parker, side view x200, core DM18, 26–28 cm.
- 8 *Sigmoilinita tenuis* (Czjzek), side view x200, core DM18, 46–48 cm.
- 9 *Sigmoilopsis schlumbergeri* (Silvestri), side view x160, core DM18, 16–18 cm.
- 10 *Neolenticulina peregrina* (Schwager), side view x100, core DM18, 26–28 cm.
- 11 *Amphicoryna scalaris* (Batsch), side view x230, core DM18, 66–68 cm.
- 12 *Brizalina albatrossi* Cushman, side view x160, core DM18, 246–248 cm.
- 13 *Brizalina alata* (Seguenza), side view x120, core DM18, 276–278 cm.
- 14 *Brizalina alata* (Seguenza), side view x130, core DM18, 258–260 cm.
- 15 *Brizalina dilatata* Reuss, side view x190, core DM18, 66–68 cm.
- 16 *Brizalina striatula* Cushman, side view x200, core DM18, 286–288 cm.
- 17 *Bulimina elongata* d'Orbigny, side view x170, core DM18, 266–268 cm.
- 18 *Bulimina marginata* d'Orbigny, side view x210, core DM18, 196–198 cm.
- 19 *Bulimina costata* d'Orbigny, side view x140, core DM18, 46–48 cm.
- 20 *Bulimina costata* d'Orbigny, side view of twin form x150, core DM18, 46–48 cm.
- 21 *Uvigerina mediterranea* (Hofker), side view x100, core DM18, 46–48 cm.
- 22 *Uvigerina mediterranea* (Hofker), side view x230, core DM18, 26–28 cm.
- 23 *Hyalinea balthica* (Schröter), side view x150, core DM18, 276–278 cm.
- 24 *Melonis barleeianum* (Williamson). (a) side view x200, core KL40, 83–85 cm; (b) apertural view x250, core KL40, 83–85 cm.
- 25 *Chilostomella ovoidea* Reuss, side view x190, core DM18, 56–58 cm.

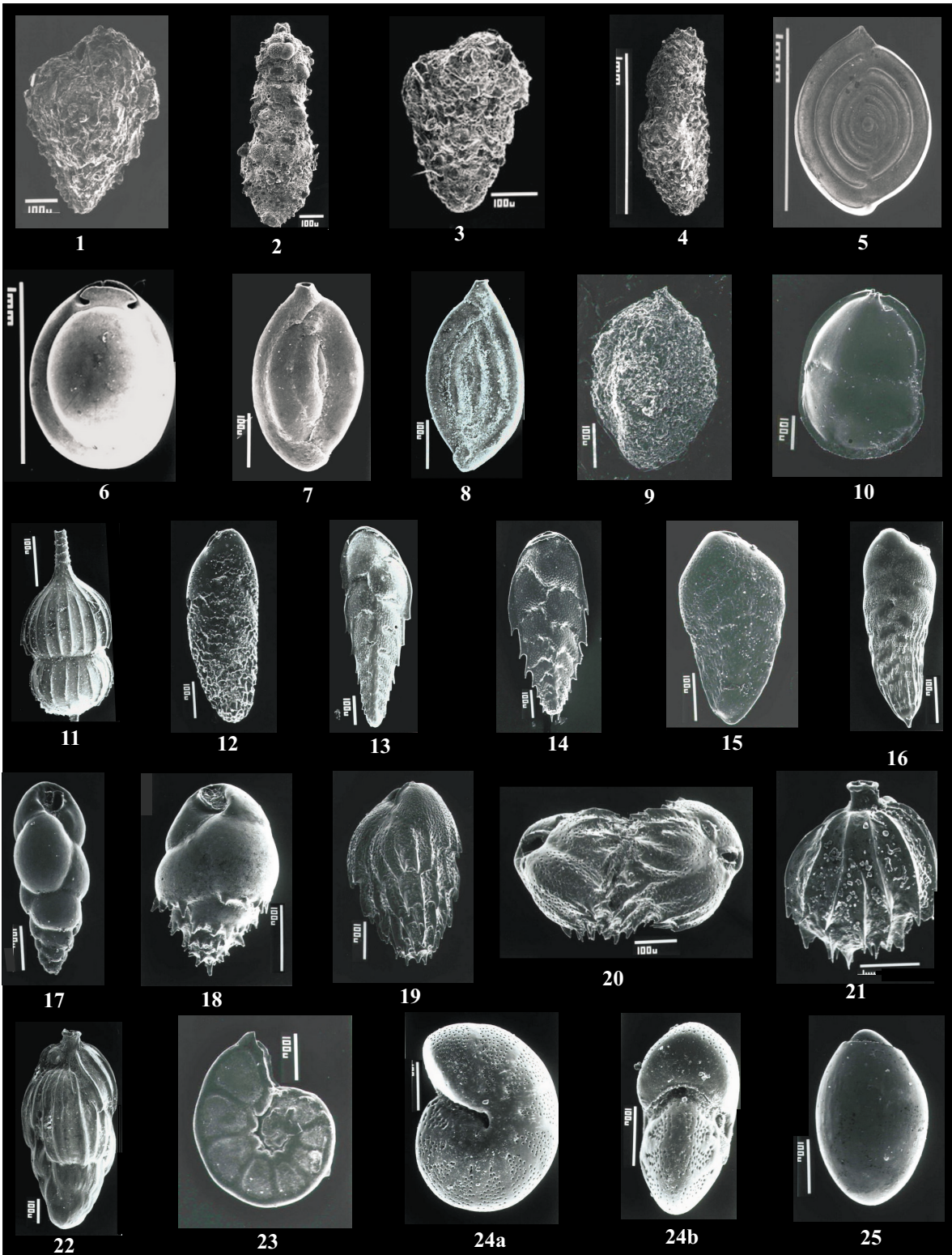


PLATE III

- 1 *Neogloboquadrina pachyderma* (Ehrenberg), umbilical view x170, core KL40, 33–35 cm.
- 2 *Neogloboquadrina pachyderma* (Ehrenberg), umbilical view (juvenile) x195, core DM18, 136–138 cm.
- 3 *Beella digitata* (Brady), umbilical view x400, core KL40, 63–65 cm.
- 4 *Beella digitata* (Brady), umbilical view x300, core DM18, 136–138 cm.
- 5 *Globigerina bulloides* d'Orbigny, umbilical view (juvenile) x360, core DM18, 136–138 cm.
- 6 *Globigerinella calida* (Parker), umbilical view x270, core DM18, 56–58 cm.
- 7 *Globigerinoides ruber* (d'Orbigny). (a) spiral view x120, core DM18, 136–138 cm; (b) umbilical view x120, core DM18, 136–138 cm.
- 8 *Globoturborotalita rubescens* (Hofker). (a) spiral view x220, core KL40, 33–35 cm; (b) umbilical view x220, core KL40, 33–35 cm.
- 9 *Globoturborotalita tenella* (Parker). (a) spiral view x260, core KL40, 33–35 cm; (b) umbilical view x280, core KL40, 43–45 cm.
- 10 *Turborotalita quinqueloba* (Natland). (a) spiral view x270, core DM18, 148–150 cm; (b) apertural view x270, core DM18, 148–150 cm.
- 11 *Orcadia riedeli* (Rögl & Bolli). (a) spiral view x470, core DM18, 136–138 cm; (b) umbilical view x330, core DM18, 118–120 cm.

