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Late Holocene Deep-Sea Benthic Foraminifera from the Sea of Marmara

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Abstract

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The benthic foraminiferal assemblages of two cores from the late-Holocene, organic-carbon-rich and carbonate-poor, deep-sea sediments of the eastern depression of the Sea of Marmara have been studied. They were deposited under high level of primary productivity and poorly oxygenated bottom-water conditions; they show low diversity and are dominated by a group of species adapted to an infaunal life style with wide bathymetric distribution (ca. 70-2000 m) in the Mediterranean Sea. Oxygen deficiency down to about 0.5 ml/l does not seem adversely to affect the rate of reproduction of the dominant species belonging to *Melonis, Chilostomella*, buliminids, and bolivinitids. Their distribution is primarily controlled by substrate conditions.

Faunal similarities with fossil assemblages in association with some late-Quaternary sapropels and related facies from the eastern Mediterranean basins suggest that they were deposited under palaeo-oceanographic conditions closely similar to those of the modern Sea of Marmara.

Introduction

This study is based on quantitative analyses of benthic foraminiferal assemblages of two deep-sea (bathyal) cores from the floor of the eastern depression of the Sea of Marmara (Figs. 1 and 2). Faunal abundance, diversity and composition are discussed and related to general hydrographic (Fig. 3) and deep-sea sedimentary conditions. The assemblages are also compared with benthic foraminifers of two other marginal basins in the eastern Mediterranean.

No previously published account of the foraminiferal fauna of the Sea of Marmara (SM) is known. Koreneva (1971) studied the palynology of a core from the western depression of the SM, and Stanley and Blanpied (1980) discussed the late-Quaternary palaeo-oceanographic developments here on the basis of four gravity cores from the floor of its eastern depression.

Although the studied cores may not truly represent a wide area of the bathyal zone, it will be shown later that they have been almost entirely deposited after the establishment of the present two-layer system of water flows along the Turkish Straits between one and three thousand years ago; therefore, the analysed assemblages can safely be related to the present environmental conditions in the deepest parts of the eastern depression of the SM.

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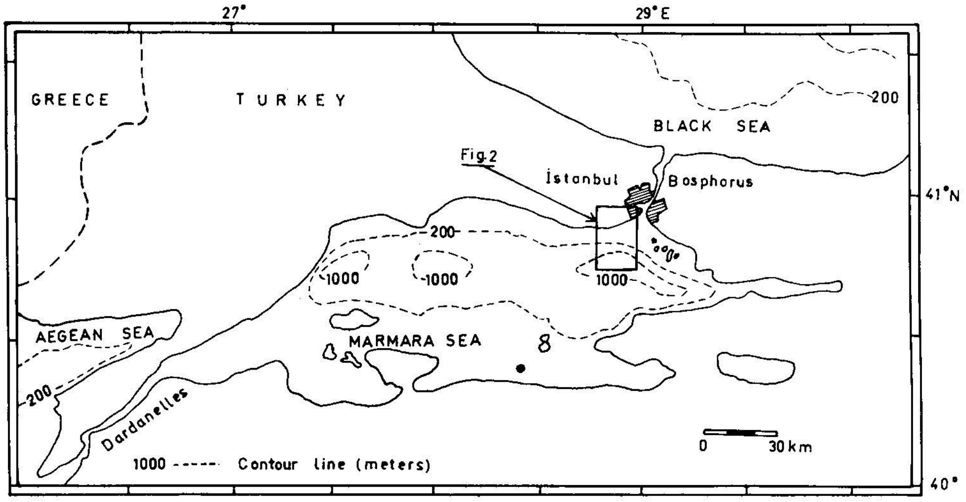


Fig. 1. Simplified bathymetry of the Sea of Marmara.

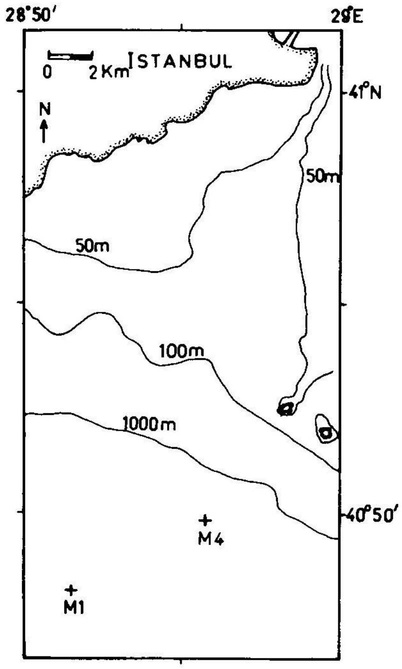


Fig. 2. Locations of cores M1 and M4.

Hydrographic setting

The hydrographic regime of the SM is largely controlled by the rates of flow, properties, and interactions of the two water-masses flowing into it via the Straits of Bosphorus and the Dardanelles. The major features of this system pertinent to the present study are shown in Fig. 3. The data presented and the following account of the general hydrographic conditions are mostly based on the reported results of a program of seasonal physical and chemical oceanographic studies conducted by the Institute of Marine Sciences (M.E.T.U.) in the Turkish Straits (the SM and the two Straits) during the past few years (Ünlüata and Özsoy, 1986; Özsoy et al., 1986, and Bastürk et al., 1986).

The outflow of brackish waters from the Black Sea leads to the formation of a thin (20–30 m) surface layer in the SM with a salinity of 22–25‰, which is separated from the underlying saline (38.5‰) Mediterranean waters by a sharp halocline. The outflow can actually be traced as far as the entrance of the Dardanelles in the Aegean Sea, although it becomes more saline along its course towards the latter. However, the maximum surface salinity is found not to exceed 30‰ at the entrance of the Dardanelles in the SM, which is still much lower than that of the subhalocline waters. Thus, a strong density stratification of the water-column prevails throughout the year, preventing efficient aeration of subhalocline waters (cf. Miller, 1983).

Surface waters of Black Sea origin also transport a substantial amount of nutrients into the

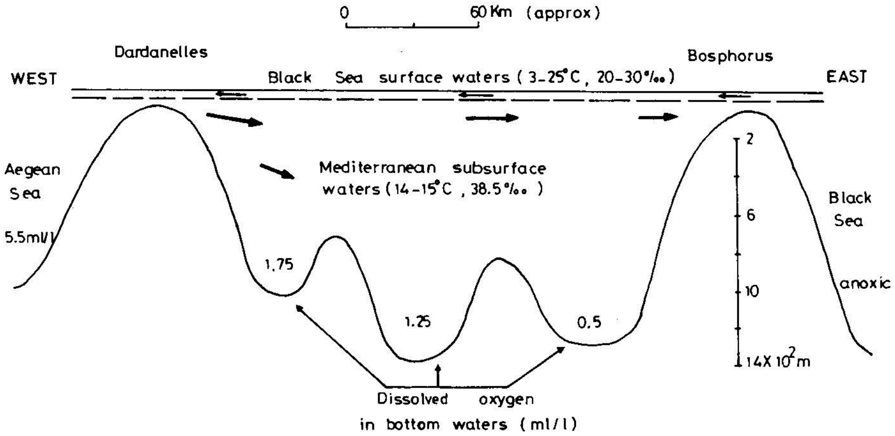


Fig. 3. Generalized oceanographic conditions along an east to west traverse in the Sea of Marmara.

SM from the fertile parts of the Black Sea around the northern entrance of the Bosphorus and initiate a relatively high level of primary productivity with an average rate of about 70 g C m^{-2} yr^{-1} (Ünlüata and Özsoy, 1986). On the basis of chlorophyll-a determinations, Yilmaz (1986) found that, compared with the offshore waters of the Aegean and the Levantine Seas, the rate of productivity is between two to three times higher here (cf. Murdoch and Onuf, 1974, and Sushchenia, 1961). Another important reason behind the high level of primary productivity is believed to be efficient upwards recycling of nutrients into the photic zone (Bastürk et al., 1986). Budgetary calculations on the salt-contents of the two water-masses in the Turkish Straits system show that about 50% of the initial volume of the Mediterranean waters entering the system is returned back to the Aegean Sea by upwards mixing and entrainment in the SM itself (Özsoy et al., 1986). Vertical mixing is particularly pronounced in the vicinity of the southern entrance of the Bosphorus where, as a result of the prevalence of jet flow and internal hydraulic jump conditions throughout the year, nutrient recycling takes place more efficiently. In this area the level of primary productivity is higher than in other parts of the Turkish Straits (Bastürk et al., 1986).

Another major aspect of the oceanography of the SM is the oxygen-deficiency of its subhalocline waters, which has long been known (Miller et al., 1970). Ünlüata and Özsoy (1986) note that whereas both water-masses flowing into the SM are well oxygenated, the reason behind the oxygen-deficiency is not immediately obvious. Seasonal measurements of the dissolved oxygen content show that the deficiency actually begins just under the halocline at about the 50 m depth-level. At a depth of about 300 m, the level of deficiency drops to almost 30% of its saturation value considering the temperature and salinity of waters at this depth. This situation is found to be in sharp contrast with that of the Aegean Sea, where the entire water-column is nearly saturated (see Miller et al., 1970). In the Levantine Sea, the level of saturation is known to drop only to about 70% of its saturation value at close to 1000 m depth.

In addition to the salinity-induced strong density stratification of the water-column, the decomposition of a large quantity of particulate organic matter — estimated to be equivalent to about ~~60~~25% of the total amount produced by primary productivity — settling from the photic zone is postulated to contribute to subsurface oxygen-deficiency, which actually intensifies towards the east and therefore shows an inverse relation with the level of primary productivity along the length of the SM.

Moreover, oxygen deficiency generally intensifies with depth in the SM. This is attributed to the poor recirculation of bottom waters whose only source of oxygen is the well-aerated subsurface waters flowing in through the Dardanelles. Thus, it is found that the bottom waters of the eastern depression are most depleted and their level of dissolved oxygen concentration at a depth of about 1000 m drops to almost 0.5 ml/l. The inefficient recirculation of bottom waters in the SM has been compared with those of some high-latitude fjords, as the replacement of dense saline Mediterranean waters, which have already occupied the deepest parts of its depressions, has to wait for the sinking of denser waters in a subsequent season by which time they have lost a considerable amount of their dissolved oxygen by the process of decomposition of abundant organic-matter detritus falling from the photic zone (Özsoy et al., 1986). Furthermore, in their analysis of seasonally collected oxygen data from 1983 to 1986, together with previously collected data by other investigators, Ünluata and Özsoy (1986) conclude that deep-water (> 500 m) renewal takes place less efficiently in the eastern depression of the SM. The higher level of surface productivity in the eastern parts of the SM mentioned above, and the greater topographic isolation of the bottom waters from the entrance point of well-oxygenated Mediterranean waters via the Dardanelles, should also contribute towards a greater oxygen-deficiency in this depression (Fig. 3).

In short, the prevailing estuarine system of circulation, intense water-column stratification, and elevated level of primary productivity bring about a hydrographic situation in the SM which stands out in sharp contrast with that of the rest of the eastern Mediterranean basins (Miller,1983). However, the impact of this hydrographic system on the bathyal fauna and processes of sedimentation in the basin remains to be studied. Such investigations may have significant implications for the understanding of the palaeo-oceanographic conditions which led to the development of repeated phases of anoxia or suboxia in the latter basins throughout the Neogene (e.g., Kidd et al., 1978 and Cita and Grignani, 1982).

Methods and materials

The cores were raised by Boomrang corers from a depth of about 1200 m at 28° 51′ 30″ E and 40° 48′ 14″ N (MI), and 28° 55′ 48″ E and 40° 49′ 48″ N (M4) on board the *R/V BILIM* of the I.M.S. (M.E.T.U.) in November, 1984. Since no lithologic breaks could be detected either on the split surfaces of the cores or on their X-radiographs, samples of about 4 cc were taken at 10-cm intervals along their split surfaces. Without drying, the samples were soaked in 10% solutions of ammonia as a dispersing agent for about 24 h and then washed on a 63-μm sieve with de-ionized water.

The residue was later sieved into three fractions (coarser than 250, 125 and 63 μm) in or-

TABLE I

Results of quantitative analyses of foraminiferal assemblages in core M1[a]

A	B	C	D	E	F	G	H	I	J
1	0- 2	167	16	31	13.8	105	37.0	89	9.5
2	10-12	162	10	18	7.7	124	33.9	18	6.1
3	20-22	38	1	18	10.8	9	65.0	69	2.6
4	30-32	113	5	24	11.2	167	42.7	82	2.6
5	40-42	127	11	24	11.1	29	52.4	128	8.6
6	50-52	174	9	30	13.1	243	32.0	28	5.1
7	60-62	202	2	32	13.4	188	35.0	108	0.9
8	70-72	144	9	24	10.7	266	44.0	108	6.2
9	80-82	134	9	22	9.9	50	53.1	152	0.0
10	90-92	176	5	23	9.8	152	52.6	192	1.7
Average				24.6	11.5	133	45.2		4.3

[a] Explanations: A = sample number; B = depth interval sampled (cm); C = total counted benthic tests; D = number of redeposited tests of shallow-water species; E = Number of indiginous benthic species; F = index of diversity; G = number of benthic tests per cc of wet sediment; H = percentage of planktic tests in total foraminiferal assemblage; I = total counted planktic tests; J = percentage of redeposited tests from shallow waters in total counted benthic tests.

TABLE II

Results of quantitative analyses of foraminiferal assemblages in core M4 (see Table I for explanations)

A	B	C	D	E	F	G	H	I	J
1	0– 2	196	23	32	13.9	1068	5.4	10	11.7
2	10–12	133	12	31	14.4	247	18.7	28	9.0
3	20–22	308	18	39	15.4	1398	21.6	111	5.8
4	30–32	189	13	32	13.8	582	43.4	135	6.8
5	40–42	272	20	44	17.9	1018	9.3	26	7.3
6	50–52	152	6	31	13.8	1553	35.9	82	3.9
7	60–62	203	13	33	14.0	771	25.7	66	6.4
8	70–72	200	9	38	16.2	488	35.0	103	4.5
9	80–82	284	9	38	15.2	1835	23.4	84	3.1
Average				35.3	14.9	995.5	24.8		6.5

TABLE IIIA

Benthic foraminiferal faunal abundance and diversity data from the southern Adriatic and the Cilician Basins[a]

A	B	C	D	E
Southern Adriatic Basin (Parisi et al., 1982)				
IN 68-5	1030	42	21.1	13.7
IN 68-6	1196	40	19.8	18.4
IN 68-7	1225	48	17.9	54.3
IN 68-8	1273	29	14.8	17.2
IN 68-9	1234	18	10.2	9.3
Average	1191.6	35.4	167	22.5
Cilician Basin (Alavi, 1980)				
166	1124	34	17.0	160
170	1415	40	19.1	119
171	1354	41	16.7	151
Average	1297.6	35.0	17.6	143.3

[a] A = sample designation; B = depth (m); C = no. of species; D = index of diversity; E = benthic foraminiferal number.

TABLE IIIB

Average late Holocene rates of deposition in the Sea of Marmara, the southern Adriatic, and the Cilician Basins[b]

Marmara	Adriatic	Cilician
ca. 26.2	ca. 20.0	14.0

[b] Source: Van Straaten (1966), Buckley et al. (1982), Koreneva (1971), and Stanley and Blanpied (1980).

der to faciliate population countings and early recognition of redepositional events (Carter, 1951). All tests in coarser than 250-μm fractions were counted, but as the coarser than 63-μm (and sometimes the coarser than 125-μm) fractions often contain large number of tests, they were split before counting. This is necessary if one is going to avoid a baised population survey by counting a disproportionately large number of small tests belonging to some bathyal species which are obviously not redeposited but are artificially concentrated in the finest fractions (e.g., species of *Bolivina* and *Cassidulina*). The number of times a fraction was split, multiplied by the number of tests counted in a split of it, will give the total number of tests in that fraction. The results for the three fractions of each sample were then added together and divided by four to obtain the number of larger than 63-μm tests per unit volume of wet sediment (Tables I and II).

All percentage abundance figures are based on the total number of tests counted in the three fractions of the coarser than 63-μm residue of each sample. The results are given in the Appendix and summarized in Figs. 6–9.

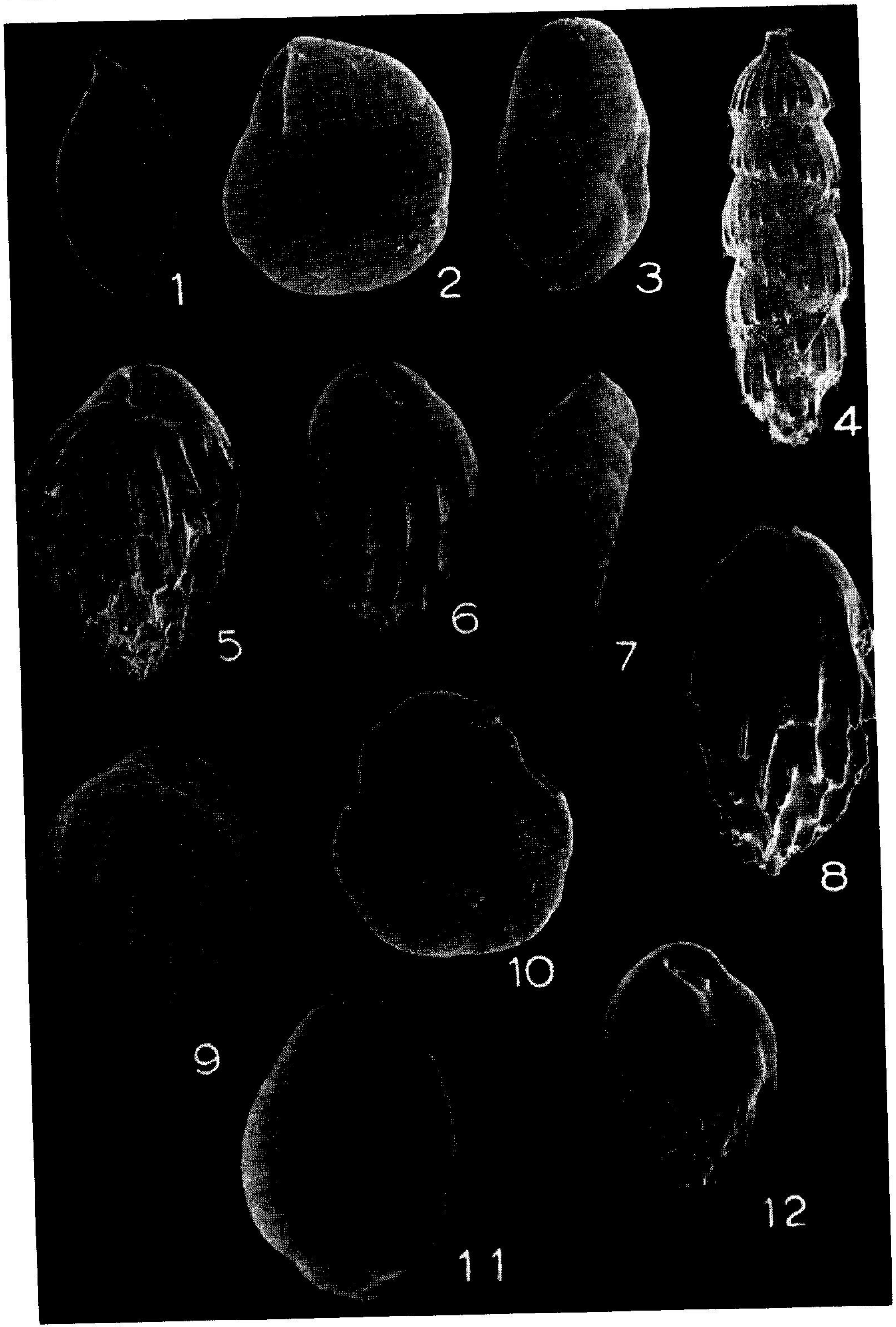
A previous scheme of nomenclature, based on the classification of Loeblich and Tappan (1964 and 1974) and numerous monographs on the modern foraminifers of the Mediterranean Sea, has been followed (Alavi, 1980). For ease of comparison, the same index of diversity employed by Parisi et al. (1982) was applied to the SM and the Cilician Basin assemblages (Tables I–III). Thus, the index of diversity $(I) = S - 1/\log N$, where S is the number of species and N the number of specimens in the same sample. All illustrated specimens are from the surface sediments of the Cilician Basin (Alavi, 1980) (Plates I and II).

Results

Sediment characteristics

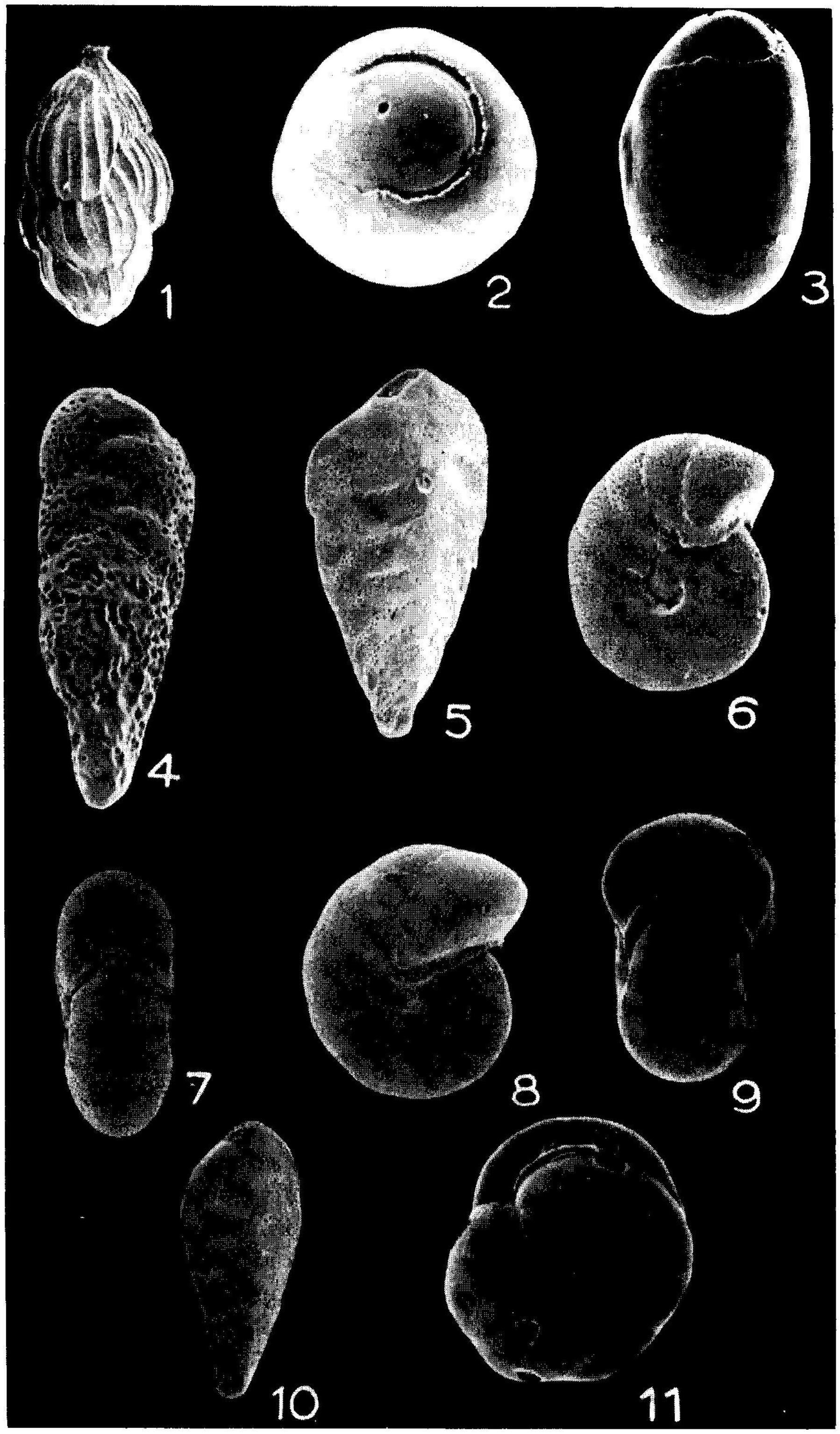
Sedimentological and geochemical studies of the sediments have not yet been completed.

PLATE I.



1. *Sigmoilina tenuis* (Czjzek), ×103.
2. *Epistominella vitrea* Parker, umbilical view, ×300.
3. *E. vitrea* Parker, peripheral view, ×349.
4. *Rectuvigerina phlegeri* Le Calvez, ×141.
5. *Bulimina inflata* Seguenza, ×83.
6. *B. costata* d'Orbigny, ×141.
7. *Brizalina spathulata* (Williamson), ×120.
8. *Bulimina costata* d'Orbigny, ×155.
9. *B. inflata* Seguenza, ×104.
10. *Epistominella vitrea* Parker, spiral view, ×275.
11. *Globobulimina* sp., ×90.
12. *Bulimina aculeata* d'Orbigny, ×168.

PLATE II.



1. *Uvigerina mediterranea* Hofker, ×59.
2. *Chilostomella mediterranensis* Cushman and Todd, apertural view, ×135.
3. *C. mediterranensis* Cushman and Todd, ×103.
4. *Bolivina variabilis* (Williamson), ×139.
5. *Bolivina dilatata* Reuss, ×136.
6. *Melonis pompilioides* (Fitchel and Moll), ×74.
7. *M. pompilioides* (Fitchel and Moll), apertural view, ×70.
8. *M. pompilioides* (Fitchel and Moll), ×98.
9. *M. pompilioides* (Fitchel and Moll), apertural view, ×78.
10. *Brizalina spathulata* (Williamson), ×107.
11. *Cassidulina minuta* Cushman, ×327.

Therefore, the following description of the sediments is based on the available data and microscopic examinations of sand fractions.

The sediments in both cores uniformly consist of a darkish green-grey mud containing a few percent of sand materials (cf. Stanley and Blanpied, 1980). X-radiographs showed that they are bioturbated and homogenized, but no laminated units or any other primary sedimentary structures could be observed (G. Evans, pers. comm., 1985). No graded sand layer or evidence of breaks in deposition was noticed. However, the presence of terrigenous sand-size mineral grains (mainly quartz), which are dominantly confined to the finer than 125-μm fractions, clearly indicates that the sediments are not entirely of hemipelagic origin.

Examination of regularly spaced samples of silt and clay fractions along both cores under the S.E.M. revealed that they are mostly composed of non-calcareous materials including some pyrite framboids at certain levels. No remains of diatoms could be seen, but coccoliths occur in isolated numbers at most levels, becoming distinctly more frequent in the lower parts of the cores.

The organic-carbon contents of the sediments are relatively high and their carbonate contents low (Table IV). As their organic-carbon contents range between 1.0 and 1.8% and their carbonate-carbon contents between 1.8 and 2.3% (the latter can be easily calculated from the carbonate content data, Table IV), the ratio of carbonate–carbon to organic–carbon remains below 2.0 for all of the samples. This ratio is very close to that given for sapropels from the late-Quaternary deep-sea record of the eastern Mediterranean basins (Anastasakis and Stanley, 1984). However, as the organic-carbon contents remain below 2.0%, in this respect they may be classified as sapropelic mud or proto-sapropel following the definitions of Kidd et al. (1978) for sapropels and their associated facies.

TABLE IV

Organic-carbon and carbonate contents of the sediments on percent dry-weight basis

Depth from top of core (cm)	Organic-carbon		Carbonates	
	Core M1	Core M4	Core M1	Core M4
0– 2	1.82	1.83	15.25	17.92
4– 6	1.41	1.43	16.58	17.08
8–10	1.30	1.31	15.42	15.50
12–14	1.28	1.21	18.58	16.00
16–18	1.33	1.45	15.00	15.50
20–22	1.36	1.28	19.25	16.92
24–26	1.82	1.26	14.75	17.25
28–30	1.74	1.28	18.67	16.33
32–34	1.64	1.51	17.50	18.33
36–38	1.47	1.25	17.58	17.83
40–42	1.44	1.14	15.25	18.17
44–46	1.72	1.09	16.08	17.58
48–50	1.56	1.18	16.08	19.08
52–54	1.21	1.22	20.50	16.08
56–58	1.38	1.11	17.17	17.08
60–62	1.15	1.16	16.50	14.58
64–66	1.30	0.96	19.08	16.33
68–70	1.24	1.22	18.67	16.00
72–74	1.57	1.17	15.75	15.58
76–78	1.44	1.24	20.17	16.00
80–82	1.26	1.72	17.17	16.67
84–86	1.43	1.30	18.58	16.00
88–90	1.47		17.67	
92–94	1.28		17.50	

Anastasakis (1985) classified the surficial sediments of the SM as gyttja and added that the modern organic-carbon-rich sediments in the Black and the Marmara Seas are richer in carbonates and different from the sapropel layers which were deposited in these basins during the middle Holocene (cf. Ross and Degens, 1974; Degens et al., 1978; Degens and Stoffers, 1980; and Calvert, 1983). Therefore, despite their relatively high content of organic-carbon, the sediments cannot be strictly regarded as sapropel. Bottom-water oxygen deficiency, high level of primary productivity, settling of a significant proportion of the particulate organic matter from the photic zone on the sea-floor (Ünlüata and Özsoy, 1986), and the high rate of bathyal sedimentation (Stanley and Blanpied, 1980; and Koreneva, 1971) are believed to be the main reasons behind their high organicediments

s
Core M4
17.92
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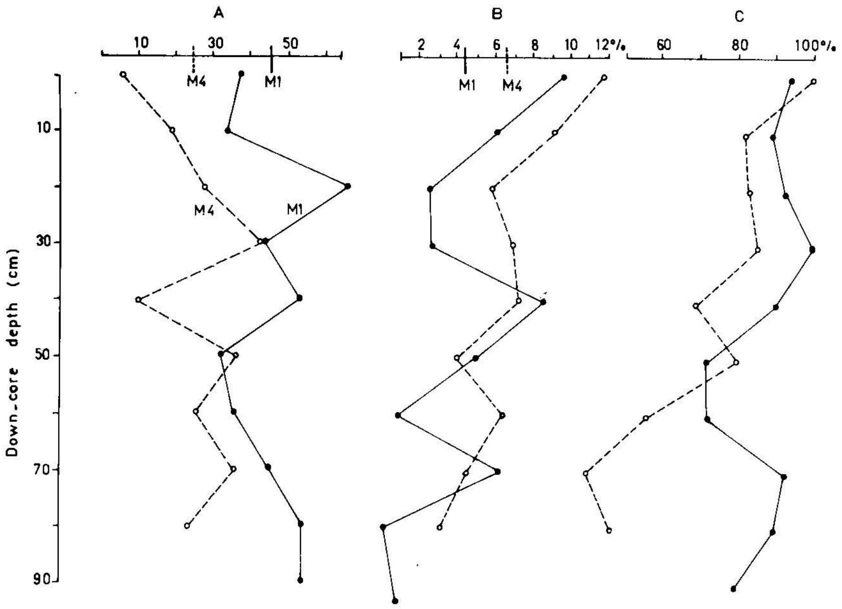

Fig. 4. Down-core variations in percentages of: (a) planktic tests in total foraminiferal tests, (b) redeposited tests of shallow water benthic species out of the total benthic tests, and (c) *Globigerina quinqueloba* in planktic tests (vertical bars indicate average values).

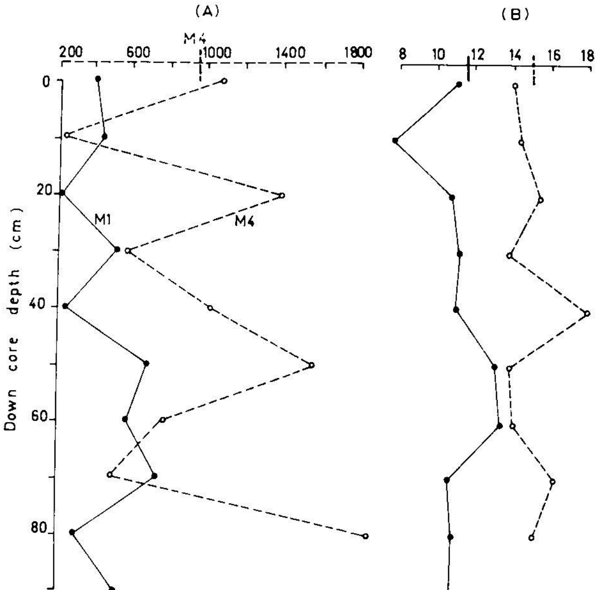

Fig. 5. Down-core variations in: (a) benthic foraminiferal test abundance (in number of tests per cc of wet sediment), and (b) index of diversity of benthic foraminiferal assemblages (vertical bars indicate average values).

carbon contents (see Demaison and Moore, 1980).

Benthic foraminiferal faunal trends

Redepositional faunal mixing and agents of test transportation

Down-core variations in proportions of redeposited tests of shallow (shelf) water species in the total counted benthic tests are shown in Fig. 4b. These are mostly confined to finer than 125-μm fractions and show no signs of reworking or transportation as bed-load (Murray, 1984). They often include juvenile tests of species of discorbids and cibicidids, which are normally found alive in association with shallow-water seaweeds around the Mediterranean Sea (Blanc-Vernet, 1969). These delicate tests would not have been found in a good state of preservation had they been transported as bed-load by downslope movements of sediments. Some of them are certainly transported offshore by drifting marine phytoclasts from shallow water. The evidence for this was found in

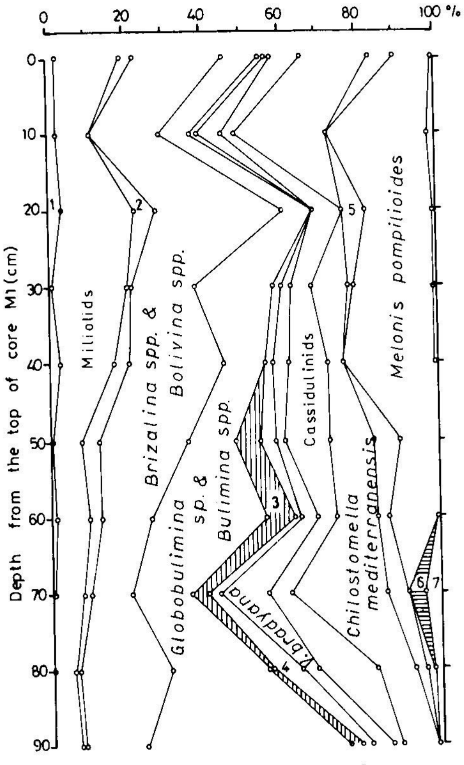

Fig. 6. Benthic foraminiferal faunal spectrum of core M1. *1*=Textulariids. *2*=Nodosariids, *3*=*Uvigerina mediterranea*. *4*=*Epistominella vitrea*. *5*=*Nonionella* spp. *6*=*Gyroidina umbonata*. *7*=others.

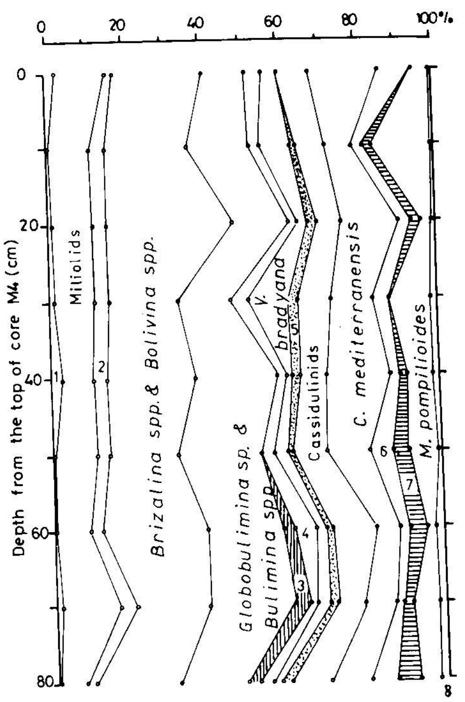

Fig. 7. Benthic foraminiferal faunal spectrum of core M4. 1–4 as in Fig. 6. *5*=*Hyalinea balthica*. *6*=*Nonionella* spp. *7*=*G. umbonata*. *8*=others.

the core-top sample from core M4. The proportion of redeposited tests reaches its top value in this sample (Fig. 4b). These include a few adult tests of shallow-water miliolids, *Planorbulina*, and *Cibicides*. The core-top sample from core M1 also contains the highest number of redeposited tests for this core (Fig. 4b).

In a few other samples, small numbers of redeposited tests were found in coarser than 125-μm fractions (e.g., 20–22 cm and 40–42 cm levels in core M1). These samples show anomalously low numbers of benthic tests per cc of sediments (Fig 5a). In the former sample the percentage of planktic tests is about 20% higher than the average value for the core (Fig. 4a). These extreme fluctuations in faunal parameters, along with higher proportions of fine and medium sand-size terrigenous particles in these samples, are probable signals of some downslope sediment movements. They may have been deposited in distal parts of turbidity currents, which are suggested to have flowed into the basin from the southern slope of the SM (Stanley and Blanpied, 1980). However, it should be pointed out that none of the samples showed the characteristic test-size distribution that has been found in some modern deep-sea turbidites (Brouwer, 1967; Griggs and Fowler, 1971; and Brunner and Normark, 1985). Thus, it seems that the majority of the redeposited tests along the cores have been transported in suspension.

The most likely agents of transportation, other than drifting marine phytoclasts, are either lutite flows (McCave, 1972) or detached turbid layers (Stanley, 1983). These are basically tongues of sediment-laden water, which may protrude horizontally into offshore waters away from shelf and slope. They can be initiated by various processes which affect the shelf-edge or the outer parts of the shelf (see Southard and Stanley, 1976). Favourable conditions for the development of these types of density currents are strong water-column stratification and flow of fast currents at about the outer shelf levels (Stanley, 1983). These conditions are met in the SM, as both strong water-column stratification and swift, permanent currents prevail in the upper few hundred meters of the water column (Fig. 3). These currents sweep over large parts of the shelf areas close to the site of coring (Fig. 2).

Similar occurrences of small and juvenile tests of shelf-dwelling species have been reported widely in deep-sea sediments from other basins of the eastern Mediterranean Sea (Parker,1958, p. 34; Cita et al., 1973; Alavi,1980; Parisi and Cita, 1982; and Schilling, 1984). Parker notes that the proportion of the redeposited tests decreases with increasing distance away from basinal margins. The same trend was also found in the Cilician Basin surface sediments, where the transported tests tend to become generally smaller in deep-water samples farther away from the slope (Alavi,1980). Some of the reported cases cited above are from Pleistocene sediments in cores collected on topographic highs on the western parts of the Mediterranean Ridge. Therefore, as noted by Parisi and Cita (1982), their transportation by downslope movements of sediments is very unlikely. These authors proposed intensive thermohaline circulation near the bottom as a possible agent of transportation. Cita et al. (1973) and Schilling (1984) advocated transportation by drifting plant debris as the main agent. According to the latter author, these plant debris are often well preserved in sapropels.

In conclusion, the present assemblages are mostly considered as indigenous bathyal death assemblages disturbed by redeposition of some tests from surrounding shelf and slope areas. Most of the redeposited tests seem to have been carried in suspension or by floating phytoclasts, causing limited post-depositional alterations of assemblages. These post-depositional events have not obliterated the main faunal trends and bathyal characteristic of the assemblages in the cores. In addition, despite some faunal differences between the cores, there is good agreement between them in terms of the faunal compositions of the assemblages and their down-core variations (Figs. 6 and 7).

Faunal abundance and diversity

Figure 5 shows curves of down-core variations in calculated number of tests per cc of wet sediments and indices of diversity of the assemblages (Tables I and II). The average index of diversity of assemblages for each core was found to be significantly lower than corresponding values for assemblages in surface sediments of two other marginal basins in the eastern Mediterranean Sea (Table III). In contrast, the average number of tests per gram of sediments seems to be at least as high as in the well-oxygenated surface sediments of the Cilician Basin, and about three times higher than the figure for the southern Adriatic Basin. Even if an unlikely maximum wet bulk density of 2 g/cc is assumed for the bottom sediments of the Sea of Marmara (Keller and Lambert, 1972), the average benthic foraminiferal number is about 500 for core M4 and 67 for core M1 (cf. data in Table III). Considering the higher average rate of deposition for the late Holocene of the Sea of Marmara (estimated to be at least twice as high as the reported rate for the Cilicean Basin, see Table III), it appears that oxygen deficiency down to about 0.5 ml/l has no perceptible effect on the rate of reproduction of most common species in the assemblages. These species are believed to be well adapted to substrate conditions in deeper parts of the SM (see below).

Assemblages of benthic foraminifers showing low diversity and high abundance of individuals are also reported from oxygen-deficient zones of some marine basins off the west coast of North America (Phleger and Soutar, 1973; Boltovskoy and Wright 1976, and Savrda et al., 1984). These faunal trends generally reflect stressful conditions under which normally a small number of tolerant species dominate the assemblages at the expense of other species which would have been present under stress-free conditions (Murray, 1973).

Faunal composition

Figures 6 and 7 show the faunal spectra of the cores. Textuariids are rare or absent. Miliolids are mostly represented by *Sigmoilina tenuis, Articulina tubulosa,* and small tests mostly belonging to *Biloculinella* and *Miliolinella.* Heavily calcified tests of some species of the *Pyrgo* and *Biloculinella labiata* group are either absent or present in the lower parts of the cores in rare numbers. These species sometimes can be found in relatively high numbers at similar depth levels in other marginal basins of the eastern Mediterranean (Parker,1958; Blanc-Vernet, 1969; Alavi, 1980; Parisi, 1981; and Parisi et al., 1982). Similarly, some typical bathyal hyaline species with strongly calcified and ornamented tests reported from these basins are absent in the SM. These include large species of *Dentalina* and *Lenticulina* and some species of *Gyroidina, Cibicidoides, Hoeglundina, Sphaeroidina, Planulina,* and *Uvigerina peregrina* (cf. Massiotta et al., 1976; Cita and Zocchi, 1978, and Bizon and Bizon, 1984). Although the possibility of the inability of some of these taxa to surmount the sill at the Dardanelles cannot be neglected at this stage, this is unlikely considering their suf-

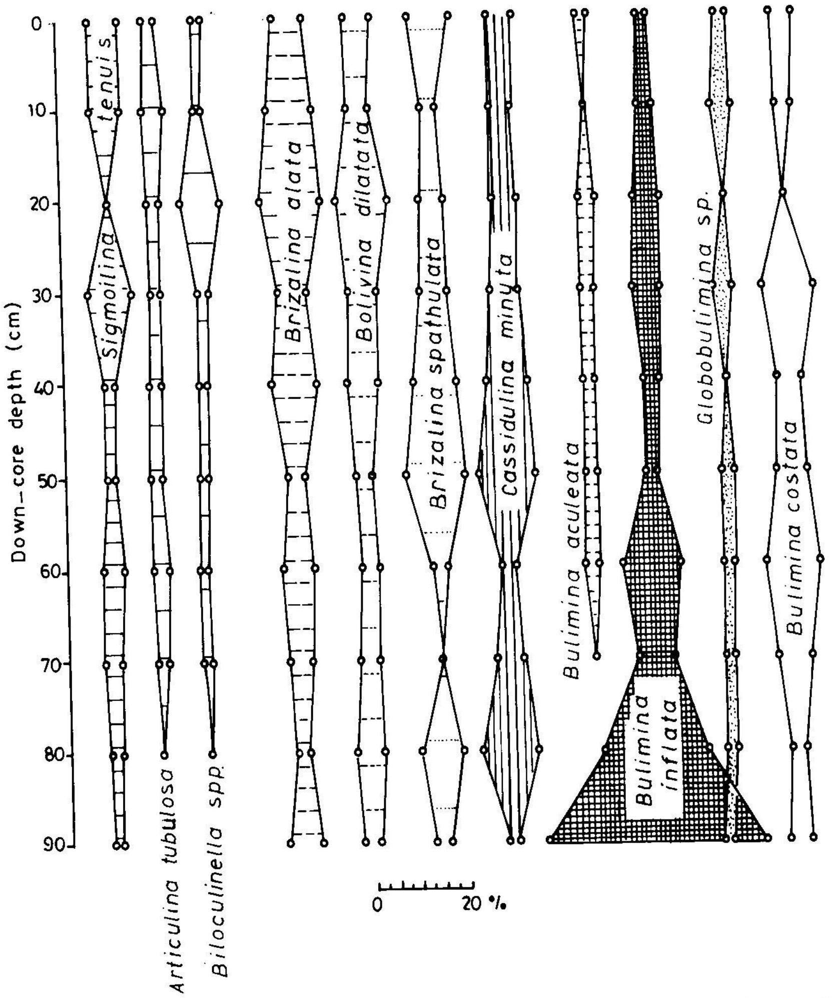

Fig. 8. Down-core variations in relative abundances of common benthic foraminiferal species in core M1.

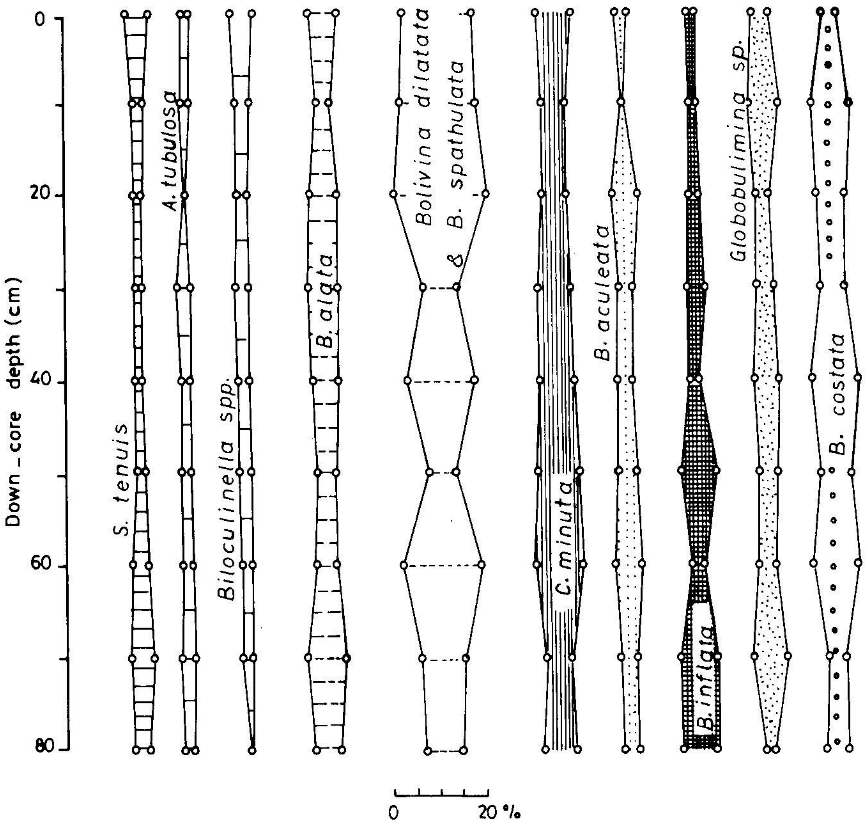

Fig. 9. Down-core variations in relative abundances of common benthic foraminiferal species in core M4.

ficiently shallow upper depth-limits in the Mediterranean Sea (Bizon and Bizon, 1984, p. 123) and favourable water properties and direction of currents over this sill (ca. 70 m) (Fig. 3). The effectiveness of this sill as a faunal barrier becomes more doubtful considering the presence of other bathyal species with upper-depth limits as shallow as those of the absent ones. These include costate species of *Bulimina, Gyroidina umbonata* (thinly calcified and small tests), *Hyalinea balthica,* and *Uvigerina mediterranea* (Figs. 7 and 8). The consistent occurrences of *Articulina tubulosa* in the assemblages suggest that the sill cannot have acted as a faunal barrier during the Quaternary. This species has an upper depth limit of about 600 m in the Mediterranean Sea (Bizon and Bizon, op.cit.). It is well-known to be a common deep-water (> 2000 m) species with preference for low oxygen conditions in the Quaternary deep-sea record of the eastern Mediterranean basins (Massiotta et al., 1976; and Parisi and Cita, 1982).

The most frequent bathyal species in the Sea of Marmara are *Melonis pompilioides, Chilostomella mediterranensis, Brizalina alata, B. spathulata,* and *Bolivina dilatata. Bulimina inflata* is less frequent in the upper parts of the cores and *Uvigerina mediterranea,* which is present in lower parts of the cores in low percentages (< 8%), disappears completely from the upper parts of the cores (Figs. 6–9). A second group of rotaliids, some of which are reported in low numbers from the bathyal (200–1800 m) zone of the Mediterranean Sea, are present at low to moderate percentage levels (5–15%) in most of the assemblages. These are *Globobulimina* sp., *Bulimina aculeata, B. costata, Valvulineria* *bradyana*, *Cassidulina minuta*, *Nonionella* cf. *opima*, *Epistominella vitrea*, *Hyalinea balthica* (in core M4 only), and *Rectuvigerina phlegeri* (1–2%).

Discussion

Depositional conditions and estimated age of the sediments

Coarser than 125 μm sand fractions are basically composed of calcareous remains of foraminifers, benthic molluscs, echinoids, and some sponge spicules. Some pyrite spherules are also present in this fraction. Pyrite-infilled foraminiferal tests are estimated to constitute about 10–15% of the total counted tests in each sample. Small masses of framboidal pyrite were also noted in silt and clay fractions of samples examined by the S.E.M. These findings indicate reducive conditions of deposition, although no trace of H_2S formation was noticed at the times of sampling or core splitting.

Presence of remains of macrobenthic organisms as well as benthic foraminifers in all samples, along with the bioturbated nature of the sediments, rule out sedimentation of any parts of the cores under anoxic conditions. In fact, there is some evidence indicating that the lower parts of the cores may have been deposited under higher levels of oxygen concentration (Alavi,1985). Furthermore, lamination due to annihilation of burrowing invertebrates is reported to develop at oxygen concentration levels below 0.15 ml/l (Emery and Hülsemann, 1962 and Savrda et al., 1984). Hence, the level of dissolved oxygen in bottom waters of this part of the SM may never have fallen below the present value of about 0.5 ml/l during the time interval represented by the cores.

At oxygen concentration levels between 0.2 and 1.0 ml/l (dysaerobic zone of Savrda et al., 1984), the macrobenthos is reported to be dominated by soft-bodied burrowers, and secretion of strongly calcified skeletal components hindered in both macro- and microbenthic forms (Rhoads and Morse, 1971 and Harman, 1964). However, some species of pelecypods (Emery and Hülsemann, 1962) and gastropods (Băcesco, 1963) with weakly calcified shells can tolerate very low levels of oxygen concentration. Similarly, some echinoids are reported to occur in large numbers in the dysaerobic zone of some of the basins off the coast of California (Savrda et al., 1984). Therefore, the sekeletal remains of molluscs and echinoids in nearly all of the samples are most proably of indigenous origin. Moreover, if any part of the cores had been deposited by a catastrophic event (e.g., seismically induced turbidity current), the burrowers would have been at least temporarily smothered and some primary sedimentary structures preserved (cf. Savrda et a., 1984).

Low biogenic carbonate production on the bottom of the basin can also partially explain low carbonate contents of the sediments (Table IV). However, the main reason behind the carbonate impoverishment of the sediments is believed to be poor biologic carbonate production in the photic zone. Aragonitic remains of pteropods and heteropods — very common in bathyal sediments of other eastern Mediterranean basins (Alavi, 1980) — are totally absent in the samples. Planktic foraminifers are only represented by two small species, *Globigerina quinqueloba* Natland and *Turborotalita clarkei* (Rögl and Bolli). Coccoliths occur in low numbers along the cores. Only one species could be found. This was identified as *Emiliania huxleyi* (Lohmann) by J. Young (pers. comm., 1985). This species is known to occur abundantly in the late Holocene sediments from the Black Sea (Bukry, 1974). It is considered to be a euryhaline species.

Other reasons for the relatively low carbonate contents of the sediments can be carbonate dissolution and a large supply of terrigenic materials into the basin. However, significant car

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bonate dissolution on the sea-floor is suspected because of the rapid development of reducive conditions which is aided by oxygen deficiency (Leventer et al., 1983). The state of preservation of foraminiferal assemblages, which include abundant delicate and small tests of both benthic and planktic species, also supports this view (Murray, 1984). A high rate of deposition of fine-grained materials also reduces the chance of carbonate dissolution on the sea-floor.

Pteropods are known to occur in plankton tows in the Aegean Sea as far as the entrance of the Strait of Dardanelles (Furnestin, 1979). They are probably excluded from the SM by oligohaline surface water conditions (Fig. 3). Similarly, a number of planktic foraminiferal species reported from the surface sediments of the Aegean Sea seem to be excluded from the Sea of Marmara (cf. Parker, 1958; and Thunell, 1978). Planktic foraminifers are reported to be totally absent in the Black Sea (Shimkus and Trimonis, 1974).

In general, the faunal and sedimentary characteristics of the sediments can be closely compared with the uppermost unit of sediments in cores G7 and G8 as described by Stanley and Blanpied (1980) from the same part of the SM. These authors correlated the base of this unit with that of the youngest Holocene stratigraphic unit from the Black Sea deep-sea sediments (unit 1 of Ross and Degens, 1974). This correlation is supported here by the presence of *Emiliania huxleyi* along the cores. This is the dominant species in the uppermost unit of sediments from the Black Sea (Bukry, 1974). On these grounds, it is estimated that the lowest parts of the cores are most probably not older than a few thousands years B.P. (Ross and Degens, 1974 and Degens and Stoffers, 1980). In other words, the sediments are interpreted as having been deposited almost entirely after the establishment of the present system of two-layer flow in the Turkish Straits during the last stage of the Flandrian transgression when the sea-level reached close to its present level (Ross and Degens, 1974).

Benthic foraminiferal response to the depositional conditions

In her classic work on the benthic foraminifers of the eastern Mediterranean basins, Parker (1958, p. 231) notes that a number of species occur both in shallow and deep-water sediments without any indication of being redeposited. Her list includes *Sigmoilina tenuis, Bulimina marginata, Bolivina dilatata dilatatissima, Globobulimina pseudospinescencs, Loxostomum alatum (=Brizalina alata), Valvulineria complanata (=V. bradyana), Chilostomella mediterranensis,* and *Cassidulina* spp. Nearly all of these species are common in the present assemblages.

S. tenuis, Bulimina spp., and *Cassidulina* spp. were listed as heterobathyal by Bandy and Chierici (1966). Wide bathymetric distributions of most of these species, often in low numbers, have been noted by other investigators in the Mediterranean Sea (e.g., Chierici et al., 1962 and Blanc-Vernet, 1969).

In the Cilician Basin, *V. bradyana*, and species of *Bulimina, Bolivina* and *Cassidulina* occur most frequently in deeper parts of shelf to upper-slope (100–400 m) surface sediments which are mainly composed of silt and clay fractions. These areas are often close to major sources of runoff waters into the basin, where the terrigenous nutrient input is known to boost productivity (Yilmaz, 1986 and Alavi, 1980).

Similar patterns of abundance distribution have been reported for species of *Melonis, Valvulineria, Bolivina, Bulimina* and *Nonionella* in surface sediments on the shelf of the Grand Rhône and in the Gulf of Ajaccio off the west coast of Corsica by Bizon and Bizon (1984). The sediments in both areas are rich in organic carbon (Added et al., 1984, and Fernex and Serra, 1984).

Bolivina dilatata, Valvulineria bradyana, Brizalina spathulata, and *B. alata* are reported to occur more frequently in some organic-carbon-rich sediments from the Pliocene and Miocene of the eastern Mediterranean basin (Van der

Zwaan, 1982; and Katz and Thunell, 1984). The first two species are found more frequently in surface sediments off the shelf of the Nile and in the Aegean Sea (Katz and Thunell, 1984). Species of *Cassidulina, Bolivina, Bulimina, Chilostomella* and *Globobulimina* are also reported to be common or abundant close to or within some of the late Quaternary sapropels from the Ionian and Levantine basins (Cita and Podenzani, 1980; Mullineaux and Lohmann, 1981; Parisi and Cita, 1982; and Schilling, 1984).

Outside the Mediterranean Sea, species of *Nonionella, Bolivina, Bulimina* and *Uvigerina* were reported in organic-carbon-rich sediments of the shallow Gulf of Cariaco (Seiglie, 1968). In the Gulf of Mexico, *Valvulineria complanata, Globobulimina affinis,* and *Uvigerina peregrina mediterranea* were listed as "delta-elevated" species (Pflum and Frerichs, 1976). These species occur in shallower parts of the bathyal zone directly off the mouth of the Mississippi River. Ingle et al. (1980) found no significant faunal difference between assemblages of foraminifers from two zones of oceanic oxygen minima, one centred at about 750 m and the other at about 1300 m, in the southeastern Pacific. Common species found in these zones belong to *Bolivina, Bulimina, Cassidulina, Epistominella, Valvulineria* and *Uvigerina* (Ingle et al. 1980, table 5). Caralp (1984) has recently reported high abundances of *Chilostomella, Melonis,* and *Bulimina* in diatomaceous abyssal sediments from the late Quaternary of the eastern North Atlantic. These sediments are believed to have been deposited under upwelling conditions. Finally, Corliss (1985) reported living specimens of *Chilostomella, Globobulimina* and *Melonis* up to 7 cm below the sediment–water interface in box-core samples from the abyssal sediments of the western North Atlantic. These species are concluded to be adapted to an infaunal life-style and their distribution principally controlled by sediment characteristics rather than water-mass properties. The morphological characteristics of infaunal species given by Corliss (1985) can also be found in the Mediterranean species of these genera as well as in *V. bradyana, Bulimina inflata, Bolivina dilatata* and *Brizalina alata.* These species and those of *Chilostomella, Globobulimina,* and *Melonis* are the most common species in the SM assemblages (Figs. 6 and 7).

In summary, the common to frequent species in the assemblages seem to have a clear preference for substrates rich in organic matter, irrespective of the depth of water in the outer shelf and the bathyal environments of the Mediterranean Sea. By virtue of their infaunal mode of life, they are probably more efficient in extraction of oxygen from water for their metabolic activities. So they may have developed resistance to oxygen deficiency. This is required for abundant preservation of organic matter in the sediments upon which these taxa may feed (Vincent et al., 1981; Lutze and Coulbourn, 1983, and Zahn et al., 1986). Thus, the reported high abundances of these species or their closely allied forms in sediments are very close to some sapropels and their related facies from the late Quaternary of the eastern Mediterranean basins (see Cita and Podenzani, 1980; Mullineaux and Lohmann, 1981; Parisi and Cita, 1982; Cita and Grignani, 1982, and Schilling, 1984), plus the bioturbated nature of some of these layers and occurrences of a number of these species in some others, indicate that hydrographic conditions in these basins, at some stages during the deposition of sapropels, may have been very close to those now prevailing in the SM and outlined above (Fig. 3). This would lend more support to the well-known model of water-column stratification as a result of excess fresh-water input in these basins and probable current reversals in the Strait of Sicily at the time of sapropel deposition (Ryan, 1972; Stanley e al., 1975, and Muerdter, 1984). Under suc conditions, primary productivity may also hav been higher than the present level as a result o the development of an overall "estuarine" sys tem of water flow in these isolated basins whose level of productivity is basically limited due to nutrient shortage and the present "anti-estuarine" system of water flow (see McGill, 1965; Murdoch and Onuf, 1974; and Miller, 1983). Some recent geochemical and micropalaeontological studies have also suggested increased levels of palaeo-productivity at the times of sapropel formation (Schrader and Matherne, 1981; Calvert, 1983; and Sutherland et al., 1984).

Conclusions

Although surficial deep-sea sediments of the Sea of Marmara cannot be considered as sapropels in the strict sense of the term (Anastasakis and Sanley, 1984; and Calvert, 1983), their microfaunal contents reflect continuous sedimentation under dysaerobic conditions (Savrda et al., 1984). Some of their properties may be compared with the "organic ooze" or "sapropelic mud" facies of Anastasakis and Stanley (1984, p. 506).

The benthic foraminiferal assemblages are rich in individuals but show lower diversity in comparison with other marginal basins in the region. The most common forms are interpreted as being adapted to oxygen-deficient conditions and an infaunal mode of life. This seems to enable them to populate any part of the bathyal zone where present bottom conditions are most suitable for them in other basins of the Mediterranean Sea. Agglutinated forms and heavily calcified species of miliolids and rotaliids are rare or absent, presumably due to their greater sensitivity to oxygen-deficient conditions.

The dominant to common faunal elements of the assemblages are also reported from fossil benthic foraminiferal assemblages in association with some organic-carbon rich sediment-layers from the Neogene of the region. These faunal similarities strengthen the suggstion that palaeohydrographic conditions at the times of deposition of these layers may have been analogous to those now prevailing in the Sea of Marmara and the northernmost parts of the Aegean Sea (see Collins et al., 1981; Mullineaux and Lohmann, 1981; and Katz and Thunell, 1984).

Acknowledgements

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APPENDIX I — Population counting data for foraminiferal assemblages from cores M1 and M4 from the Sea of Marmara.

Figures in brackets are percentages, J = juvenile, R = redeposited, N-number of indigenous individuals, and S = number of indigenous species.

Taxa	Core M1									
	Down-core depth (cm)									
	0-2	10-12	20-22	30-32	40-42	50-52	60-62	70-72	80-82	90-92
1 *Adercotryma glomerata*	1(0.6)									
2 *Trochamina* sp	1(0.6)									
3 *Textularia sagittula*	1(0.6)	3(0.9)					1(0.5)			
4 *Textularia sp.* (J)			1(2.1)		2(1.1)		1(0.5)			
5 *Bigenerina nodosaria*				1(0.9)	1(0.8)					
6 *Cyclogyra carinata*		1R								
7 *C. involvens*							1(0.5)	1(0.1)		
8 *Spiroloculina excavata*	1R	1(0.6)		1(0.9)		1(0.9)	2(1.0)			
9 *Quinqueloculina* sp 1	6(3.9)	1(1.6)	1(2.1)		3(2.1)					2(1.1)
10 *Q.* sp. 2				4(3.6)	5(4.3)	2(1.2)	1(0.5)			
11 *Q.* sp. 3					4(3.4)	4(3.4)	1(0.5)			
12 *Q. pygmea*							1(0.5)			
13 *Q. pentagona*										2(1.1)
14 *Pyrgo anomala*								1R		
15 *P. elongata*										4(2.3)
16 *Sigmoilina tenuis*	10(6.1)	9(5.9)		10(9.1)		2(1.2)	5(2.5)	4(2.9)	5(3.7)	2(1.1)
17 *Sigmoilopsis schlumbergeri*						1(0.6)		2(1.4)	1(0.7)	
18 *Triloculina* sp.						1R				
19 *Miliolinella subrotunda*	4(2.6)	2(1.3)	1(2.7)	2(1.8)						3(1.7)
20 *M.* sp.				2(1.8)	2(1.7)				2(1.4)	
21 *Biloculinella* sp.	2(1.3)		3(8.1)	1(0.8)				1(0.7)		
22 *B. cylindrica*					1(0.8)	1(0.6)	2(1.0)			
23 *B. labiata subsphaerica*	1(0.6)					1(0.6)				
24 *Articulina tubulosa*	3(1.9)		1(2.7)	1(0.9)	1(0.8)	1(0.6)	6(3.0)	3(2.2)		
25 *Amphicoryna* sp.			1(2.7)			1(0.6)				
26 *Dentalina* sp. 1					1(0.8)					
27 *D.* sp. 2					1(0.8)					1(0.5)
28 *Lagena striata*	1(0.6)			1(0.8)						
29 *L. laevis*			1(2.7)							
30 *L. gibbera*				1(0.9)						
31 *L. clavata*						2(1.2)				
32 *L. gracillima*							1(0.5)			
33 *L.* sp.							2(1.0)			
34 "*L*" *fornasinii*	1(0.6)						2(1.0)			
35 *Fissurina* spp.	2(1.3)					1(0.6)			1(0.7)	
36 *Lenticulina peregrina*					1(0.8)	4(2.4)	4(2.0)	2(1.4)		
37 *Brizalina alata*	10(6.6)	13(8.5)	5(13.5)	5(4.5)	10(8.6)	4(2.4)	14(7.0)	6(4.4)	3(2.2)	12(6.9)
38 *Bolivina dilatata*	7(4.6)	6(3.9)	4(10.8)	4(3.6)	8(6.9)	4(2.4)	4(2.0)	6(4.4)	8(5.9)	6(3.4
39 *Brizalina spathulata*	14(9.2)	5(3.2)	2(5.4)	5(4.5)	11(9.4)	21(12.7)	5(2.5)	3(1.2)	12(8.9)	5(2.8
40 *Bolivina* spp.	4(2.6)	3(1.9)	1(2.7)	3(2.7)		8(4.8)	3(1.5)		8(5.0)	4(2.3
41 *Bulimina inflata*	3(1.9)	2(5.4)	4(3.6)	4(3.4)	4(3.4)	1(0.6)	27(13.5)	9(6.7)	29(21.6)	79(45.
42 *B. costata*	7(4.6)	5(3.2)		13(11.8)	6(5.1)	11(6.6)	24(12.0)	10(7.4)	3(2.2)	9(5.2
43 *B. aculeata*	2(1.3)		1(2.7)	2(1.8)	2(1.7)	3(1.8)	5(2.5)		1(0.7)	1(0.5

APPENDIX I (continued)

Taxa	Core M1									
	Down-core depth (cm)									
	0-2	10-12	20-22	30-32	40-42	50-52	60-62	70-72	80-82	90-92
44 *Globobulimina* sp	3(1.9)	5(3.1)		4(3.6)		5(3.0)	1(0.5)	1(0.7)	1(0.7)	2(1.1)
45 *Rectuvigerina phlegeri*								1(0.7)		
46 *Uvigerina mediterranea*						10(6.7)	14(7.0)	5(3.7)	1(0.7)	4(2.3)
47 *Epistominella vitrea*	1(0.6)	2(1.3)		2(1.8)	2(1.7)	7(4.2)	2(1.0)	3(2.2)	10(7.4)	3(1.7)
48 *Valvulineria bradyana*	1(0.6)	9(5.9)		2(1.8)	5(4.3)	3(1.8)	8(4.0)	18(13.3)	5(3.7)	11(6.3)
49 *Spirillina vivipera*	1(0.6)	3(1.9)						2(1.4)		1(0.5)
50 *Turrispirillina lucida*	1(0.6)					1(0.6)				
51 *Patellina corrugata*								1(0.7)		
52 Discorbids (J)(R)	4	6		3		2	1	4		3
53 *Ammonia beccarii* (R)								1	1	
54 *Elphidiids* (J)(R)	5	1		3		2	1	4		3
55 *Hyalinea balthica*	1(0.6)			2(1.8)		2(1.2)	1(0.6)			
56 *Cibicides* spp		1R			2R	1R				1(0.5)
57 *Fursenkoina* sp.							1(0.5)	1(0.7)		
58 *Cassidulina minuta*	7(4.6)	5(3.2)	2(5.4)	6(5.4)	10(8.6)	19(11.5)	6(3.0)	6(4.4)	17(12.6)	3(1.7)
59 *Globocassidulina subglobosa*	3(1.9)		1(2.7)		1(0.8)		3(1.5)	2(1.4)	3(2.2)	
60 *Chilostomella mediterranensis*	26(17.2)	36(23.6)		11(1.0)	4(3.4)	20(12.1)	19(9.5)	34(25.1)	14(10.4)	16(9.2)
61 *Nonion* spp. (R)	6	1				3				3
62 *Nonionella opima*	10(6.6)		2(5.4)	1(0.9)		10(6.0)	5(2.5)	8(5.9)	4(2.9)	1(0.5)
63 *N.* sp.			1(2.7)					4(2.9)		
64 *Gyroidina umbonata*	1(0.6)					4(2.4)	1(0.5)	3(2.2)	3(2.2)	1(0.5)
65 *Melonis pompilioides*	16(10.6)	41(26.9)	7(18.9)	23(20.9)	30(25.8)	11(6.6)	29(14.5)		2(1.4)	
Total benthic tests	167	162	38	113	127	174	202	145	134	176
Redeposited benthic tests	16	10	1	3	11	9	2	10	0	6
Indigenous benthic tests (*N*)	151	152	37	110	116	165	200	135	134	173
Number of species (*S*)	31	18	18	24	24	30	32	24	22	23
Globigerina quinqueloba	84(94.9)	70(89.7)	64(92.8)	82(100)	116(90.7)	56(71.8)	78(72.2)	99(92.5)	120(78.9)	152(79.2)
Turborotalita clarkei	5(5.6)	8(10.3)	5(7.2)	0	12(9.3)	22(28.2)	30(27.8)	8(7.5)	32(21.1)	40(20.8)
Globigerinoides ruber							1	1		
Total planktic tests	89	78	69	82	128	78	108	108	152	192

APPENDIX I (continued)

Taxa	Core M4									
	Down-core depth (cm)									
	0-2	10-12	20-22	30-32	40-42	50-52	60-62	70-72	80-82	90-92
1 *Adercotryma glomerata*	2(1.1)									
2 *Textularia sagittula*	1R		2R		5(1.9)			2(1.0)		
3 *Textularia agglutinans*			1R		2(0.7)					
4 *Bigenerina nodosaria*			2(0.6)	2(1.1)				1(0.5)		
5 *Siphotextularia concava(R)*	1		1							
6 *Cyclogyra carinata(R)*			1							
7 *C. involvens*	1(0.5)	1(0.8)		2(1.1)					1(0.3)	
8 *Ophthalmedium acutimargo*	2(1.1)	1(0.8)			1(0.4)		1(0.5)	2(1.0)		
9 *Spirolculina excavata*	2(0.5)(1R)		2(0.6)		2(1.3)					
10 *Quinquloculina* cf. *rugosa*(R)	1									
11 *Q* spp. (3 species)	4R	2(1.6)	11(3.8)	1(0.6)	3(0.7)1R	5(3.4)	3(1.5)		3(1.0)	
12 *Q. pentagona*					1(0.4)					
13 *Pyrgo anomala*					1(0.4)			2(1.0)		
14 *P.* cf. *depressa*					1(0.4)			1(0.5)		
15 *Sigmoilina grata*(R)	1									
16 *S. tenuis*	5(2.9)	3(2.5)	3(1.0)	1(0.6)	4(1.6)	2(1.4)	5(2.6)	11(5.7)	8(2.9)	
17 *Sigmoilopsis schlumbergeri*	1(0.6)	1(0.8)	5(1.7)		2(0.8)					
18 *Triloculina tricarinata*	2(1.1)		1(0.3)		1(0.4)	1(0.7)		1(0.5)		
19 *Miliolinella subrotunda*			2(0.7)				1(0.5)	2(1.0)	2(0.7)	
20 *M* sp.				4(2.3)	1(0.4)		2(1.0)	1(0.5)	1(0.4)	
21 *Biloculinella cylindrica*	2(1.1)			1(0.6)	2(0.8)	1(0.7)	3(1.6)	2(1.0)		
22 *B. labiata depressa*				1(0.3)		1(0.4)	1(0.7)			
23 *B. labiata subsphaerica*	3(1.7)	1(0.8)	4(1.4)	2(1.1)	4(1.6)	3(2.0)				
24 *B.* sp	4(2.3)	2(1.6)	2(0.7)	2(1.1)						
25 *Articulina tubulosa*	2(1.1)	2(1.6)		5(2.8)	4(1.6)	2(1.4)	2(1.0)	5(2.6)	3(1.1)	
26 *Amphicoryna scalaris*						2(1.4)				
27 *Dentalina* sp.				1(0.6)			1(0.5)	1(0.5)		
28 *Lagena striata*					1(0.4)	1(0.7)				
29 *L. clavata*			2(0.7)							
30 *L.* sp			2(0.7)		1(0.4)		1(0.5)			
31 *Fissurina* spp.	1(0.6)	2(1.6)	1(0.3)	1(0.6)	1(0.4)		1(0.5)	2(1.0)	4(1.4)	
32 *Lenticulina peregrina*	1(0.6)		4(1.4)	5(2.8)	4(1.6)		2(1.0)	4(2.0)	3(1.1)	
33 *L.* sp.		2(1.6)				1(0.7)				
34 *Sphaeroidina bulloides*			1(0.3)						1(0.4)	
35 *Brizalina alata*	11(6.3)	3(2.5)	23(7.9)	11(6.2)	15(5.9)	6(4.1)	8(4.2)	16(8.4)	13(4.7)	
36 *Bolvina dilatata* and *Brizalina spathulata*	27(15.6)	21(17.3)	58(20.0)	12(6.8)	39(15.5)	7(4.7)	34(17.9)	17(8.9)	23(8.4)	
37 *B.* spp.	2(1.1)	2(1.6)	13(4.5)	8(4.5)	5(2.0)	12(8.2)	9(4.7)	2(1.0)	24(8.7)	
38 *Bulimina inflata*	2(1.1) 7(4.0)	1(0.8) 9(7.4)	5(1.7) 18(6.2)	6(3.4) 8(4.5)	2(0.8) 25(9.9)	12(8.2) 9(6.2)	2(1.0) 19(10.0)	15(7.8) 8(4.2)	20(7.3) 13(4.7)	
39 *B. costata*	5(2.9)	1(0.8)	11(3.8)	5(2.8)	8(3.2)	6(4.1)	11(5.8)	6(3.1)	11(4.1)	
40 *B. aculeata*	5(2.9)	8(6.6)	9(3.1)	5(2.8)	17(6.7)	5(3.4)	6(3.1)	13(6.8)	2(0.7)	
41 *Globobulimina* sp.										

APPENDIX I (continued)

Taxa	Core M4									
	Down-core depth (cm)									
	0-2	10-12	20-22	30-32	40-42	50-52	60-62	70-72	80-82	90-92
42 *Stainforthia* sp.									1(0.4)	
43 *Rectuvigerina phlegeri*			3(1.0)		2(0.8)		1(0.5)	2(1.0)	2(0.7)	
44 *Uvigerina mediterranea*							4(2.1)	6(3.1)	7(2.5)	
45 *Epistominella vitrea*	8(4.6)	3(2.5)	5(1.7)	8(4.5)	3(1.2)	4(2.7)	10(5.3)	3(1.6)	9(3.3)	
46 *Patellina corrugata*					1(0.4)			1(0.5)		
47 *Valvulineria bradyana*	5(2.9)	10(8.3)	7(2.4)	18(10.2)	4(1.6)	5(3.4)	6(3.1)	7(3.6)	6(2.2)	
48 *Sprillina vivipera*				1(0.6)				1(0.5)	2(0.7)	
49 *Turrispirillina lucida*	1(0.6)				1(0.4)			1(0.5)		
50 *Siphonina reticulata*(R)					1					
51 *Gavelinopsis praegeri*									1R	
52 *Rosalina* spp. (R)	3		2		2		2			
53 *Eoponidella adriatica*									1R	
54 *Discorbids* (J)(R)		3	2	5	6	3	3	2	1	
55 *Ammonia beccarii* (R)	4	2	3	2	2	1	1	1	1	
56 *Elphidium spp.* (R)	3	1	2	1	5	1	3	3	2	
57 *Cribrononion cuvillieri*		3		3				2		
58 *Protelphidium granosum*				1						
59 *Hyalinea balthica*	1(0.6)	1(0.8)	5(1.7)	4(2.3)	4(1.6)	1(0.7)	2(1.0)	3(1.6)	6(2.2)	
60 *Cibicidina boueana*	1(0.6)	1(0.8)	1(0.3)	1(0.7)	1(0.4)			1(0.5)		
61 *Cibicides lobatulus* (R)		1	1		2	1			1	
62 *Planorbulina mediterranensis* (R)			1						1	
63 *Fursenkoina* sp.	2(1.1)				1(0.4)		2(1.0)		3(1.1)	
64 *Cassidulina carinata*		1(0.8)	3(1.0)	1(0.7)	3(1.2)		2(1.0)		2(0.7)	
65 *C. carinata* (reworked)			2		1					
C. minuta	14(8.0)	7(5.8)	15(5.2)	12(6.8)	16(6.3)	14(9.6)	22(11.6)	11(5.7)	25(9.1)	
67 *Globocassidulina subglobosa*		2(1.6)	4(1.4)	3(1.7)	1(0.4)			2(1.0)	2(0.7)	
68 *Chilostomella mediterranensis*	31(17.9)	8(6.6)	42(14.5)	20(11.4)	42(16.6)	17(11.6)	11(5.8)	18(9.4)	29(10.54)	
69 *Nonion cf. depressulus (R)*	4			1			4	2		

APPENDIX I (continued)

Taxa	Core M4									
	Down-core depth (cm)									
	0-2	10-12	20-22	30-32	40-42	50-52	60-62	70-72	80-82	90-92
70 *Astrononion* sp. (R)		2								
71 *Nonionella opima*	9(5.2)	3(2.5)	11(3.8)		7(2.8)	3(2.0)			11(4.0)	
72 *N* sp.	6(3.4)			7(4.0)		5(3.4)	6(3.1)	4(2.1)	8(3.0)	
73 *Gyroidina umbonata*		1(0.8)	7(2.4)		3(1.2)	7(4.7)	9(4.7)	4(2.1)	16(5.8)	
74 *Melonis pompilioides*	9(5.2)	21(17.3)	7(2.4)	20(11.4)	17(6.7)	12(8.2)	4(2.1)	13(6.8)	13(4.7)	
75 *Robertina translucens*									1(0.4)	
Total benthic tests	169	133	308	189	272	152	203	200	284	
Redeposited tests	23	12	18	13	20	6	13	9	9	
Indigenous tests (*N*)	173	121	290	176	252	146	190	191	275	
Number of species (*S*)	32	31	34	32	44	31	33	38	38	
Globigerina quinqueloba	10(100)	23(88.1)	92(82.9)	115(85.2)	18(69.1)	65(79.3)	37(56.1)	41(39.8)	43(51.2)	
Turborotalita clarkei		5(17.8)	18(16.2)	20(14.9)	8(30.8)	17(20.7)	29(44.0)	62(60.2)	41(98.8)	
Globigerinoides ruber			1							
Total planktic tests	10	28	111	135	26	82	66	103	84	

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