

THE RESPONSE OF MODERN BENTHIC FORAMINIFERAL ASSEMBLAGES TO WATER-MASS PROPERTIES ALONG THE SOUTHERN SHELF OF THE MARMARA SEA

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Abstract. Beginning in 1997 when Ryan & Pitman published their so-called „Noah's flood Hypothesis” the Sea of Marmara has become an area of intensified study. This small seaway serves as the only connection between the Mediterranean and Black seas, and because of its unique hydrography may actually magnify changes in oceanographic conditions.

This study is a preliminary report based on the analysis of modern foraminiferal assemblages collected from grab samples, in combination with CTD measurements from one of the three bathymetric transects collected on board the R/V K. Piri Reiss during the summer of 2002. We analysed 30 sediment samples from the southern shelf area of the Marmara Sea (transect 1) with a bathymetric range from 15 to 350 meters, and compare the foraminiferal data with the hydrographical parameters. The CTD measurements reveal that the Sea of Marmara has a stratified water column comprised of two distinct water bodies. The lower, saltier, denser Mediterranean water is separated from a brackish water layer at a depth of about 25 m, generating a dysoxic environment in the deeper parts of the basin. As a response to these oceanographic parameters, the proportions of some foraminiferal species (e.g. *Uvigerina mediterranea*, *Asterigerinata adriatica*, *Reussella spinulosa*) show a critical threshold at about 150m water depth.

We therefore recognise two main benthic foraminiferal assemblages in the study area: a shallower assemblage dominated by *Ammonia beccarii*, *A. parkinsonia*, *Porosonion* sp., *Elphidium* sp.; and a deeper assemblage dominated by *Brizalina* sp., *Bulimina* sp., *Cassidulina* sp., *Gyroidina lamarckina*. We also noticed meaningful responses of several foraminiferal species to the oxygen level in the southern Marmara Sea.

Keywords: benthic foraminifera, Marmara Sea, paleoecology, Holocene

INTRODUCTION

The Marmara Sea occupies a transtensional basin situated along a set of *en echelon* dextral strike-slip faults that form part of the North Anatolian Transform Fault system (Aksu *et al.*, 2000). It is a critical oceanographic gateway connecting the Aegean Sea to the west, and the Black Sea to the northeast, and serves as the only link between the Black Sea and the Mediterranean. Two relatively shallow and slender straits, the Dardanelles and the Bosphorus, connect the Marmara Sea to the Aegean and Black seas, respectively (Fig. 1). Even though the Dardanelles strait reaches depths of 100–110 m, several sills are present to contemporary depths of 60–70 m. These sills prevent the exchange of deep water between the Marmara Sea, Aegean Sea, and Black Sea (Ergin *et al.*, 1997). Today, brackish surface water exits the Black Sea through the Bosphorus strait, while saline deeper water of Mediterranean origin flows northward as a countercurrent. An identical two-way flow exists in the Dardanelles Strait, thereby establishing an overall estuarine circulation within the Marmara Sea. Because of the existence of brackish Black Sea outflow water, a

strong halocline is present throughout the Marmara Sea, leading to low-oxygen conditions below a thin well-mixed surface layer.

The nature of the marine connections between the Black Sea and Mediterranean have a profound influence on the biotic record of the Marmara Sea. In recent years, a much-publicised controversy has emerged concerning the timing and development of marine connections to the Black Sea following the last deglaciation. On the one hand, geochemical studies of the youngest sapropel horizon (S1, ~9.5–6.4 ka) in the Aegean Sea (Aksu *et al.* 1995, 1999) and a partly contemporaneous sapropel in the deep Marmara Sea (~10.6–6.4 ka; Çag, atay *et al.* 2000; Aksu *et al.*, 2002) suggest a strong outflow of low-salinity water from the Black Sea beginning at ~10.5 ka. The presence of a strait-exit delta with an age of ~10–9 ka at the southern end of the Bosphorus Strait supports the timing of this outflow (Hiscott *et al.*, 2002; Kaminski *et al.*, 2002). On the other hand, Ryan *et al.* (1997) cited sedimentological and faunal evidence from the northern Black Sea that in their opinion points to the catastrophic inundation of the Black Sea by water of Mediterranean origin at ca. 7.5 ka, an event that

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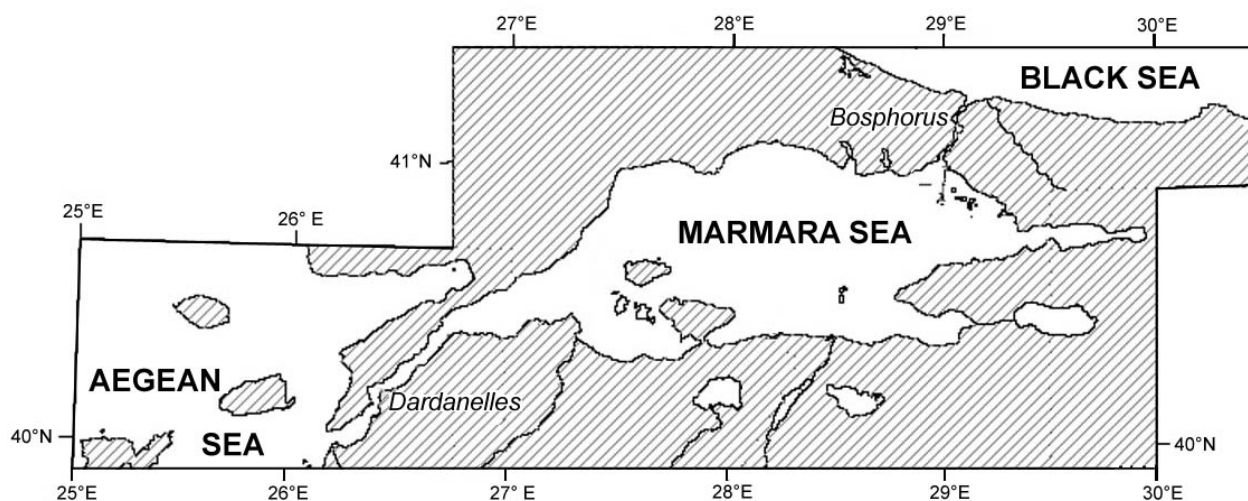


Figure 1. Geographical position of the Marmara Sea

could have been the origin of the 'Noah's Flood' legend recorded in ancient Middle Eastern texts. This reported young age for the marine layer in the Black Sea spawned the "Noah's Flood Hypothesis" that has been circulating through the popular literature (Ryan & Pitman, 1998).

Micropalaeontological and sedimentological studies of the Holocene sediments in the Marmara Sea will be instrumental in settling this debate. However, our interpretations of the palaeoceanography of the Marmara seaway based on micropalaeontological proxies will only be as accurate as our understanding of the modern ecology of benthic foraminifera found in the area. Unfortunately, to date there has been no rigorous survey of the depth distribution of modern foraminifera living the Marmara Sea. Clearly, there is a need to establish a baseline understanding of the benthic foraminiferal ecology and distribution in relation to the hydrography of the Marmara Sea area. Therefore, the overall aims of this study are:

- to document the distribution of benthic foraminifera in a depth transect in the Marmara Sea.
- compare the faunal data to hydrographical parameters measured at the same stations.

As a first step towards improving our understanding of the distribution of benthic foraminifera in the Marmara Sea, we selected a study area on the southern Marmara Shelf (Fig. 2). The area is far removed from the adverse affects of human activities, and therefore we believe that the foraminifera recovered in the area are most representative of the natural Marmara Sea assemblages, rather than faunas that may have been altered by pollution.

PREVIOUS FORAMINIFERAL STUDIES

Benthic foraminifera from the Eastern Mediterranean have been studied by Parker (1958), and Cimerman & Langer (1991), who produced a workable taxonomic framework for the region. This framework has been expanded by faunal studies of the Gulf of Naples, Italy by Sgarrella & Moncharmont Zei (1993). Shallow-water benthic foraminifera have been recently studied from Iskundrun Bay on the Mediterranean coast of Turkey (Basso & Spezzaferi, 2000), and from the area adjacent to Gökçeada Island (Meriç & Avsar, 2001). These studies provide calibration of the depth ranges of neritic benthic foraminifera in these sectors of the eastern Mediterranean and Aegean Seas, and many of the same species are found in our sediment samples. However, the eastern Mediterranean and Aegean Seas differs in their much higher salinity in comparison with the Marmara Sea. Black Sea foraminifera have been documented by Yanko & Troitskaja (1987), and their ecology summarised by Yanko (1990). These studies are relevant owing to the presence of Black Sea outflow water in our study area. The only published studies of foraminifera from the Marmara Sea are (1) the early work of Alavi (1988), who examined two sediment cores collected from a depth of 1200 m in the deep basin south of Istanbul, (2) descriptions of upper Pliocene to Holocene foraminifera from geotechnical boreholes in the Gulf of Izmit (Meriç *et al.*, 1995), and (3) initial studies of Kaminski *et al.* (2002) who documented benthic foraminifera from three gravity cores, one of which was collected on the Marmara Shelf. Unfortunately, little is still known about the depth distribution of modern benthic foraminifera within the Marmara Sea itself.

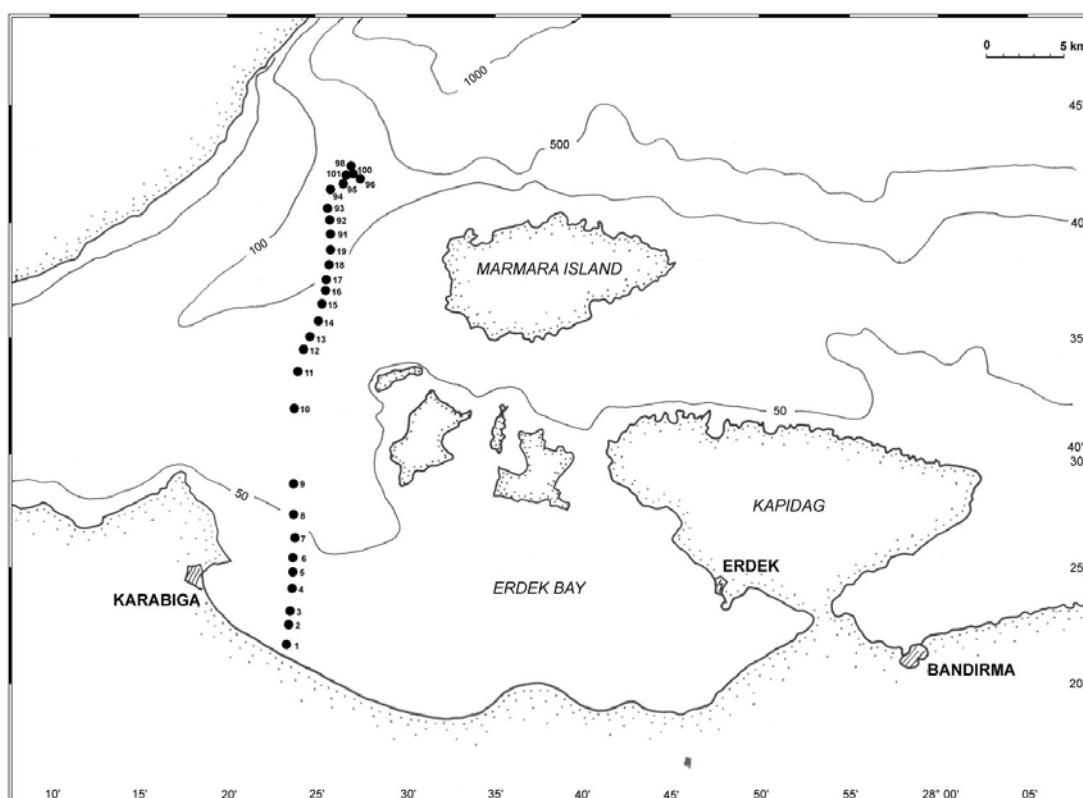


Figure 2. Location of the studied grab sample stations collected on the southern Marmara shelf during the MAR-02 Cruise.

METHODS

Samples collected for Micropaleontology were collected on board the R/V Koca Piri Reis of the Institute of Marine Sciences and Technology, Dokuz Eylül University, Izmir, Turkey during Cruise MAR-02. We used a Shipeck grab sampling device to collect our samples. Surficial sediment was scraped from the core with a spoon, immediately washed on board ship through a 63 μm sieve, and preserved in ethanol with Rose Bengal. Samples were subsequently washed again, dried, and split into aliquots using a modified Otto microsplitter. Benthic foraminifera picked from the $>125 \mu\text{m}$ fraction and mounted onto cardboard reference slides for counting. A total of 31 samples were studied in this manner. Photographs of selected specimens were made on a Zeiss-940 digital SEM at University College London. Plates were made at BBU using Adobe Photoshop.

RESULTS

Water mass properties

Temperature and salinity measurements (Fig. 3) from the southern Marmara shelf area carried out during the MAR-02 cruise show that the water column has a strongly stratified structure, and is composed of two distinct water bodies separated at about 25m

depth. From the surface to ~12m the conditions are homogeneous, brackish (21.5-22.5 g/l) with cooler, less dense water and oxygen values reaching 3.5 ml/l near the lower boundary. The water mass properties identify the Black Sea as source area.

The next 40m represents the mixing zone, where the salinity increases, but the oxygen level drops abruptly to ~2ml/l at 38m because of the lack of mixing across brackish lid.

Stable salinity conditions (38.8-38.6 ml/l) are established below the halocline (50m) with denser, warmer water, characteristic of the eastern Mediterranean Sea. The top of this layer is well oxygenated, rising the O_2 level from 2.1 to 3.9 ml/l generating a subsurface peak in oxygen content. Nevertheless, over the next 15m, oxygen rapidly decreases, reaching again a value of 2 ml/l at 68m. From this point downward, the oxygen content slowly decreases, reaching a value of 1.1 ml/l at 350m. The deeper parts of the basin therefore must be regarded as a dysoxic environment. The oxygen peak at 288m at this station might be an instrumentation problem because we could not observe any submarine current on the salinity readings. The interval between 250m and 350m was not sampled we could not see the assemblage response to a possible oxygenation peak

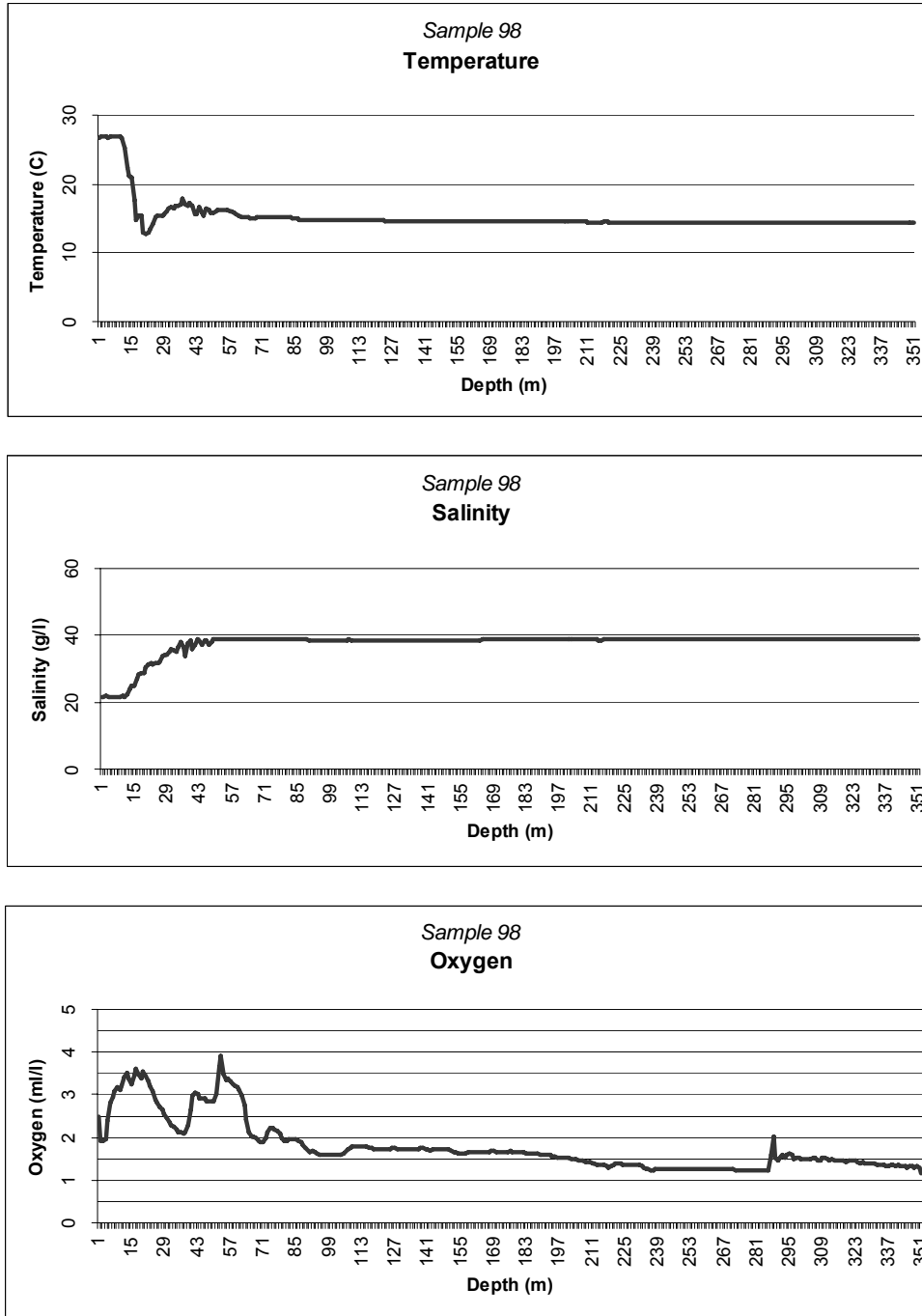


Figure 3. Variation of the main hydrographic parameters in relation to the depth

on the graphs.

Benthic foraminifera

The benthic foraminiferal present in the samples are generally abundant, well preserved, and diverse. The relative abundance of representative species and taxonomic groups are plotted in Fig. 4. Kaminski et al. (2002) provided a taxonomic list of the species found on the southern Marmara Shelf.

As a response to the layered structure of the

water column, we distinguished two main benthic foraminiferal assemblages: a shallower one, dominated by *Ammonia beccarii*, *Ammonia parkinsonia*, *Porosononion* sp., *Elphidium* sp. characteristic for a brackish environment. These genera are also present in large proportions on the Black Sea shelves (Yanko & Troitskaya, 1987), indicating a close link with the outflow from the Black Sea.

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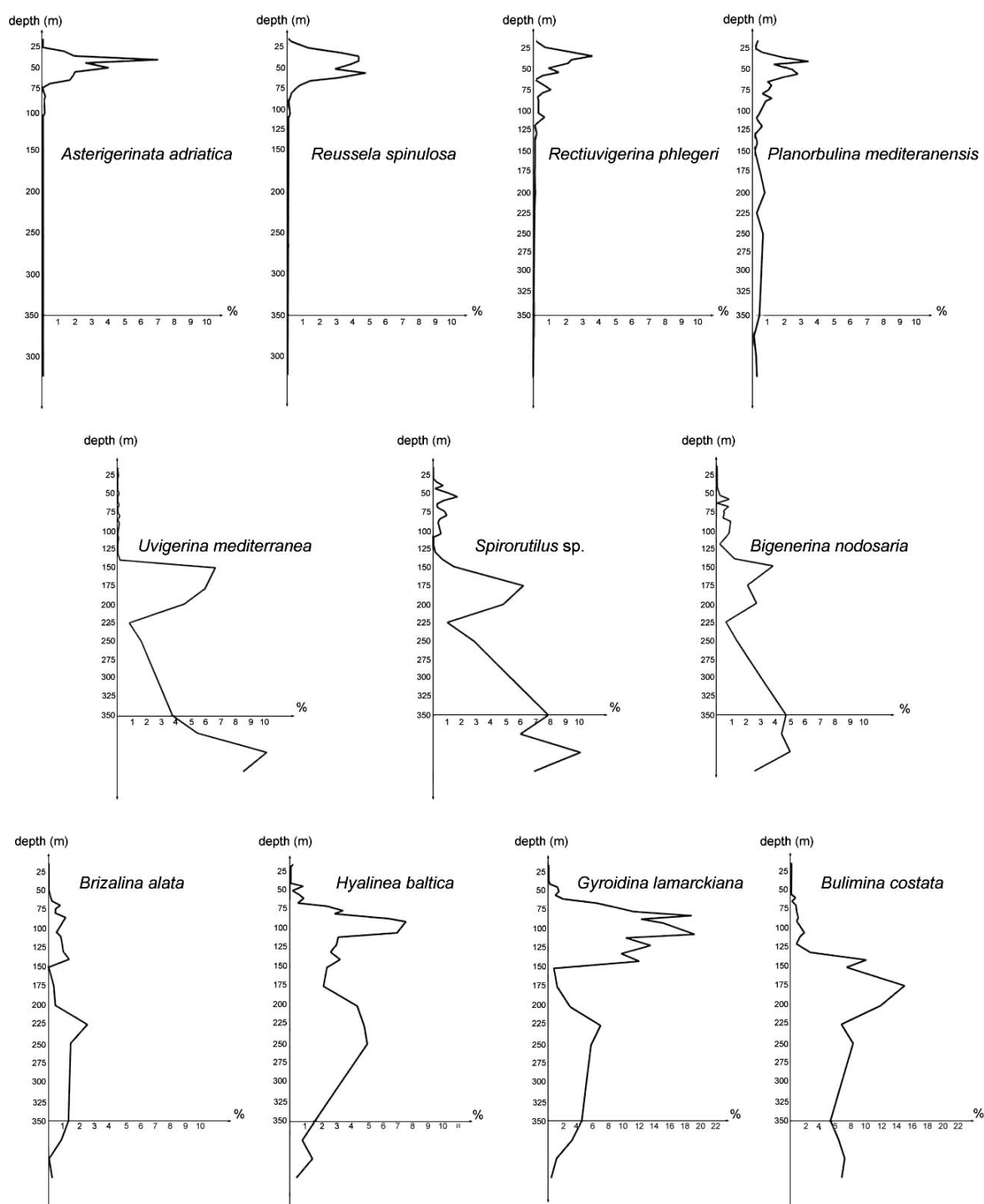


Figure 4. Relative abundances of the predominant species and faunal groups in the southern Marmara transect

The deeper assemblage is dominated by Mediterranean species such as *Brizalina spathulata*, *B. alata*, *B. catanensis*, *Bulimina aculeata*, *B. costata*, *Cassidulina carinata*, *Gyroidina lamarckiana* etc., These taxa are characteristically found in dysoxic environments. We identified a single specimen of *Elphidium reginum* at the depth of 105m not

documented in the Recent deposits of this area, but present in the Miocene sediments.

Large numbers of agglutinated foraminifera, such as *Ammoscalaria pseudospiralis*, *Reophax* sp., *Lagenammia fusiformis* etc. occur within the mixing zone between the two main watermass-related assemblages.

Ammonia beccarii displays a strong affinity to the brackish layer, possibly as a response to the oxygen peak (15m below the surface), and comprises about 48% of the total assemblage in sample no. 1.

Rectivigerina phlegeri is a shallow Mediterranean species and gives the strongest response to the low oxygen level within the mixing zone. It disappears below 140m.

The second subsurface oxygen peak, recorded at the top of the Mediterranean water body is a bimodal one (40 and 53m). It possibly influences the distribution of some shallower species such as *Asterigerinata adriatica*, *Reussella spinulosa*, *Planorbulina mediterraneensis* etc. which present the same bimodality as the strongest response.

Strong responses from *Bulimina costata*, *Bigennerina nodosaria*, *Uvigerina mediterranea*, *Spirorutilus* sp. occur below 140m, with a critical point at about 220m depth. The descendent trend begins at about 200m, where the oxygen level is about 1.5 ml/l. This oxygen level may represent a critical threshold, below which the composition of the benthic assemblage changes rapidly.

CONCLUSIONS

The distribution of benthic foraminifera has been documented in a depth transect extending from 15 to 350 m on the southern Marmara Shelf. The total (living + dead) benthic foraminiferal fauna in the study area can be subdivided into two assemblages, which correlate with the predominant water masses in the Marmara Sea. A shallow assemblage with species of *Ammonia*, *Porosononoion* and *Elphidium* is found within the brackish surface water of Black Sea origin. Within the mixing zone between the water masses a maximum in agglutinated taxa is observed. A more diversified assemblage dominated by Mediterranean

species characterises the more saline deeper water mass below ca. 25 m water depth. In the deeper part of the transect, typical „dysoxic” taxa such as *Brizalina*, *Bulimina*, *Globobulimina*, *Cassidulina* are numerically dominant. These „dysoxic” taxa show a marked increase in relative abundance around a critical oxygen threshold of around 1.5 ml.l.

Acknowledgements

We thank Prof. Dr. Erol Izdar, the Director of the Piri Reis Foundation for Maritime and Marine Resources Development and Education, and Prof. Dr. Orhan Uslu, the Director of the Institute of Marine Sciences and Technology, for their support and encouragement. We extend our special thanks to the officers and crew of the R/V *Koca Piri Reis* for their assistance in data acquisition. We gratefully acknowledge the assistance of Erin Lane, Michelle, Seyed, and Kamal in core handling and sample preparation. The MAR-02 Cruise was supported by research and ship-time funds from the Natural Sciences and Engineering Research Council of Canada (NSERC) to Aksu and Hiscott, travel funds from the Dean of Science at Memorial University of Newfoundland, and special grants from the Piri Reis Foundation for Maritime and Marine Resources Development and Education, Turkey. MAK's participation in the cruise was supported by grants from the UCL Graduate School and the KLFR. CC's visit in London was supported by a mobility grant from the European Community SOCRATES Programme and by a “Stanislaw Geroch Memorial Student Grant-in-Aid” from the Grzybowski Foundation.

REFERENCES

- Aksu, A.E., Yaflar, D., Mudie, P.J., 1995. Paleoclimatic and paleoceanographic conditions leading to development of sapropel layer S1 in the Aegean Sea basins. *Paleoclimatology Paleogeography Paleocology*, 116, 71–101.
- Aksu, A.E., Hiscott, R.N. & Yaflar, D. 1999. Oscillating Quaternary water levels of the Marmara Sea and vigorous outflow into the Aegean Sea from the Marmara Sea – Black Sea drainage corridor. *Marine Geology*, 153, 275-302.
- Aksu, A.E., Hiscott, R.N., Mudie, P.J., Rochon, A., Kaminski, M.A., Abrajano, T., and Yasar, D. 2002a. Persistent Holocene outflow from the Black Sea to the Eastern Mediterranean contradicts Noah's Flood Hypothesis. *GSA Today*, 12 (5), 4-10.
- Aksu, A.E., Hiscott, R.N., Kaminski, M.A., Mudie, P.J., Gillespie, H., Abrajano, T., and Yasar, D. 2002b. Last Glacial to Holocene paleoceanography of the Black Sea and Marmara Sea: Stable isotopic, foraminiferal and coccolith evidence. *Marine Geology*, 190, 119-149.
- Alavi, S.N., 1988. Late Holocene deep-sea benthic foraminifera from the Sea of Marmara. *Marine Micropalaeontology*, 13: 213–237.
- Algan, O., Çağatay, N., Tchepalyga, A., Ongan, D., Eastoe, C., and Gökaflan, E., 2001. Stratigraphy of the sediment infill in Bosphorus Strait: water exchange between the Black and Mediterranean Seas during the last glacial Holocene. *Geo-Marine Letters*, 20, 209–218.
- Basso, D. and Spezzaferri, S. 2000. The distribution of living (stained) benthic foraminifera in Iskenderun Bay (Eastern Turkey): a statistical approach. *Bollettino della Societa Paleontologica Italiana*, 39 (3), 358–379.
- Çağatay, M.N., Görür, N., Algan, O., Eastoe, C., Tchepalyga, A., Ongan, D., Kuhn, T., and Kuficü, I., 2000. Late Glacial – Holocene palaeoceanography of the Sea of Marmara: timing of connections with the Mediterranean and the Black Seas. *Marine Geology*, 167, 191–206.
- Ergin, M., Kazancı, N., Varol, B., Ileri, O., and Karadenizli, L., 1997. Sea-level changes and related depositional environments on the southern Marmara shelf. *Marine Geology*, 140, 391–403.
- Hiscott, R.N. Aksu, A.E., Yasar, D., Kaminski, M.A., Mudie, P.J., Lord, A.R., MacDonald, J., and Isler, F.I. 2002. Deltas at the southern exit from the Bosphorus Strait document Black Sea outflow to the Marmara Sea since ~10 ka and refute catastrophic flooding of the Black Sea at ~7.15 ka. *Marine Geology*, 190, 95-118.
- Kaminski, M.A. Aksu, A.E., Box, M., Hiscott, R.N., Filipescu, S., & Al-Salameen, M. 2002. Late Glacial to Holocene benthic foraminifera in the Marmara Sea: Implications for the Black Sea – Mediterranean Sea connections following the last deglaciation. *Marine Geology*, 190, 165-202.
- Meriç, E., Yanko, V., and Avsar, N., 1995. Foraminiferal fauna of the Quaternary sequence in the Gulf of Izmit (Hersek Burnu-Kaba Burnu) [in Turkish]. In: Meriç, E. (Ed.), Quaternary Sequence in the Gulf of Izmit. Istanbul, pp. 105-151.
- Meriç, E., and Avsar, N. 2001. Benthic foraminiferal fauna of Gökçeada Island (northern Aegean Sea) and its local variations. *Acta Adriatica*, 42 (1), 125-150.
- Parker, F.L., 1958. Eastern Mediterranean foraminifera. *Reports of the Swedish Deep Sea Expedition, Sediment cores from the Mediterranean and Red Sea*, 8 (4), 219–283.
- Ryan, W.B. & Pitman, W.C. 1998. *Noah's Flood: The new scientific discoveries about the event that changed history*. Simon and Schuster, New York, 319 pp.
- Ryan, W., Pitman, W., Major, C., Shimkus, K., Moskaleno, V., Jones, G., Dimitrov, P., Gorur, N., Sakinc, M., and Yuce, H., 1997. An abrupt drowning of the Black Sea shelf. *Marine Geology*, 138, 119–126.
- Sgarrella, F. and Moncharmont Zei, M. 1993. Benthic Foraminifera of the Gulf of Naples (Italy): Systematics and autoecology. *Bollettino della Societa Paleontologica Italiana*, 32 (2), 145–264.
- Yanko, V.V. 1990. Stratigraphy and Paleogeography of the marine Pleistocene and Holocene deposits of the southern seas of the USSR. *Memorie della Societa Geologica Italiana*, 44, 167-187.
- Yanko, V.V., and Troitskaja, T.S. 1987. *Late Quaternary Foraminifera of the Black Sea* [in Russian]. Trudy Instituta Geologii i Geofisiki; Akademiya Nauk SSSR, Siberskoye Otdeleniye, 694, 111 pp.

PLATES (scale bar 100 µm)

PLATE I

1. *Lagenammia fusiformis* (Williamson, 1858); 25m
2. *Reophax scorpius* Montfort, 1808; 80 m
3. *Ammoscalaria pseudospiralis* (Williamson, 1858); 80 m
4. *Eggerelloides scabrus* (Williamson, 1858); 15 m
5. *Bigenerina nodosaria* d'Orbigny, 1826; 85 m
6. *Textularia cushmani* Said, 1949; 175 m
7. *Textularia* sp.; 75 m
8. *Adelosina* sp.; 200 m
9. *Spiroloculina excavata* d'Orbigny, 1846; 90 m
10. *Quinqueloculina seminula* (Linné, 1758); 75 m
11. *Triloculina tricarinata* d'Orbigny, 1826; 65 m
12. *Sigmoilopsis schlumbergeri* (Silvestri, 1904); 40 m
13. *Lenticulina gibba* d'Orbigny, 1826; 65 m
14. *Amphicoryna scalaris* (Batsch, 1791): 14a. macrospheric form, 44 m; 14b. microspheric form, 80 m
15. *Lagena striata* (d'Orbigny, 1839); 80 m
16. *Favulina hexagona* (Williamson, 1848); 44 m
17. *Robertina translucens* Cushman & Parker, 1936; 80 m

PLATE II

1. *Brizalina alata* (Seguenza, 1862); 75 m
2. *Brizalina catanensis* (Seguenza, 1862); 60 m
3. *Brizalina spathulata* (Williamson, 1858); 65 m
4. *Cassidulina carinata* Silvestri, 1896; 44 m
5. *Rectiuvigerina phlegeri* Le Calvez, 1959; 40 m
6. *Bulimina costata* d'Orbigny, 1852; 105 m
7. *Bulimina elongata* d'Orbigny, 1846; 80 m
8. *Bulimina aculeata* d'Orbigny, 1826; 80 m
9. *Globobulimina affinis* (d'Orbigny, 1839); 80 m
10. *Uvigerina mediterranea* Hofker, 1932; 175 m
11. *Reussella spinulosa* (Reuss, 1850); 25 m
12. *Valvulineria bradyana* (Fornasini, 1900); 12a. spiral view, 44 m; 12b. umbilical view 35 m
13. *Siphonina reticulata* (Czjzek, 1848); 80 m

PLATE III

1. *Hyalinea baltica* (Schroeter, 1783): 1a. apertural view, 80 m; 1b. side view, 70 m
2. *Cibicides refulgens* Montfort, 1808; 40 m
3. *Discorbinella bertheloti* (d'Orbigny, 1839): 3a. spiral view, 80 m; 3b. umbilical view, 40 m
4. *Lobatula lobatula* (Walker & Jakob, 1798); 325 m
5. *Planorbulina mediterranea* d'Orbigny, 1826; 40 m
6. *Asterigerinata adriatica* Haake, 1977: 6a. dorsal view, 40 m; 6b. apertural view, 40 m
7. *Haynesina depressula* (Walker & Jakob, 1798); 25 m
8. *Nonionella opima* Cushman, 1947: 8a. umbilical view, 40 m; 8b. spiral view, 80 m

PLATE IV

1. *Melonis barleanum* (Williamson, 1858); 70 m
2. *Gyroidinoides lamarckina* (d'Orbigny, 1839): 2a. umbilical view, 70 m; 2b. spiral view, 70 m
3. *Pullenia quinqueloba* (Reuss, 1851); 175 m
4. *Ammonia parkinsonia* (d'Orbigny, 1839): 4a. umbilical view, 18 m; 4b. spiral view, 18 m
5. *Ammonia beccarii* (Linné, 1758); 18 m
6. *Porosonion* sp.; 18 m
7. *Porosonion granosum* (d'Orbigny, 1826); 18 m
8. *Elphidium macellum* (Fichtel & Moll, 1798); 18 m
9. *Elphidium reginum* (d'Orbigny, 1846); 105 m
10. *Elphidium articulatum* (d'Orbigny, 1839); 15 m

