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Organic carbon distribution in the surface sediments of the Sea of Marmara and its control by the inflows from adjacent water masses

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ABSTRACT

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The organic carbon contents and textural composition of a total of 166 surficial sediment samples (from 10 to 1226 m water depths) together with data on primary productivity rates and dissolved oxygen concentrations have been studied to investigate the main controls on the distribution of organic carbon buried within the modern sediments across the Sea of Marmara.

The distribution of average annual primary production rates in the Sea of Marmara exhibits great lateral variations; the highest values are calculated for the southern shelf (161 g C m^{-2} $year^{-1}$), the areas with high terrigenous input supplied by the southerly major rivers, and on the northeastern shelf (104 g C m^{-2} $year^{-1}$) where organic- and nutrient-rich surface inflow from the Black Sea is prominent. The low primary productivities estimated for the southwestern shelf of the Sea of Marmara (64 g C m^{-2} $year^{-1}$) suggest influences from the relatively organic- and nutrient-poor subsurface inflow from the Aegean or Mediterranean.

Organic carbon contents in sediments from the northeastern (0.37–2.16%), northern (0.57–1.64%), southern (0.44–1.90%) and southwestern shelf regions (0.37–1.51%) all appear to be within the same range and show no direct relationship with surface productivity and oxygen deficiency in the Sea of Marmara. Production and accumulation of organic matter in the Sea of Marmara are believed to have been mostly affected by the inflow of relatively organic-rich Black Sea waters, by the southerly major rivers, and by inflow of organic-poor Aegean or Mediterranean waters. Lateral offshore transport in surface waters must have resulted in the decrease of organic carbon fluxes to the sediments.

INTRODUCTION

As the preservation and burial of organic matter in marine environments is a function of the rate of primary productivity, water depth, dissolved oxygen content in the water column, sedimentation rate, biological activity, and sediment stability, the organic carbon contents of sediments can be a sensitive indicator of the nature of source areas and the environments of deposition (e.g. Muller and Suess, 1979; Suess and Muller, 1980; Ibach, 1982; Glenn and Arthur, 1985; Rowe and Deming, 1985; Pace et al., 1987; Emerson and Hedges, 1988). However, it must be pointed out that such processes normally control the cycle of organic carbon in a given region only if there is little lateral transport.

Most oceanographic studies in the Sea of Marmara have focused on the production and distribution of organic matter within the water column in response to various environmental aspects (Unluata and Ozsoy, 1986; Basturk et al., 1990). However, very little is known on the basin-scale distribution of organic carbon in the sediments of the Sea of Marmara, and the results

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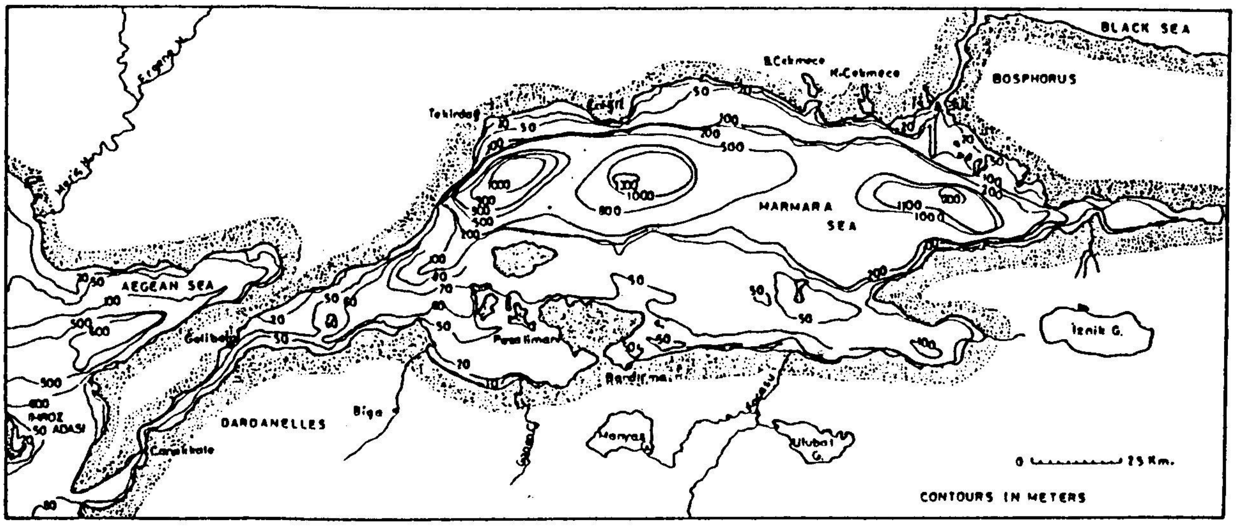

Fig. 1. Location map of the study area, the Sea of Marmara, showing its connection to the Black Sea via the Bosphorus and to the Aegean Sea via the Dardanelles.

previously presented are limited to small areas in this sea (Evans et al., 1989; Ergin and Yoruk, 1990; Ergin et al., 1991). The primary purpose of this investigation is, therefore, to determine the distribution of organic carbon in the surficial Marmara elements, and the extent to which this distribution is related to other oceanographic factors, such as primary productivity, oxygen contents, bottom topography, and hydrodynamic control.

Oceanographic characteristics of the study area

The Sea of Marmara forms a transition between the Black Sea and the Aegean Sea (Fig. 1), and thus its physical, chemical, and biological properties are greatly influenced by the hydrochemistry of these two adjacent water masses (Basturk et al., 1988; Ozsoy et al., 1988). In general, the circulation in this sea is dominated by the permanent flows of two-layer water masses (Fig. 2); a southwestward current carrying relatively low-salinity waters (S = 17.8–22.0 ppt) from the Black Sea which flows at the surface towards the Aegean Sea, and below it, a northeastward-flowing current which carries the relatively high-salinity Mediterranean waters (S = 38.5–38.8 ppt) towards the Black Sea (Ozsoy et al., 1988; Unluata et al., 1990). The mean flow of the surface waters is controlled by basin-scale anti-cyclonic circulation under the influence of Coriolis force, Bosphorus outflow, wind stress, and coastline geometry (Besiktepe, 1991). As a result of its permanently stratified character and the bacterially mediated oxidation of sinking organic matter, sub-halocline water masses (below 20–30 m water depths) of the Sea of Marmara are permanently depleted in dissolved oxygen (Basturk et al., 1990). The oxygen-rich waters entering from the Aegean Sea through the Dardanelles underflow lose a considerable proportion of their oxygen content immediately upon entering the Marmara Basin (Unluata and Ozsoy, 1986). Figure 3 shows dissolved oxygen concentrations of the sub-halocline Marmara waters, which can practically be regarded as aerobic (more than 1 $ml\,l^{-1}$ O_2) to dysaerobic (0.1–1.0 $ml\,l^{-1}$ O_2), according to the classification by Savrda and Bottjer (1987).

A further distinguishing feature of the Sea of Marmara is that it occupies, in terms of primary production, an intermediate position between the Black Sea and the Mediterranean Sea. In general, the chlorophyll-*a* values are found to be

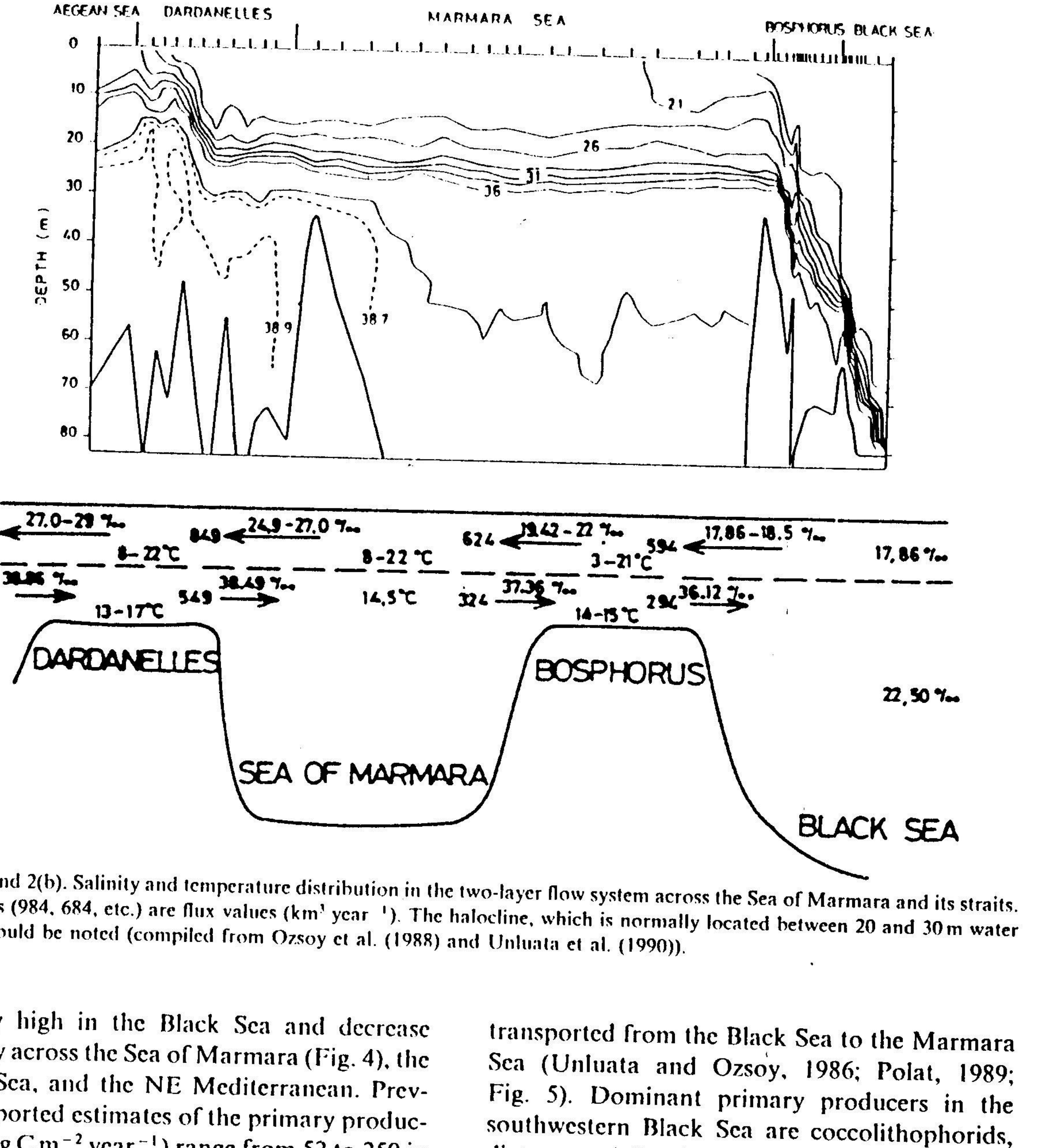

Fig. 2(a) and 2(b). Salinity and temperature distribution in the two-layer flow system across the Sea of Marmara and its straits. The figures (984, 684, etc.) are flux values (km^3 $year^{-1}$). The halocline, which is normally located between 20 and 30 m water depths, should be noted (compiled from Ozsoy et al. (1988) and Unluata et al. (1990)).

relatively high in the Black Sea and decrease gradually across the Sea of Marmara (Fig. 4), the Aegean Sea, and the NE Mediterranean. Previously reported estimates of the primary productivity (in $g\,C\,m^{-2}\,year^{-1}$) range from 52 to 250 in the Black Sea (Sorokin, 1983; Yilmaz, 1986; Gocmen, 1988), from 60 to 100 in the Sea of Marmara (Yilmaz, 1986; Unluata and Ozsoy, 1986; Gocmen, 1988), around 36 in the Aegean Sea (Yilmaz, 1986), and from 16 to 25 in the NE Mediterranean Sea (Murdoch and Onuf, 1974; Yilmaz, 1986; Gocmen, 1988). Thus, a considerable amount of organic matter is expected to be transported from the Black Sea to the Marmara Sea (Unluata and Ozsoy, 1986; Polat, 1989; Fig. 5). Dominant primary producers in the southwestern Black Sea are coccolithophorids, diatoms and dinoflagellates, which bloom several times during the year (Izdar et al., 1987); however, diatoms and dinoflagellates quickly decompose at the sediment–water interface whereas coccoliths do not dissolve significantly, and thus remain the dominant component within the sediment (Hay et al., 1990). Similarly, primary production in the Sea of Marmara appears to be highly controlled by the diatom

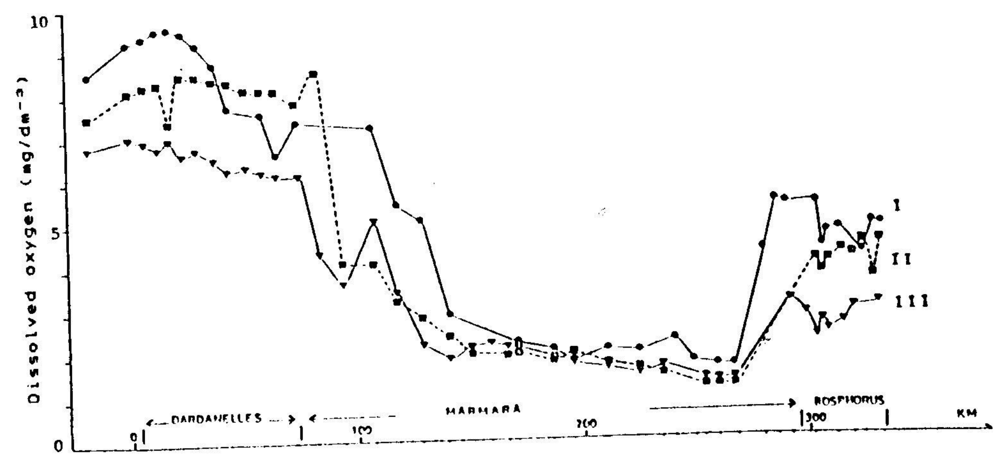

Fig. 3. Sub-halocline average oxygen concentrations of the Sea of Marmara obtained during 1986 (after Unluata and Ozsoy, 1986). The generally increasing dissolved oxygen concentrations towards the Aegean Sea should be noted. Data obtained in March 1986 (I), April-May 1986 (II), and July 1986 (III).

and dinoflagellate blooms during the winter–spring and summer–late summer periods (Unsal and Uysal, 1988). These results are in good agreement with the distribution of nutrients (Basturk et al., 1988) and chlorophyll-*a* concentrations (Gocmen, 1988) determined in the Sea of Marmara.

MATERIAL AND METHODS

A large number of surface sediment samples have been recovered from the Sea of Marmara and its straits (Fig. 6). In this study, we shall concentrate only on the samples recovered at 166 stations (between 10 and 855 m water depths)

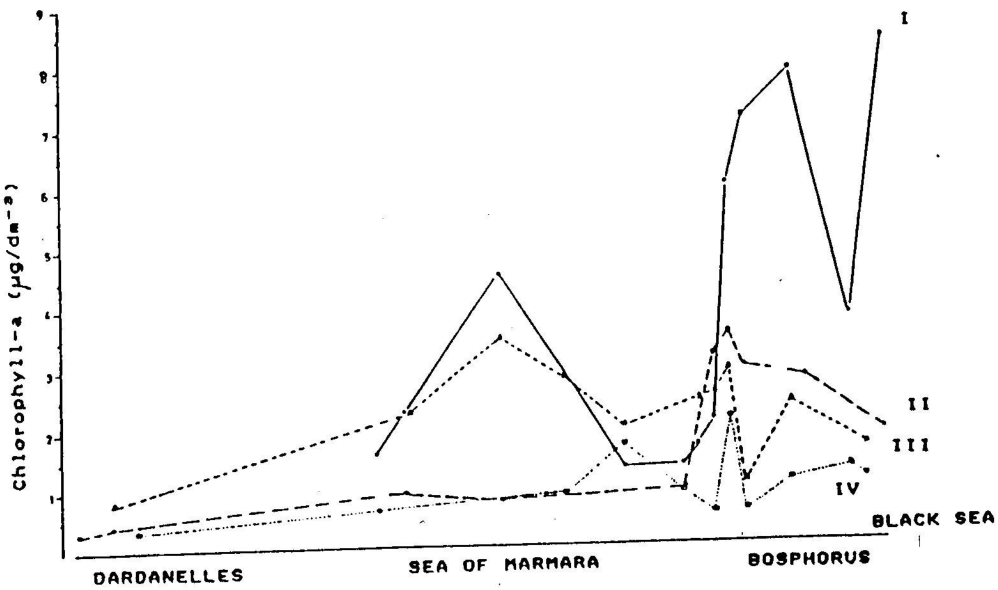

Fig. 4. Seasonal variations of chlorophyll-*a* concentrations in the Sea of Marmara (after Basturk et al., 1988). The generally higher values towards the Bosphorus and southwestern Black Sea regions, and the tendency to decrease towards the Dardanelles and Aegean Sea regions, should be noted. Data obtained in May 1987 (I), November 1986 (II), February 1987 (III) and July 1987 (IV).

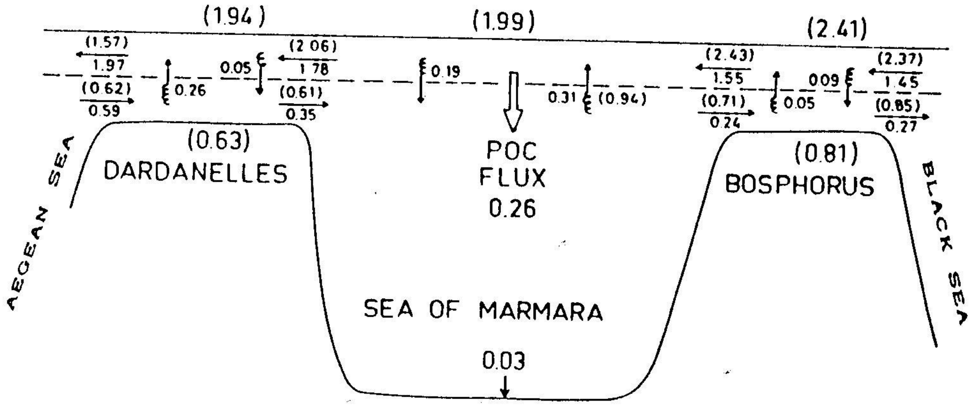

Fig. 5. Horizontal and vertical organic carbon concentrations and fluxes ($\times 10^6$ tons C year^{-1}) for budget calculation. The values in parentheses indicate total organic carbon (i.e. dissolved and particulate) concentration and the others denote dissolved organic carbon (in mg C l^{-1}) (after Polat, 1989). The generally decreasing organic carbon content with increasing distance from the Black Sea, as a result of lateral changes in the primary production between the Black Sea and the Aegean Sea, should be noted. Numbers with circular arrows represent vertical fluxes ($\times 10^6$ tons C year^{-1}) between the upper and lower layers. The high average values 1.94, 1.99, and 2.41 are from above halocline, and the values 0.63, 0.26, and 0.81 are from the sub-halocline waters.

during the 1988–1990 cruises of R/V "Bilim" in the Sea of Marmara, excluding the Bosphorus and Dardanelles Straits. Of these, 49 samples were obtained on the northeastern shelf (Bosphorus–Marmara junction; 13–250 m water depths), 19 from the northern shelf (12–855 m), 48 from the southern shelf, and 50 from the southwestern shelf (Dardanelles–Marmara junction; 25–150 m). In addition, a boomerang-corer (M-3, 80 cm length, 1200 m water depth) was taken in the eastern Marmara basin, aboard the R/V "Bilim" in 1984 (Fig. 6). Further sediment samples were taken at six stations (between 54 and 1226 m water depths) using a Soutar box-corer device

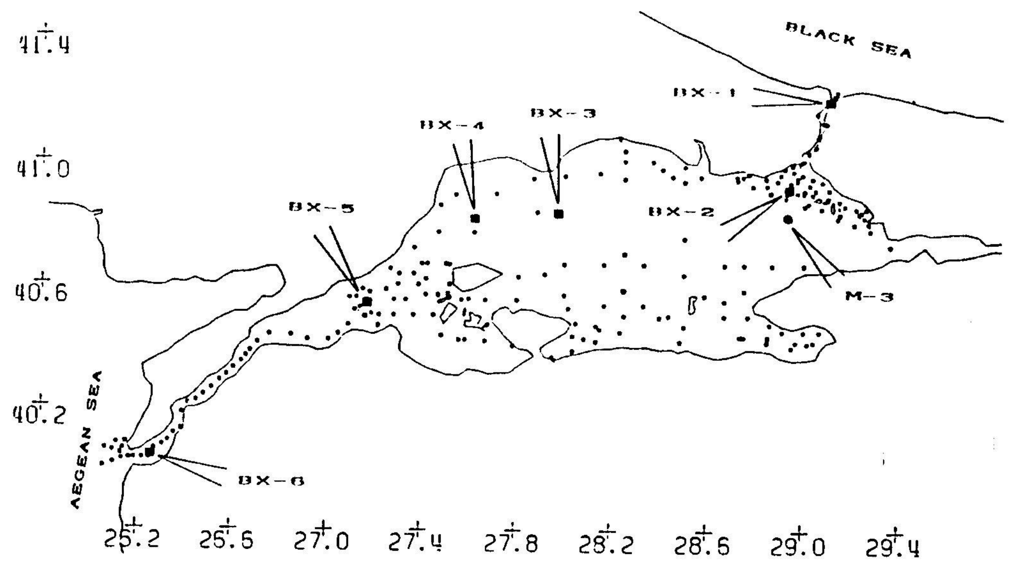

Fig. 6. Sampling stations of the studied recent sediments from the Sea of Marmara. ■, Box-corer sites; ●, boomerang-corer site. The remaining stations are sites of grab-sampling. Samples from the straits are not used here.

(50 cm × 50 cm × 50 cm) during the R/V "Knorr" expedition in this sea in 1989 (BX-1–BX-6; Fig. 6).

Sediment samples after recovery were kept frozen until they were examined further in our laboratory. Grain size analyses were performed using standard sieves for the sand and gravel fraction and pipette analysis for the mud (silt plus clay) fraction, according to the procedures outlined by Folk (1974). For determinations of carbonate and organic carbon contents of the sediments, samples were dried at 50–60°C and finally ground in a mortar. Organic carbon was measured using the modified Walkley–Black method (Gaudette et al., 1974), which is based on the exothermic heating and oxidation of organic matter with potassium dichromate and concentrated sulphuric acid, followed by back-titration with ferrous ammonium sulphate using phenylamine as an indicator. The accuracy of this method is ±0.25%. The carbonate content was determined using a gasometric method which is a modified 'Scheibler' gasometer system (Muller, 1967). This method is based on the volumetric determination of CO_2 released by acidification of the dry sample with 10% HCl solution (absolute error is ±0.5%). The quality of the chemical analysis was monitored by the simultaneous analysis of standards prepared in our laboratory using known quantities of extra pure carbonate, sucrose, and silicates.

Primary productivity rates were obtained by converting the chlorophyll-*a* measurements to gross primary productivity values using the equation of Ryther and Yentsch (1957):

$$PP_T = \frac{RP}{K} \times C \times 3.7$$

wherein PP_T is the gross primary productivity ($g\,C\,m^{-2}\,day^{-1}$), RP is the intensity of relative photosynthesis ($m^3\,day^{-1}$), C is the chlorophyll-*a* concentration ($g\,cm^{-3}$), K is the average extinction coefficient (m^{-1}), and the factor 3.7 is the average assimilation number of the phytoplankton for 1 mg of carbon and 1 mg of chorophyll per hour. Chlorophyll-*a* was determined after membrane filtration by the fluorimetric and photometric method of Yentsch and Menzel (1963); no correction was made for phaeophytin-*a*. Chlorophyll-*a* surveys were conducted at or very close to the sediment sampling stations, from 1986 to 1990. Details on primary productivity estimates have been described elsewhere (Gocmen, 1988; Salihoglu et al., 1990).

TABLE I

Average annual primary production rates in the Sea of Marmara, calculated from chlorophyll-*a* data collected from 1986 to 1990 (note the most productive southern inner-shelf areas of this sea)

Region	Primary productivity ($g\,C\,m^{-2}\,year^{-1}$)
Northeastern Sea of Marmara	104
Northern Sea of Marmara	83
Central Sea of Marmara	68
Southern Sea of Marmara	107 (inner shelf) 161 (outer shelf)
Southwestern Sea of Marmara	64

RESULTS AND DISCUSSION

Primary production rates in the Sea of Marmara

Unluata and Ozsoy (1986) and Polat (1989) have shown that the main source of organic matter in the Sea of Marmara is the biogenic material related to the primary productivity of the basin itself and the flux of organic material from the Black Sea. However, as shown in Table 1 and Fig. 7, significant variations do occur in the distribution of average annual primary production rates in the Sea of Marmara. The highest primary production rates found on the southern inner shelf (161 $g\,C\,m^{-2}\,year^{-1}$) were also confirmed by occurrences of very high plankton density in shallower waters (less than 45 m depth) along the southern coasts (Cebeci and Tarkan, 1990).

Although continental shelf regions are often sites of relatively high primary production as a result of coastal upwelling, as found off Benguela (Calvert and Price, 1983), Peru–Chile (Reimers,

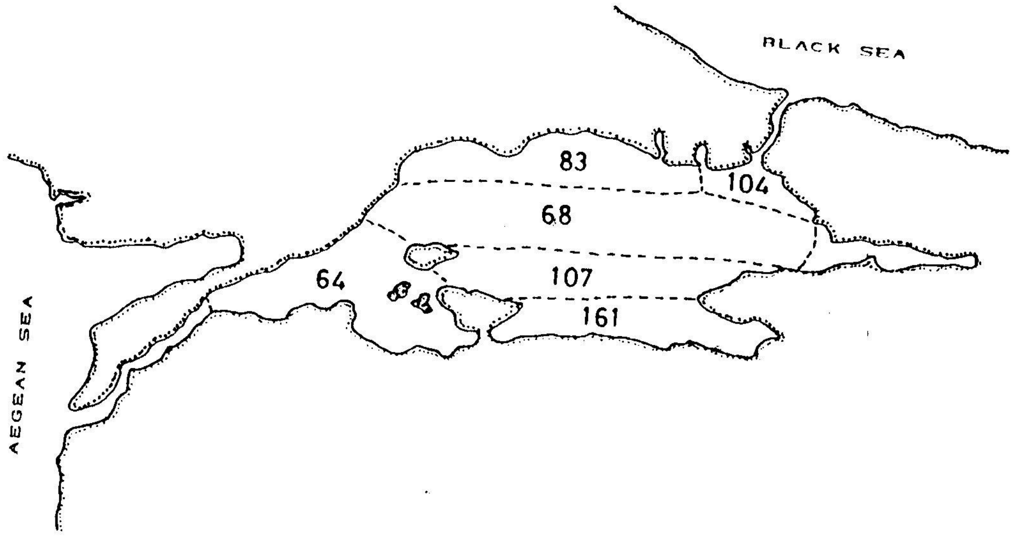

Fig. 7. Average annual primary production rates in the Sea of Marmara. Based on chlorophyll-*a* data obtained from 1986 to 1990. The most productive southern shelf areas of the sea should be noted.

1981), and in the Arabian Sea (Naidu, 1990), no good evidence is yet available to support the occurrence of upwelling on the southern shelf of the Sea of Marmara. It is more likely that the influence of nutrients from southerly major rivers is of great importance in the increase of local primary production along the southern inner shelf of the Sea of Marmara. This is a dominant trend observed in many nearshore/deltaic environments (Schemainda et al., 1975; Naidu, 1990) where the river-derived nutrients can contribute to a considerable increase in the primary production of organic matter.

Lower primary productivity was calculated for the northern shelf of the Sea of Marmara (83 g C m^{-2} $year^{-1}$; Fig. 7) where major rivers are absent. The primary production rates from the northeastern (104 g C m^{-2} $year^{-1}$) and southwestern (64 g C m^{-2} $year^{-1}$) parts of the Sea of Marmara (Fig. 7) appear to be influenced by the organic-rich surface inflow from the Black Sea (52–250 g C m^{-2} $year^{-1}$: Sorokin, 1983; Gocmen, 1988) and organic-poor subsurface inflow from the Aegean (36 g C m^{-2} $year^{-1}$; Yilmaz, 1986) or Mediterranean (16–25 g C m^{-2} $year^{-1}$; Murdoch and Onuf, 1974; Yilmaz, 1986; Gocmen, 1988).

As mentioned above, the Black Sea waters are rich in organic matter because of relatively high production and terrigenous inputs. The resultant transport of organic matter and nutrients from the Black Sea (Fig. 5) has already been recognized by Unluata and Ozsoy (1986), Gocmen (1988), Polat (1989) and Ergin et al. (1991). Furthermore, studies have shown that in the northeastern Sea of Marmara, nutrients are supplied not only externally to the surface layer of the Marmara Basin from the Black Sea via the Bosphorus but also from the sub-halocline waters by the upward mixing induced by the internal hydraulic jumps in the vicinity of the Bosphorus–Marmara junction (Fig. 8). Thus, the renewal of the deep Marmara waters by the saline Mediterranean inflow must have resulted in displacement of nutrients to the surface and this in turn increased primary organic production on the northeastern shelf of the Sea of Marmara (regenerated–new production; Polat, 1989).

Based on the above arguments, the Bosphorus approach of the Sea of Marmara has been regarded, until now, as the most productive region of this sea (Basturk et al., 1988; Gocmen, 1988); however, the results obtained in the

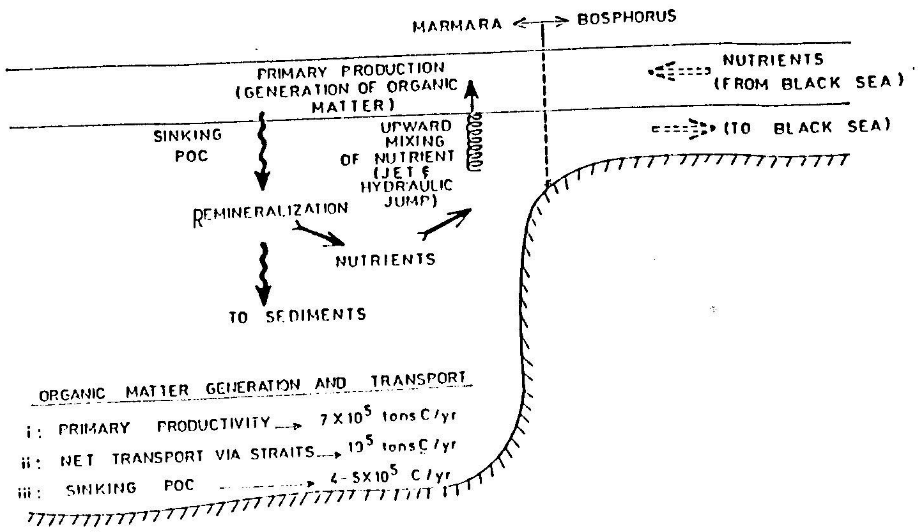

Fig. 8. Schematic diagram of generation and transport of particulate organic carbon in the northeastern Sea of Marmara. (After Unluata and Ozsoy (1986).)

present study (Fig. 7) have revealed that the southern shelf regions of the Sea of Marmara, in fact, are much more productive.

Sediment texture

The surficial sediments of the Sea of Marmara in this study have shown a wide range of grain sizes, from clay to sandy gravel (Fig. 9). In any discussion of the marine sediments, it must be realized that the changes in the amount of various grain size fractions can significantly influence the chemical compositions of the sediments (Romankevich, 1984). In most studies, therefore, values are expressed on a carbonate-free basis or with reference to a conservative element or to the fine-grained fraction. To normalize organic carbon data, and thus to reduce the diluting effect of grain size (caused by clastic sand and gravel, and benthic shell debris), we have prepared a distribution map of mud (composed mainly of siliciclastics) in the Sea of Marmara (Fig. 10). It shows that sediments with high mud contents occur widely in the deeper offshore waters, coastal embayments, and cyclonic/gyral areas where hydrodynamic conditions favour sedimentation by fine detritus, except for regions off river mouths with high terrigenous input.

Carbonate distribution

Total carbonate contents (expressed as per cent $CaCO_3$) of the surface sediments (grab samples) showed a wide range, between 2 and 90% (Fig. 11). $CaCO_3$ contents between 10 and 30% appear to be the rule, with the lower and higher values being exceptions (Fig. 11). Microscopic studies revealed that most of the carbonates occurred in the relatively coarse sediment fractions and were derived from the skeletal and shell remains of benthogenic organisms, such as pelecypods, calcareous coralline algae, gastropods, and some other molluscs.

Organic carbon distribution

Total organic carbon concentrations of the surface sediments (grab samples) from the Sea of Marmara varied between 0.37 and 2.16%, with a general tendency to increase in finer-grained sediments (Fig. 12). The results obtained here were nearly within the same range, i.e. between 0.37 and 2.16% on the northeastern shelf (Bosphorus-Marmara approach), 0.57–1.64% on the northern shelf, 0.44–1.90 on the southern shelf, and 0.37–1.51 on the southwestern shelf (Dardanelles–Marmara approach). As shown in

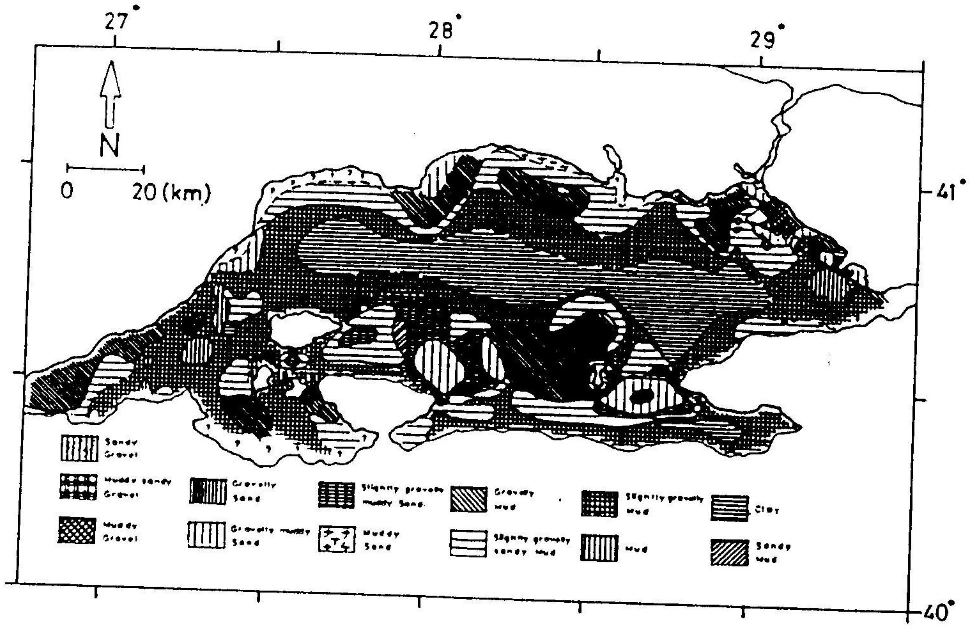

Fig. 9. Principal types of surface sediments in the Sea of Marmara.

Fig. 13, the organic carbon concentrations in the northeastern half of the Sea of Marmara are generally higher (1.0–1.5%) than those from the southwestern half of this sea (0.5–1.0%). This would mean that the distribution pattern of organic carbon in these sediments supports the importance of the influences from the two adjacent seas, the Aegean Sea and the Black Sea.

With the exception of surface sediments (0–6 cm) from the two cores BX-1 (0.21–0.62% C_{org})

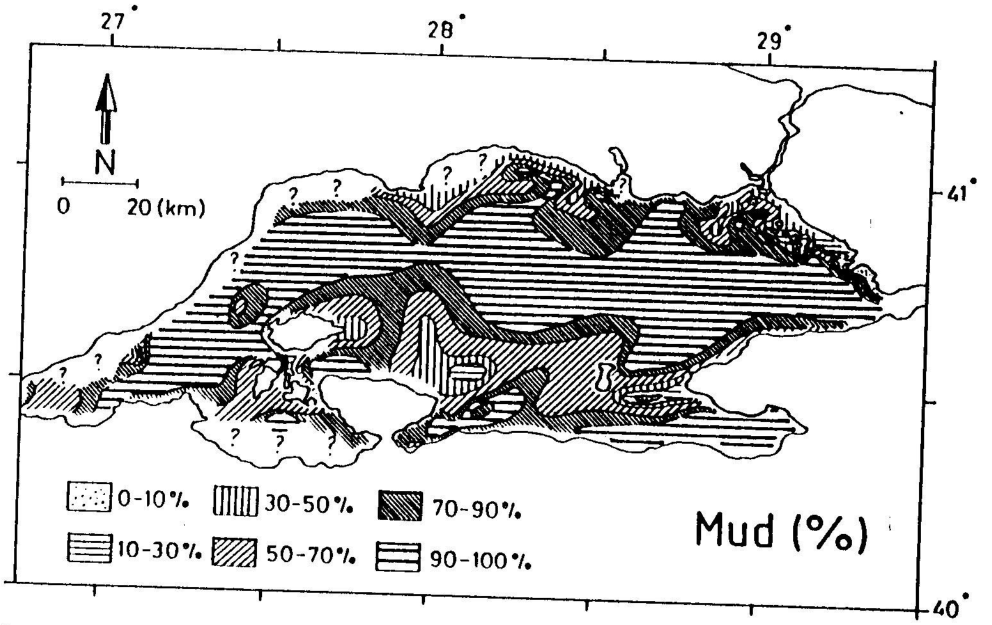

Fig. 10. Distribution map of mud (grain size less than 63 μm) in surface sediments from the Sea of Marmara.

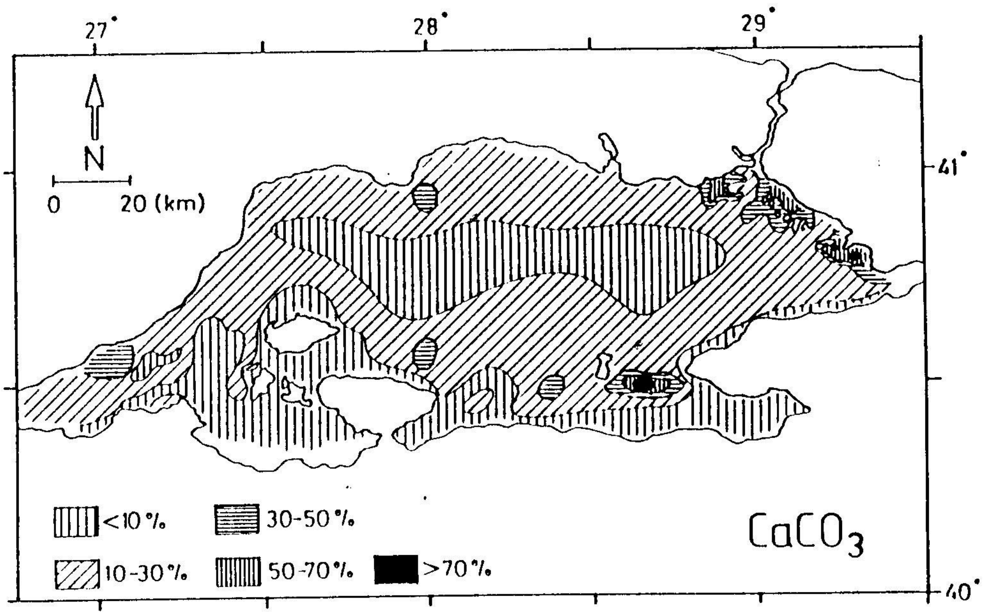

Fig. 11. Distribution map of the total carbonate contents (expressed as per cent $CaCO_3$) of surface sediments in the Sea of Marmara.

and BX-6 (0.10–0.17% C_{org}) obtained at the Black Sea and Aegean Sea exits of the Sea of Marmara (Fig. 14), respectively, the remaining surface sediments from other corers (BX-2, M-3, BX-3, BX-4 and BX-5) showed organic carbon values ranging from 0.84 to 1.15% (Bodur and Ergin, 1992). The fluctuations observed in the C_{org} contents of sediments in cores BX-1 and BX-6 (Fig. 14) are attributed to the variations in lithogenic and benthogenic constituents of sediment admixtures in the cores.

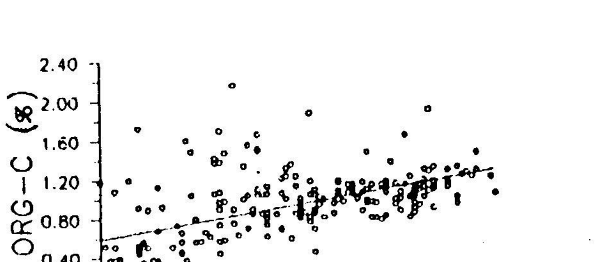

Fig. 12. Relationships between the total organic carbon contents and fine size fractions of the surface sediments (including the top 10 cm of the cores) in the Sea of Marmara.

Compared with sedimentary organic carbon data from other offshore waters in the eastern Mediterranean (0.11–0.85%: Emelianov and Romankevich, 1979; Ergin et al., 1988) and the Aegean (0.30–0.70%: Voutsinou-Taliadouri and Satsmadjis, 1982; Ergin et al., 1992), the organic carbon concentrations obtained in this study (0.37–2.16) and those by others (0.38–1.83%: Ergin and Evans, 1988; Evans et al., 1989; Ergin et al., 1991) have revealed relatively high organic carbon concentrations in the sediments of the Sea of Marmara. Similar higher C_{org} contents are known from the Black Sea sediments (0.50–2.00%: Shimkus and Trimonis, 1974; Rozanov et al., 1974; Yucesoy and Ergin, 1992). From this, one may infer the possible effects of lateral transport of organic matter/nutrients from the adjacent Aegean Sea and Black Sea. This finding is also supported by the results of Basturk et al. (1986), who showed that the distribution and the levels of humic substances were well correlated with primary production, which in turn was significantly influenced by the transport from the Black Sea.

Patchy occurrences of relatively high C_{org} per-

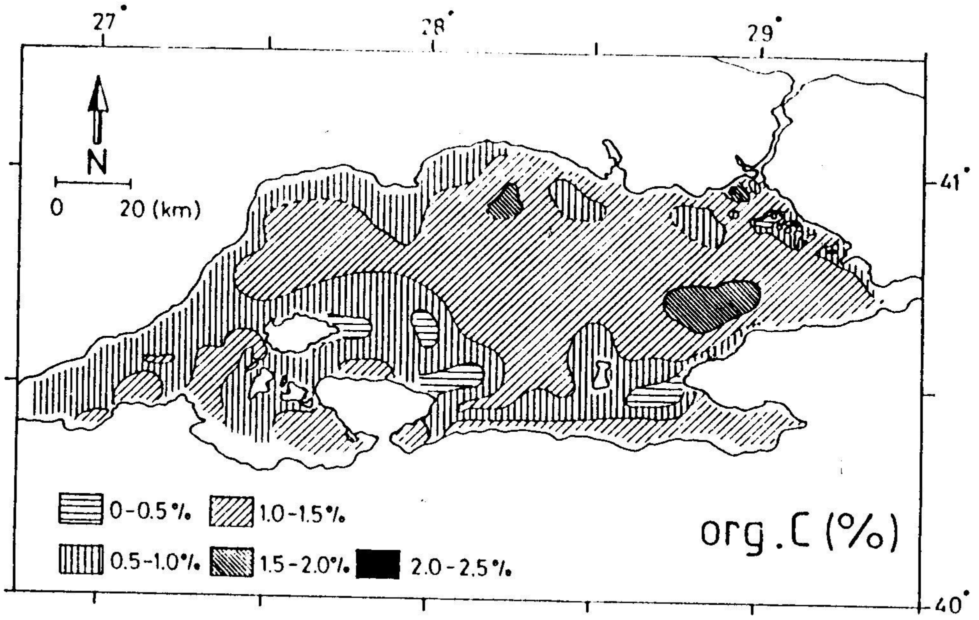

Fig. 13. Distribution map of the total organic carbon contents of surface sediments (grab samples) in the Sea of Marmara.

centages (1.0-1.5%) along the southern inner shelf (near the coasts) probably indicate influences from terrigenous sources in addition to marine organic production, because the southern Marmara shelf receives large quantities of terrigenous materials through the major rivers entering the sea from the south (Ergin et al., 1991).

Relationship between primary productivity and total organic carbon in sediments within the Sea of Marmara

Average annual primary production rates and total organic carbon contents (recalculated on a $CaCO_3$-free basis) of selected fine-grained (more than 90% mud) sediment samples obtained in this study are interrelated, as shown in Fig. 15. It is apparent that there might be a general increase

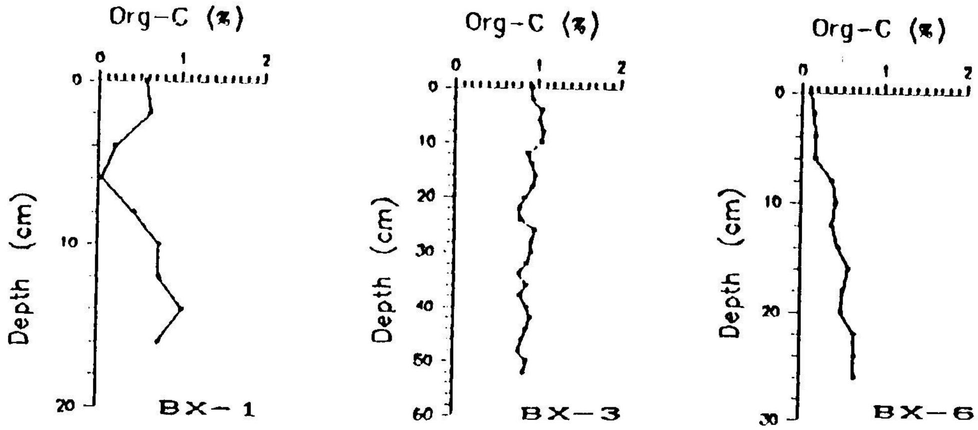

Fig. 14. Downcore distribution of total organic carbon contents in the sediments from the Black Sea exit (BX-1), central deep basin (BX-3), and from the Aegean exit (BX-6) of the Sea of Marmara. (See Fig. 6 for locations.)

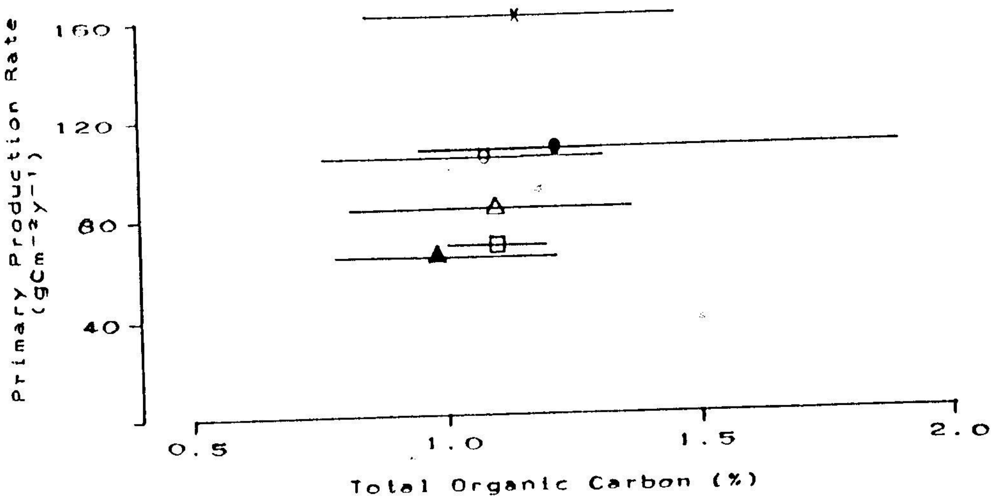

Fig. 15. Total organic carbon vs. primary production rates obtained in the Sea of Marmara. x, Southern inner shelf; ●, southern outer shelf; O, northeastern shelf (Bosphorus–Marmara approach); △, northern shelf; □, deep-sea basins; ▲, southwestern shelf (Dardanelles–Marmara approach).

in organic carbon contents of sediments with increasing primary production. However, this observed relationship is not direct and therefore it is less significant than would normally be expected in many marine environments where the dependence of sedimentary organic carbon contents on primary production rates are much more pronounced (Muller and Suess, 1979). In the fine-grained surface sediments of the Sea of Marmara, organic carbon contents showed approximately 1.2-fold increase with each 2.6-fold increase in the primary production rate (Fig. 15).

Particularly on the southern shelf, where the primary production rates increase from 107 g C m^{-2} $year^{-1}$ on the inner shelf to 161 g C m^{-2} $year^{-1}$ on the outer shelf, organic carbon contents of the sediments do not follow the same trend. A significant amount of the organic matter from primary production may have been removed from the water column before settling to the bottom, or increased removal of organic matter occurs as a result of rapid degradation and biological activities at or near the sediment surface or within the sediment. It is well known that vertical transport of particulate organic matter in the water column — except for living organisms — is dominated by relatively large, rapidly settling particles (more than 100 μm), with settling velocities of about 100 m day^{-1}, which occur as a result of processes such as aggregation, flocculation, and coagulation (McCave, 1975; Eisma and Kalf, 1979; Honjo and Roman, 1979; Shanks and Trent, 1980; Ergin et al., 1990). For example, in the northeastern Pacific Ocean, aggregates were usually the dominant form of carbon leaving the euphotic zone (Silver and Gowing, 1991). In fact, with low sinking rates, phytoplankton itself remains in suspension, unless it flocculates or becomes attached to larger particles (Platt et al., 1983). Under such conditions, especially in the Sea of Marmara, where current velocities in offshore surface waters are approximately 5–10 cm s^{-1} (M.A. Latif, personal communication, 1991), and 80–200 cm s^{-1} at the approaches of the Bosphorus and Dardanelles Straits (after Defant (1961), Daniel, Mann, Johnson, and Medenhall/Alvord, Burdic and Howson/Motor-Columbus/Checchi (DAMOC) (1971) and De Filippi et al. (1986) in Unluata et al. (1990)), a considerable portion of the primary organic matter might have been laterally transported offshore via the prevailing surface flow.

The rapid decay of organic matter as a result of microbial degradation is typical for many nearshore and deltaic environments (Tissot and Welte, 1978; Coleman et al., 1979). However, the results obtained here make it difficult to identify the extent of such a rapid organic matter decomposition because of the overwhelming influences of terrigenous inputs and the particular hydrographic conditions prevailing in the study area. On the other hand, of course, the presence of increasing benthic activities — as indicated by the occurrences of relatively high biogenic carbonate contents in some nearshore samples — would not only produce dilution of organic matter by carbonate admixtures, but also would cause the organic matter preserved in the sediment to be utilized by the benthos (e.g. Rowe et al., 1988). In this work, these processes must be limited to the areas of sediments relatively rich in benthogenic carbonate but low in organic carbon contents which were not taken into account to establish basin-wide production–flux relationships in the Sea of Marmara.

From the above discussion, we imply that there is no evidence to suggest a direct relationship between surface productivity and the C_{org} distribution in sediments. It is more likely that loss of organic matter as a result of lateral transport by surface waters can be considered as a reasonable explanation for the imbalance between primary production and carbon flux from the euphotic zone in the Sea of Marmara. Variations in the intensity of biological processes would thus play a secondary role.

Relationship between total organic carbon content in sediments and the concentration of dissolved oxygen in the Sea of Marmara

As shown in Fig. 3, dissolved oxygen concentrations below the halocline of the Sea of Marmara generally decrease from the Dardanelles approach towards the deep basins offshore, but again increase slightly in the Bosphorus approach. This is one of the distinguishing features of the Sea of Marmara, which has a permanent oxygen deficiency below the halocline, which in turn is the lower limit of the euphotic zone; therefore, the oxygen deficiency below the halocline reflects the competition between the oxidation of organic matter and the supply of dissolved oxygen by physical processes (Unluata and Ozsoy, 1986). The latter results from the oxygen-rich subsurface water masses which enter from the Aegean Sea and flow through the Strait of Dardanelles losing a considerable proportion of their oxygen content immediately upon entering the Marmara Basin (Fig. 3). The dissolved oxygen transport from the surface to sub-halocline waters can only be by diffusion, and hence is small (Besiktepe, 1991). As the average renewal time for the sub-halocline Marmara waters was estimated to be roughly 5 years (residence times for the surface waters are about 3 months) and the annual supply of oxygenated water through the Dardanelles Strait is only a small fraction of the basin volume (Unluata et al., 1990), the deep Marmara waters are significantly depleted in oxygen content (0.8–1.4 mg O_2 l^{-1}; Basturk et al., 1991).

It has been suggested that settling fluxes of organic matter can also greatly vary from place to place in the sea, depending not only on the level of production, water depth, rate of sedimentation, and the transport mechanisms but also on the availability of oxidants (e.g. Pedersen and Calvert, 1990). Thus, one might expect that in relatively oxygen-rich waters on the southwestern shelf of the Sea of Marmara, the decomposition of sinking organic matter would have proceeded much faster than in the relatively oxygen-deficient or oxygen-poor waters of the central basins and the northeastern shelf of this sea. In consequence, the organic carbon contents of sediments in this study would reflect, to some degree, marked variations in the oxygen concentrations in the water column across the Sea of Marmara. However, the results show (Figs. 3 and 13) that there is no direct relationship between oxygen deficiency in the overlying water masses and C_{org} distribution in sediments of the Sea of Marmara; a fact that may find support in the works of Glenn and Arthur (1985), Calvert (1987), and Pedersen and Calvert (1990), who have revealed that variations in the oxic and anoxic conditions do not appear to have a direct effect on the carbon accumulation in modern seas.

CONCLUSION

Studies on primary production, sedimentary organic carbon, and oxygen deficiency distribution in the Sea of Marmara have shown that there is no direct relationship between these parameters for this sea. Productivity and organic carbon accumulation in the sediments are strongly affected by the inflow of relatively organic-rich Black Sea waters, by the southerly major rivers, and by inflow of organic-poor Aegean or Mediterranean waters.

Lateral offshore transport in surface waters and, to a lesser degree, oxygen deficiency and biological activities in the water column are believed to be important factors resulting in the decrease of particulate organic carbon fluxes to the sediments in this sea.

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