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SEDIMENTOLOGY AND GEOCHEMISTRY OF THE LATE-HOLOCENE SEDIMENTS FROM THE SEA OF MARMARA AND ITS STRAITS

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by

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ABSTRACT

SEDIMENTOLOGY AND GEOCHEMISTRY

OF THE LATE-HOLOCENE SEDIMENTS FROM

THE SEA OF MARMARA AND ITS STRAITS

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Recent sediments (mainly of Late-Holocene age) from the Sea of Marmara and its straits ("Bosphorus" and "Dardanelles"), have been investigated using box (at 6 stations) and boomerang corers (at 1 station) and grab (*Dietz Lafonde*) sampler (at 209 stations). A large number of petrographic and chemical data was obtained to study the geochemistry of the modern sedimentary deposits in the region

In the straits of Dardanelles and Bosphorus, as well as, in many near-coastal zones where wave, current, and/or benthic activities are effective, the sea-floor is mostly covered by the coarse-grained sediments (rich in sand and gravel). These samples are composed of the varying proportions of terrigenic and biogenic admixtures, depending on the prevailing topography-related hydrodynamic conditions and the biological activities. The former is best shown not only in the channels but also in the canyon systems of the

straits. The seaward increase in the fine components of sediments along the downcanyon-axis is prominent. Microscopic examination of the sediments revealed that the terrigenous constituents, largely reflected the influences from the land-based geological sources, most probably delivered by river-runoff and coastal erosion.

Biogenic components were mostly derived from the molluscan shell fragments of various pelecypod species. Exceptions are the occurrences of the calcareous, coralline-algal (chiefly *Lithothamnium calcareaum*, *L. fruticolusum* and *Lithophyllum racemus*) sediments particularly on the nearshore region of the Bosphorus-Marmara, Marmara-Dardanelles, and Dardanelles-Aegean Junctions, where the influences of the Mediterranean undercurrents are predominant.

Organic carbon contents of the sediments (0.10 to 2.16 % org.C) normally reflect the transitional character of the Sea of Marmara, between the organic-rich Black Sea and the relatively organic-poor Mediterranean Sea. The fine-sediments are probably favoured for the accumulation of organic matter.

Total carbonate contents of the sediments (expressed as % $CaCO_3$) ranging from 2 to 90 %, are widely consistent with the presence of the calcareous-biogenic fractions, usually in the sand- and gravel-size groups of the samples.

Heavy metal concentrations reflect marked variations in the sediment texture and lithology, as well as, the changes in post-depositional process in response to various environmental conditions. With the exception of Mn, the heavy metal data show that the concentrations of Fe, Ni, Zn, Cr, Co, Cu, and Pb in the samples are largely at natural levels when compared with their baseline in the deeper core sediments and their possible source rocks in the region. There is no satisfactory evidence for an anthropogenic input of the metals studied, although this can not be ruled out, especially for Cu, Pb and Zn in the southern Bosphorus exit. The role of diagenesis seems to be effective in the increased Mn concentrations from the deep-sea sediments of the Marmara Trough.

ÖZET

Marmara Denizi ve Boğazlardaki
Geç Holosen Çökellerinin
Sedimentolojisi ve Jeokimyası

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Bu çalışmada Marmara Denizi ve Boğazlardan, 7 adet sonda (6 Box, 1 Boomerang) ve 209 adet kepçe (*Dietz Lafonde*) örnekleyicileri yardımıyla alınan güncel (Geç Holosen) çökeller incelenmiştir. Bölgedeki güncel çökellerin dağılım şekilleri ve kökenlerini saptamak için çok sayıda petrografik ve kimyasal veriler elde edilmiştir. Dalga, akıntı ve/veya bentik aktivitenin etkin olduğu İstanbul ve Çanakkale Boğazları ve hatta birçok yakın kıyı alanlarında, deniz tabanı ekseriyetle kum ve çakıl yönünden zengin iri taneli çökellerle kaplanmıştır. Bu çökeller değişen oranlarda terrijenik ve biyojenik karışımlardan oluşmuştur, ki bunlar bölgede hüküm süren topoğrafya ile ilişkili olarak hidrodinamik koşullara ve biyolojik aktiviteye bağlı olmaktadır. Bu koşullar yanlızca kanallarda değil hatta boğazların kanyon sıstemlerinde de görülmektedir Kanyonun ekseni boyunca çökellerin ince taneli kısımlarının denize doğru artışı bariz olarak görülmektedir. Çökellerin mikroskopik olarak incelenmesi sonucunda ekseriyetle karasal

bileşenlerin muhtemelen kıyı erozyonu ve nehirlerin getirdiği karasal kökenli jeolojik kaynaklardan oluştuğu görülmektedir.

Biyojenik bileşenler ekseriyetle farklı türdeki yumşakçaların kavkılarından oluşmuştur. Istisnai olarak kısmen İstanbul Boğazı ve Marmara girişinin yakın kıyısında, ve Akdeniz alt akıntı etkilerinin yoğun olduğu Marmara-Çanakkale ve Çanakkale-Ege girişlerinde kalkerli mercan algleri (başlıca *Lithothamnium calcareaum*, *L. fruticolusum* and *Lithophyllum racemus*) çökellerinin varlığı ayrıca tesbit edilmiştir.

Normal olarak çökellerdeki organik karbon miktarı (0.10 ila 2.16 % arasında değişmektedir), organikce zengin Karadeniz ve organikce fakir Akdeniz arasında bir geçiş karakterini yansıtmaktadır.

Yüzde olarak kalsiyum karbonat cinsinden ifade edilen ve yüzde 2'den 90'a kadar değişen çökellerdeki toplam karbonat miktarı yaygın olarak genellikle çakıl ve kum boyutlu örneklerde kalkerli biyojenik kısımların varlığı ile ifade edilmektedir.

Ağır metal konsantrasyonları çökellerin dokusunda ve litolojisindeki belirli faklılıkları yansıttığı gibi, farklı ortam şartlarına bağlı olarak çökelme işlemleri sonrası değişiklikleride yansıtmaktadır. Örneklerde bulunan Manganez metalinin haricindeki diğer metallerin (Fe, Ni, Zn, Cr, Co, Cu, and Pb) değerleri bölgedeki mümkün olan kaynak kayaçlarla ve derin deniz örnekleri ile karşılaştırıldığında doğal seviyelerdedir. Kural dışı olmadığı halde incelenen metallerin, özellikle Boğazın Güney çıkışında bulunan Cu, Pb ve Zn, alıcı ortama endüstriyel olarak girdisini kanıtlayacak tatmin edici herhangi bir kanıtın olmadığı görülmüştür. Diyajenezin, Marmara Çukurundaki derin deniz çökellerinde bulunan manganez konsantrasyonlarındaki artışta etkin rol oynadığı görülmektedir.

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CHAPTER ONE

1. INTRODUCTION

In the following, the general characteristics of the study area, namely the Sea of Marmara and its surroundings have been summarized. In this Chapter, also, the physiography, geology, and atmospheric settings as well as, other oceanographic parameters are discussed.

1.1. PHYSIOGRAPHY

The Sea of Marmara -covering a surface area of about 11500 km^2 and a volume of approximately 3378 km^3- shows the relief characteristics of a miniature ocean. It is an almost totally enclosed depression lying between the Black and Aegean Seas, those are connected by the two elongated narrow and shallow straits (Fig. 1.1).

The Strait of Bosphorus (also called "İstanbul Boğazı), which is directed in the NNE-SSW, varies from 0.7 to 3.5 km in width (avg. 1.6 km) and is about 31 km long. The water depths change in both, transversal and longitudinal directions, with an average of 36 m and the maximum depth of approximately 110 m is located in front of Kandilli (TNHC; Turkish Navy Hydrographic Chart No.2921). Two sills are

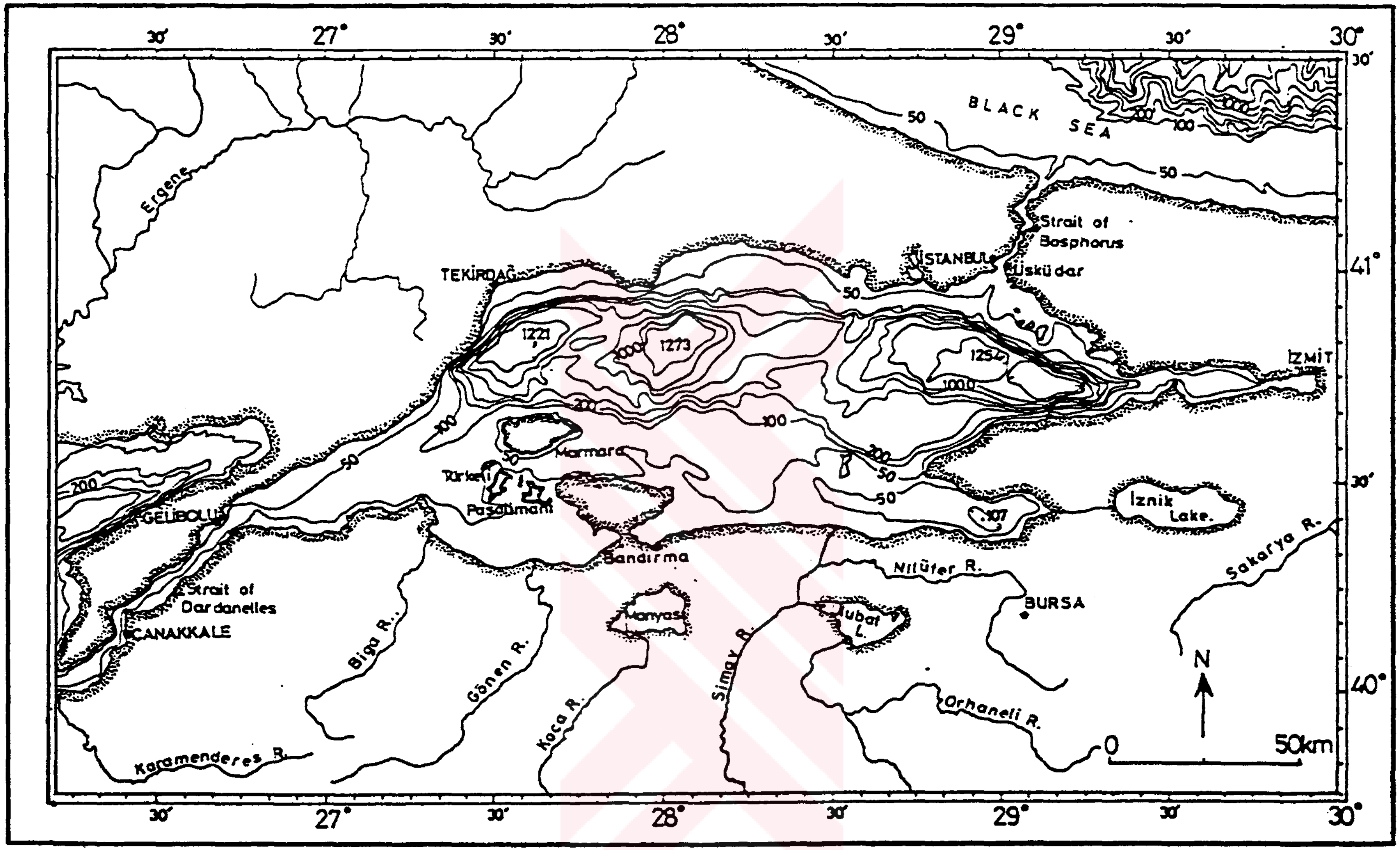


Figure 1.1 : Bathymetry of the Sea of Marmara and its straits "Bosphorus" and "Dardanelles" (Modified from IOC, 1981).

present at the strait's exits; one of these, with about 32 m depth is located about 3 km north of the Bosphorus with Marmara in junction, and another sill (approximately 60 m depth) is situated at the junction of Bosphorus with the Black Sea. Strait of Dardanelles (also known as "Çanakkale Boğazı") is the southwestern exit of the Marmara Sea and has a length of about 62 km (avg. depth is approximately 55 m). The width of Dardanelles Strait varies from 1.2 to 7 km (avg. 4 km; TNHC No.212). The general orientation of the strait axis is along the northeast-southwest direction, however a prominent change occurs in the lower part of the strait, about 20 km away from the Aegean entrance. In this part, the channel makes an abrupt bent, from west to south, to form the so-called Nara Passage (TNHC No.212). At the Strait of Dardanelles and the Sea of Marmara Junction, the strait widens gradually to join the western deep Marmara basin in the north and the southern Marmara shelf in the east (TNHC No.295).

Over half of the basinal area of the Sea of Marmara is occupied by the continental shelf. The shelf along the northern coast is narrow varying from 2 to 13 km in width with a shelf edge around 20 to 110 m. The southern shelf is much broader (33 km wide) with a break at about 100 m, except in the southeast, where it is 2 to 3 km wide and breaks at 20 to 30 m. The continental slope which is interrupted in the southeast by a marginal plateau lying from 200 to 400 m depths (Carter *et al.*, 1972 and IOC, 1981), extends down to 1200 m, to reach the Marmara Trough. The Marmara Trough (about 210 km long) is a submarine morphological extension of the North Anatolian Fault Zone (Şengör *et al.*, 1985). This trough consists of three pull-apart sub basins oriented in east-west direction and the maximum depths of these sub basins are respectively 1254, 1389, and 1221 m (Carter *et al.*, 1972; IOC, 1981; TNHC No.29), and those are separated from each other by relativelyy low sills with depths of about 550-700 m.

1.2. GEOLOGIC SETTING

Here, the surroundings of the study area will be described in its geologic setting. For this, the especially important topics such as paleogeography, paleotectonism and the general geological characteristics will be briefed.

1.2.1. PALEOGEOGRAPHY

There are two branches of the Tethyan domain separated by the inner Anatolian massifs; namely the Karadeniz Dağları (Pontics Mountains) and the Toros Dağları (Taurus Mountains). Ternek *et al.* (1987) mentioned that the western extension of the Karadeniz Dağları, east of Sakarya branches into two units, one extending from the north of Bosphorus and Istranca massives into the fore-Balcans, whereas the other extends between İznik and Bilecik being further divided into several branches by geanticlines.

The basement of crystalline rocks of Paleozoic age is mainly composed of banded gneisses which are believed to have been folded through Caledonian and Hercynian movements (Ternek *et al.*, 1987). They noted that there is a major synclinorium passing through Anatolia, Balcans and Ucrania. The basement comprises rocks of sedimentary origin deposited at various depths as alternating series which have later been metamorphosed. The Ordovician transgression came from the south. The clastics were derived from terrestrial area which is now occupied by the Black Sea. The transgression overlapped to İstanbul and Kocaeli during Silurian. The northern shore of the Tethys has further moved to the north with resultant occupancy of the Black Sea area during Devonian. There has been an uplift between Ordovician and Silurian. The Carboniferous sea had open sea conditions due to long lasting deposition during Devonian, tectonic activity and regional collapse structures. The Carboniferous type environment turns into a shallow sea environment during Middle and Upper Permian. The Paleozoic and older units have been intermittently transgressed during Triassic with littoral and lagoonal environments dominating. The shallow nature of this sea continued during the Middle and Upper Triassic. An eugeosynclinal environment in the Istranca, a shallow marine environment east and south of Kocaeli and the Marmara Sea and a continental environment in Thrace were prevailing in the early Jurassic. The Upper Cretaceous facies show shoreline facies at the beginning followed by deep marine conditions (Ternek *et al.*, 1987). During the

Tertiary, the Mediterranean was repeatedly connected with the Black Sea by a strait via southern Thracia and the Marmara area (Brinkmann, 1976). A shallow marine environment existed in Gemlik, Silivri, Edirne, north of Marmara Island and Dardanelles during Paleocene. The alternation of marine and lagoonal sediments shows progress of the sea which is somewhat deepened during Lower Eocene, into the terrestrial domains intermittently. The mountains of northern shores of the Marmara and north of Edremit collapsed with resultant transgression covering the lowlands of the Biga peninsula. Submarine volcanism was active. The Eocene sea transgressed the Istranca massive and Gelibolu peninsula. Lagoonal and shallow marine environments were prevailing around İznik, Armutlu peninsula and south of Mudanya during Oligocene and alternating sediments in the Marmara region show that the Oligocene sea was regressed. Lagoonal and fluviatile regimes were prevailing around Gönen, Yenişehir-İnegöl, Kocaeli peninsula, Ergene basin and Gelibolu during Pliocene. The same was existing during Plio-Quaternary, in the early Pleistocene, a renewed subsidence and transgression occurred (Ternek *et al.*, 1987; Brinkmann, 1976). The Dardanelles-Marmara region with the exception of terraces, has been formed by fluviatile processes, and these observations strongly suggest repeated fluctuations of the sea level and the Dardanelles were river valley that drained the Sea of Marmara towards the Aegean Sea at low water levels, than they formed a strait during the periods of transgression (Brinkmann, 1976). He noted that in contrast to the

Dardanelles, the slopes of the Bosphorus show a sequence of fluviatile terraces only. Fairbridge (1972) stated that the incision of the Bosphorus channel was only achieved in the last glacial stage. As a consequence of the world-wide eustatic movements during the Last Glacial, the sea-level around Turkey was about 90-100 m lower than at present (Erinç, 1978). Thus, some 20,000 years ago the Straits were transformed into land, the Sea of Marmara was occupied by a lake, and the Black Sea was in a state of regression and desalinization (the so-called New Euxine stage), while streams were actively cutting down their beds because of their increased gradients (Erinç, 1978). At the Post Glacial "climatic optimum" (7000-5000 B.P) sea level probably rose 2-3 meters above the present level and resulted in the transformation of the former stream valleys in the Bosphorus and Dardanelles into the Black Sea (Erinç, 1978). Herman (1989) pointed out that, when the sea level reached the Bosphorus sill (approximately -36 m) about 11,000 years ago, the connection between the Mediterranean and Black Sea was reestablished and the low-salinity Black Sea water spilled over into the Mediterranean. He also stated that significant increase in precipitation and river runoff was also recorded during transitional climatic periods.

The paleo-oceanographic conditions has been stratigraphically discussed by Stanley and Blanpied (1980) (Fig. 1.2).

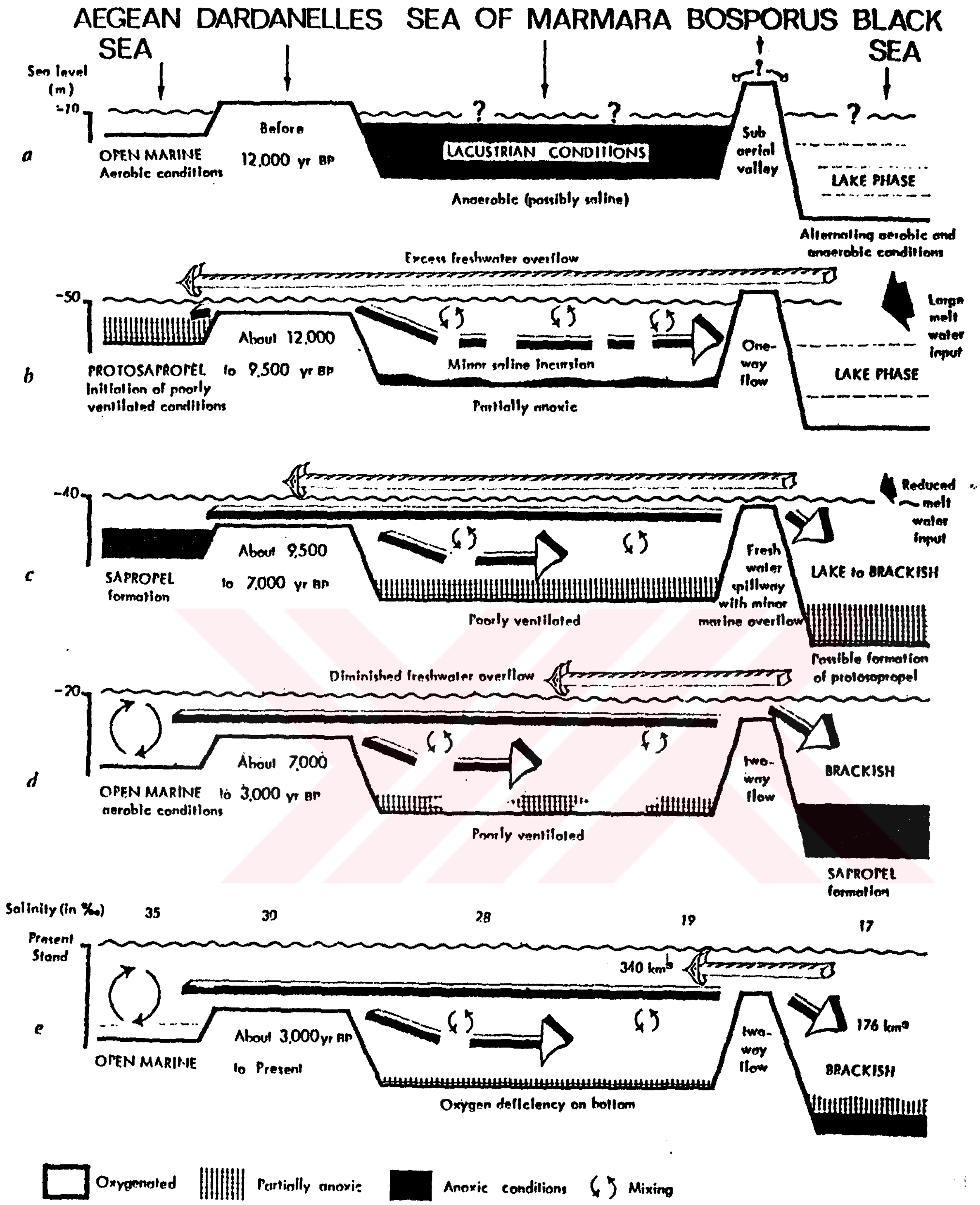


Figure 1.2 : Paleo-oceanographic conditions in the Aegean-Black Seas (from Stanley and Blanpied, 1980).

According to Erol (1987), during the upper Pleistocene, time to time, Dardanelles and Marmara region was invaded by the Mediterranean waters and he stated that the first invasion of these regions was started during the Tyrrhenian period (Last Glacial). The marine deposition around Dardanelles is the product of the present sea and the low inclinations of Quaternary beds, presence of terraces both on the river beds and shores, frequently occurring earthquakes are indications of continuous crustal movements up to the present (Ternek *et al.*, 1987). The rifting of the Aegean Sea after Miocene was intermittently effective and the collapsed areas were covered by the sea and the tectonic development of this sea continued until today as evidenced by the present seismic activity (Ternek *et al.*, 1987). Although, the first vertical displacements (which cause the formation of Upper Miocene Basins) started between Upper and Middle Miocene, the morphotectonic effects on the formation of Marmara and Black Sea Basins (which are affected by North Anatolian Fault Zone and other displacements parallel to it) was observed during the Pliocene and Quaternary (Erol, 1989). Hence, the Bosphorus and Dardanelles Strait channels were drained by rivers during the Upper Pliocene and Lower Pleistocene (Erol, 1989). Three fluvial terraces of Lower and Middle Pleistocene age, and three marine terraces of Upper Pleistocene age were developed in the Dardanelles depression (Erol, 1991). Also, that those straits which were previously river valley, Marmara and Black Sea Basins were invaded by the Mediterranean Waters after tectonic movements during the

Middle Pleistocene (about 300,000 years B.P). Erol (1991) noted that fairly important tectonic movements had occurred between the formation of higher Tyrrhenian and Lower Monastrian terraces of the upper Pleistocene age, and he also noted that there are indications of Holocene movements in the Dardanelles Region. Artüz (1990) has reported that the Bosphorus and Dardanelles straits were formed during the Würm II/III (40,000-65,000 years B.P). Ketin (1967) noted that the evolutions of the Bosphorus and the Sea of Marmara are related to epeirogenic movements in Pliocene times. It has been also suggested that a depression occupied the northern part of the Aegean and the Marmara Seas including the Dardanelles and the Bosphorus, which were formerly river valleys and assumed their present form in the Early Pleistocene (Pınar-Erdem and İlhan, 1977). Meriç (1990) have recently noted that the Bosphorus Strait was formed as an epeirogenic valley and was affected by some faults and fault-like features during the late Quaternary period. Meriç and Sakınç (1991) recently found that the age of deposits drilled at Golden Horn and at the south of Bosphorus determined by ESR (Electron Spin Resonance) to be 7400-5700 B.P., and it is also supported by paleontological investigations on those sediment deposits.

1.2.2. PALEOTECTONISM

The Marmara Basin is a region where there is an immense number of faults (Fig. 1.3). Kaya (1991) recently stated that the northerly faults controlled the morphologic evolution of the İstanbul region, especially around Bosphorus Strait from Late Tertiary to Recent. The distribution of hot water springs and volcanic rocks are elements defining the fault pattern of the region (Ternek *et al.*, 1987). In the earlier Quaternary, the overflow channel "the Sakarya-Izmit Strait" lay farther east and may have been blocked by motion in the active E-W tectonic belt which lies just north of the right-lateral strike-slip Anatolian Fault (Fairbridge, 1972).

Crampin and Evans (1986) suggested that the Marmara Block is being rotated and sheared in order to accommodate the right-lateral motion of the North Anatolian Fault (NAF) and the extensional tectonics of the southwestern Anatolia. It was reported that troughs of deep water in the Marmara Sea and the north Aegean Sea, together with Tertiary volcanism in Bulgaria, and intermediate depth earthquakes in Romania are probably relics of one of the last of these subduction episodes (Crampin and Evans, 1986). Since the Late Miocene western Turkey has undergone dominantly N-S extension (Eyidoğan, 1988). This extensional regime caused the formation of E-W trending grabens and similarly orientated normal faults. The dominant mode of deformation in the Marmara province is amounting to right-lateral displacement

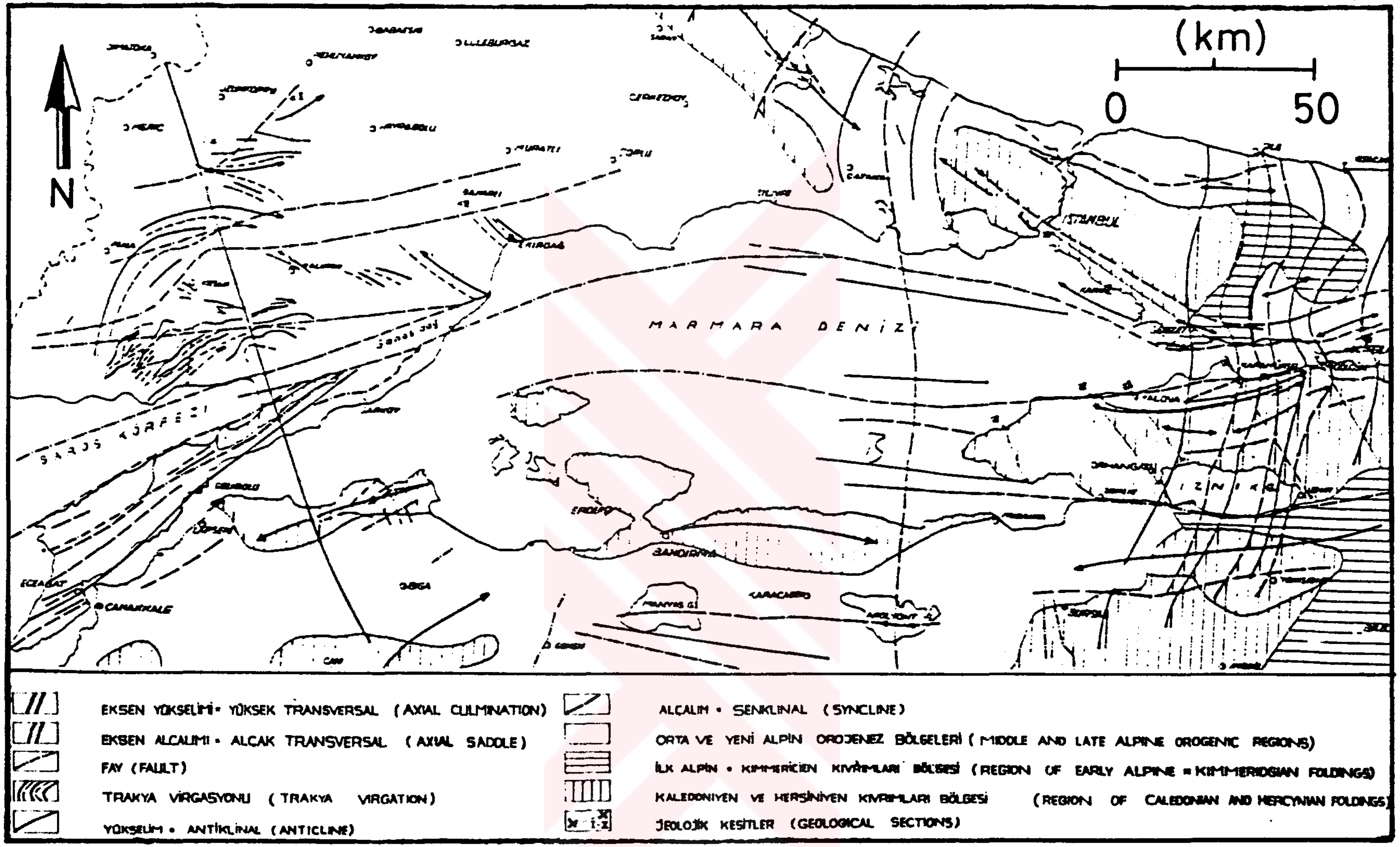


Figure 1.3 : Tectonic map of the Marmara region (from Ternek *et al.*, 1987).

(24 mm/yr), and the other modes of upper crustal deformation in this province can be explained by an average 7.1 mm/yr N-S extension, 10 mm/yr E-W contraction, and 0.13 mm/yr thinning of a 10 km seismogenic layer (Eyidoğan, 1988). It is found that the N-S extension in the western Anatolia increases from north to south, while E-W compression in the Marmara province changes to E-W extension in the south-western Anatolia (Eyidoğan, 1988). It has also been suggested (Ergün, 1990) that the Marmara Sea is the extension of the Thrace Basin in the north and Neogene lateritic deposits are present at the boundaries of this basins. During the Quaternary, the Marmara Sea must have subsided more than 1000 m, accompanied by extension and transform motions (Ergün, 1990). The primary vertical tectonics is uplift, but where transform faults cut across the direction of transform motion, crustal attenuation and subsidence prevail, leading to the formation of pull-apart basins. It was also notified that the area in the Marmara Sea and its surroundings is seismologically very active region (Ergün, 1990).

1.2.3. GENERAL GEOLOGY OF THE MARMARA SEA AND ITS SURROUNDING AREAS

The most important geological formations and their rock/sedimentary units, which are found in outcrops in the Sea of Marmara and its surrounding land areas (Ternek *et al.*, 1987), are summarized below, and illustrated in Fig. 1.4.

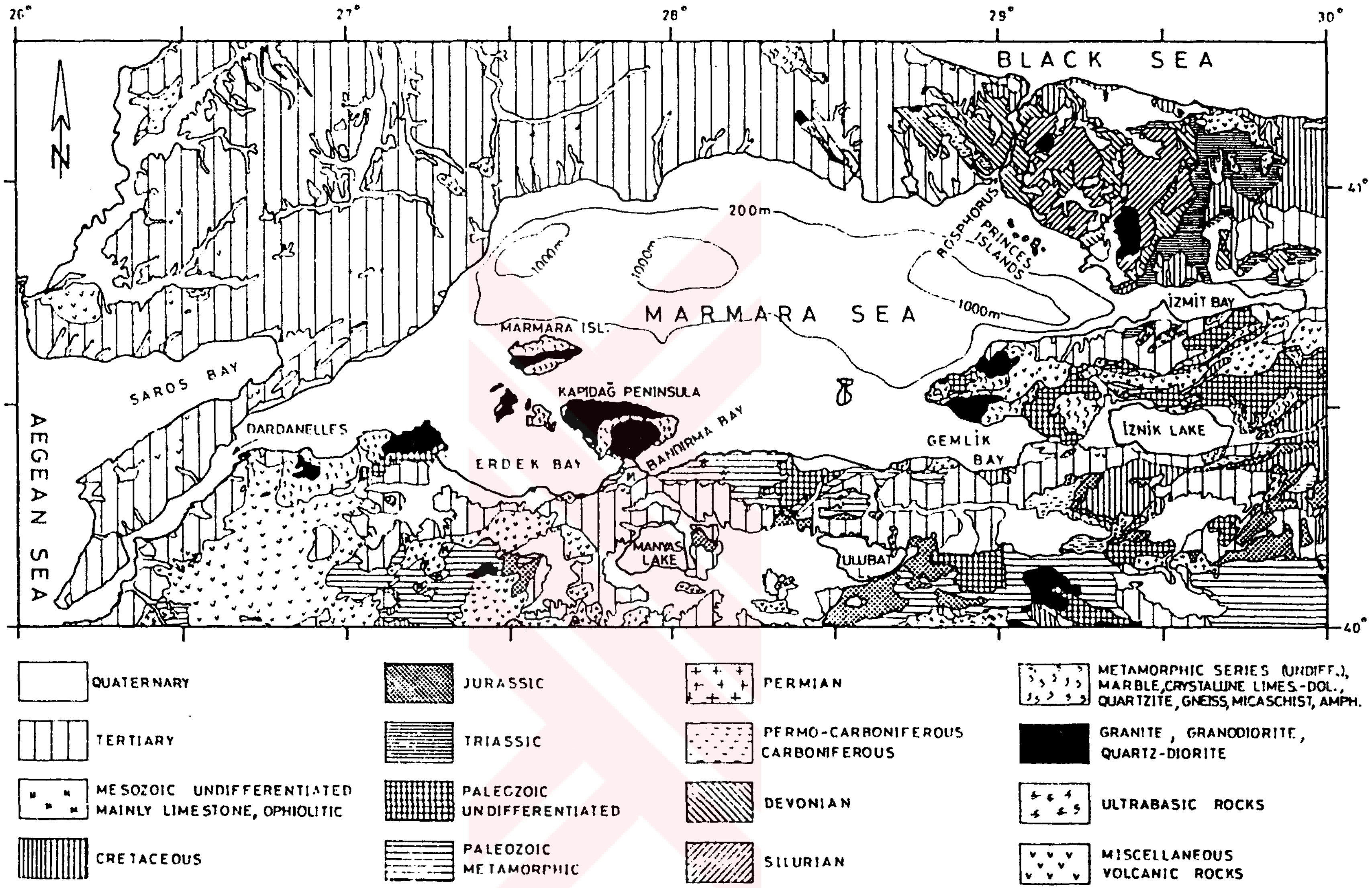


Figure 1.4 : Geological map of the surrounding land areas of Marmara Sea (simplified from Ternek *et al.*, 1987).

As shown, the catchment areas surrounding the Marmara Sea consist of rocks/sediments from different ages and of origin. These are unconformably overlying the Paleozoic basement rocks (Rigassi, 1971).

METAMORPHIC ROCKS :

These units outcrop in Istranca Mountains, Armutlu Peninsula in the east, on the shoreline between Gemlik-Mudanya-Bandırma in the south, northeast of Çan, between Karabiga and Lapseki, south of Çanakkale and in the vicinity of Şarköy-Bolayır on Gelibolu Peninsula. The metamorphic rocks consist of gneiss, schists of various textures and origin, and amphibolite, quartzite, meta-conglomerate, meta-graywacke, marble and partly crystalline limestones. These rock types, also referred to as the "basement" are intruded by granite, granodiorite and dykes of aplite (Ternek *et al.*, 1987).

PALEOZOIC :

UNDIFFERENTIATED :

The non-fossilliferous units comprising conglomerate, sandstone and crystalline limestone set between the metamorphics and younger units, which are mapped as "Paleozoic Undifferentiated". It unconformably overlies the crystalline schists in the vicinity of Sakarya river and eastern parts of the Armutlu Peninsula. The Paleozoic sediments are observed usually in yellowish colors, and feldspathic, with a poor fossil content. They are represented by sandstones and conglomerates (Ternek *et al.*, 1987).

ORDOVICIAN :

İstanbul-Kocaeli region is known to be one of the best outcrop area for Ordovician deposits in the Marmara area. This period is represented largely by conglomerate, quartzitic sandstone (partly pink), graywacke and shales (Ternek *et al.*, 1987).

SILURIAN :

The fossilliferous Silurian units are observed east of Bosphorus and on the Kocaeli Peninsula striking N-S. The Silurian unit in the eastern part of Bosphorus consists, from base to top, of the following: 1- siltstone, claystone, sandstone and red conglomerates of arkosic composition, 2- orthoquartzite, 3- siliceous shale and graywacke, 4- subarkose and 5- reefal limestone unit which is grayish-black, and its fossil content essentially consists of algae and biostramol coelenterate (Ternek *et al.*, 1987).

DEVONIAN :

The dark blue and coral limestones of the İstanbul region are dated as either Silurian (Late) or Upper Devonian. These limestones are also widespread the southern parts of Kocaeli Peninsula and are differentiated as Silurian-Devonian. The Devonian rocks of the region are represented by graywackes, limestones and sandstones, shales, slates, sandy mudstones and also schists cropping out in especially north-eastern corner of the Marmara Sea. Devonian is well preserved in the coastal areas of the Bosphorus (Ternek *et al.*, 1987).

CARBONIFEROUS :

The lower series consists of blue limestone, slate, graywacke and sandstones. Carboniferous rocks, previously attributed to the Devonian, is stated to consist of the following formations: 1- nodular limestone, 2- radiolarite -siliceous schist, 3- plant bearing slate, graywacke (locally with limestones), 4- conglomerate, sandstone and graywacke, 5- Cebeciköy slate-graywacke, 6- Cebeciköy limestone, and 7- Cebecikoy siliceous schists. Carboniferous unit is outcropped in around Golden Horn directed to NW (Fig. 1.4) (Ternek *et al.*, 1987).

PERMIAN :

Permian rocks outcrop north and east of Bursa plain, in the region lying between Inegöl and Yenişehir plains, south of Manyas, east of Armutlu Peninsula and along shores of Sakarya river bed. Permian units outcropping in northern parts of Dışkaya Mountains are represented by limestones of a dark blue color, fractured, frequently crystallized, occasionally oolitic or massive. The dark sandstones on the Osmaneli-İznik road are of Permian age. This unit is outcropped in especially southern part of the Marmara Sea far away from the coast (Ternek *et al.*, 1987).

MESOZOIC :

UNDIFFERENTIATED AND OPHIOLITIC SERIES :

The undifferentiated units of Mesozoic age consist of white, pink, gray limestones with a fine grained texture located around the southern shore area of the Marmara Sea. Ternek *et al.* (1987) have figured out the presence of the ophiolitic series in Mesozoic age consisting of serpentinite, peridotite, pyroxinite, harzburgite, diorite, gabbro, splite, diabase, andesite and basalt in the southern parts of the Marmara Sea (Fig. 1.4).

TRIASSIC :

It outcrops in Kocaeli Peninsula, in Iğdır village lying north of Bursa plain, between Biga and Çan, and in the area lying between Yalova and Karamürsel south of İzmit Gulf. The Triassic consists of splite and graywackes with blocks of limestones metamorphosed incipiently. It is intruded by granites and granodiorites of pre-Upper Triassic age (in Biga-Çan area). The units of Triassic age consist, from base to top, of gray carbonate sandstones, ophiolite bearing yellow limestones, conglomerates and compact sandstones bearing brachiopods in vicinity of Iğdır village. It consists of red sandstones and conglomerates with some other outcrops in the Yalova-Karamürsel area and Kocaeli Peninsula.

The Triassic formation starts with a transgression ending up with a regression (Ternek *et al.*, 1987). The observed lithologies from base to top are reported by Ternek *et al.* (1987) as following: 1- basal conglomerates and sandstones nonfossiliferous, 2- sandstone, marly-limestone, 3- nodular limestones intercalated with thin marls, 4- limestones of a nodular appearance, 5- gray-green shales and 6- yellow to yellowish brown sandstones, containing plant remains, and unconformably overlain by the Upper Cretaceous basal conglomerates (Ternek *et al.*, 1987). These rock series of the Triassic have been found usually in the east-northeastern and partly in the southern adjacent areas of the Marmara Sea (Fig. 1.4).

JURASSIC :

The Jurassic rocks are represented by red marly limestones and greenish sandstones with intercalations of tuffs, fossilliferous sandstones, cherty limestones and breccias, near the southern shore of the Marmara Sea. In general, the lithologies of the Jurassic units are, from base to top, basal conglomerates and sandstones, marls and cryptocrystalline limestones (Ternek *et al.*, 1987).

CRETACEOUS :

This unit consists mainly of radiolarian limestone, radiolarite, sandstone and flysch in the southern shore of the Marmara Sea, and northeast Istranca Mountains. Volcanic facies of Upper Cretaceous consists of dark green to brown, fine to coarse grained sandstones with intercalations of tuffs and lava flows in the northeastern part of the Marmara Sea. Cretaceous limestone facies contain rudists and volcanic facies and is locally covered by cherty limestones of Maestrichtian age. The Upper Cretaceous flysch in southern shore of the Marmara Sea consists of sandstone with cross-bedding, marl, shale and conglomerate alternations with fossils. In Istranca Mountains, lithologies are, from base to top, 1- conglomerate-sandstone, 2- blue limestone, 3- Orbitolina limestone and 4- an alternation of limestone, marl, andesite and sandstone (Ternek *et al.*, 1987).

CENOZOIC :

TERTIARY :

It is observed in depressional basins, preserved in marginal areas and as a comprehensive series in Thrace basin (Fig. 1.4). This unit consists of flysch -of which the lower parts are intercalated with andesite, basalt and tuffs-, lava, agglomerate, limestone, conglomerate and sandstone, reefal limestone and detritic facies, marl. Paleocene units are represented by white marls and marly limestones, shales. Eocene flysch consists of alternations of conglomerates, sandstones and locally represented by fossilliferous limestones. Oligocene unit outcrops south of the Marmara Sea and Thrace. The unit, between Gemlik and Bursa, consists of bituminous and gypsyferous series at the base and is over-lain by Muratoba series which consists of conglomerate, sand-stone, coal and plant bearing horizons, and variegated marls consisting of alternations of marls and sandstones. Oligocene is mainly represented by volcanics in the Biga peninsula. Upper flysch (Oligocene in age) in Thrace consists of sand-stone, marl, tuff, thin bedded volcanogenic limestone and conglomerate. Continental Oligocene consists of lagoonal limestones with clay interbeds. Lower part of marine Oligocene consists of marls and shales and the upper unit of lignite bearing sandstones. Lower Eocene unit consists of sandstones and limestones with marl intercalations containing fossils and this unit overlies andesites and andesitic tuffs. Middle Miocene units were differentiated as; sandstone, conglomerate and marl; limestone with abundant shell fragments; sandstone and marl from base to top (Ternek *et al.*, 1987). The lower unit consisting of sandstone, conglomerate and marl unconformably overlies red sandstones and red limestones of Upper Oligocene age. The Tortonian unit consists of fossilliferous gray marl, yellow sandy claystone, gray-green sandy clay with pecten of limestone. Sarmatian-Pontian units consist of limestone and sandstone with Congeria; marls, limestone and marly limestone; sands and gravels with bones; clay and marls; limestones with Mactra from base to top. Green plastic clays; quartz sands with minor gravels; fine grained sand, clayey and with white mica flakes; marls with white shells of molluscan and Mactra; limestone bands with Melanopsis and Mactra. Sarmatian-Pontian units of the Çekmece lakes consist of conglomerate, sand, gravel, clay and marl in the lower, and alternation of marl and marly limestone in the medial and of limestones and thin marl beds in the upper sections. Sarmatian-Pontian units of the İmroz Island outcrop in the SE and SW parts and consist of disintegrated sandstones with intercalated horizontal beds of marls. Marine Miocene units which differently changes from place to place are represented by, from top downward; Mactra limestone, sandy clays, sandy and micaceous red marls, lagoonal limestones with lignite and petroleum odor; Sandstone, conglomerate, clay, marl, limestone, sandstones with thin lignite beds, gray-blue clay and sandstones with lignite and gypsum; marine limestone, clay marl, basal conglomerates, variegated marls and sandstone (Ternek *et al.*, 1987). Continental Neogene is especially seen south of Marmara Sea around plains. This unit consists of from base to top; conglomerate continental marly limestone, lagoonal limestone, travertine, marl, sandstone, and limestone, marl. Continental Pliocene unit consists, from base to top, of conglomerate, sandstone, clay, marl and lagoonal limestone. The continental Pliocene consists of gravel, sand and marls outcropping at hills, slopes and depressions with thicknesses locally exceeding 100 m, in the Ergene basin of Thrace (Ternek *et al.*, 1987).

QUATERNARY :

Plio-Quaternary unit may be seen on the northern Kocaeli Peninsula, Ergene basin of Thrace and Gelibolu Peninsula. The unit consists of lagoonal and fluviatile sediments covering large areas in northern parts of Kocaeli Peninsula and is represented by indurated sand, clay and gravels. Pleistocene (old alluvium) forms a terrace made up by soil in the Ergene basin seen in the slopes of large valleys of Pliocene age. Holocene (new alluvium) represented by stream sediments consisting of gravel, sand, clay and soil. It is well-developed in Thrace covering beds of valleys and tributaries of Ergene ad Hebrus rivers. It is also observed in depressional areas such as in the southern part of the Marmara Sea (Ternek *et al.*, 1987).

Ternek *et al.* (1987) have reported the occurrence of marine Quaternary deposits in the south of İzmit Gulf and southern shores of Dardanelles. These deposits consist of yellowish, in color, badly cemented fossilliferous sand overlain by a conglomeratic sandstone with fragmented shells of fossils. They also reported the presence of undifferentiated continental Quaternary deposits which consist of sand, gravel and cobbles sometimes alternating and generally with lateral and vertical gradation and travertines varying in thickness are encountered in Bursa and Armutlu Peninsula.

1.3. ATMOSPHERIC SETTING

The Marmara region is affected by two distinct seasonal climatic regimes (Ünlüata *et al.*, 1990). During the winter, the weather is dominated by an almost continuous passage of cyclonic systems. In the summer period, northeasterly winds from the Black Sea are dominant. The systems affect the region for periods between three to ten days, and often result in winds of 8 m/s to 10 m/s (hourly average speeds) sustained over one to two days. Maximum speeds of 35 m/s have been observed as gusts. These are also reported by DMIGM (1989) and illustrated in Fig. 1.5.

On an annual basis, northerly winds (from the NW-NE sector) are dominant with a frequency of 60 %, with southerlies (SW-SE sector) occurring 20 % of the time (De Filippi *et al.*, 1986). However, during the winter, winds from either

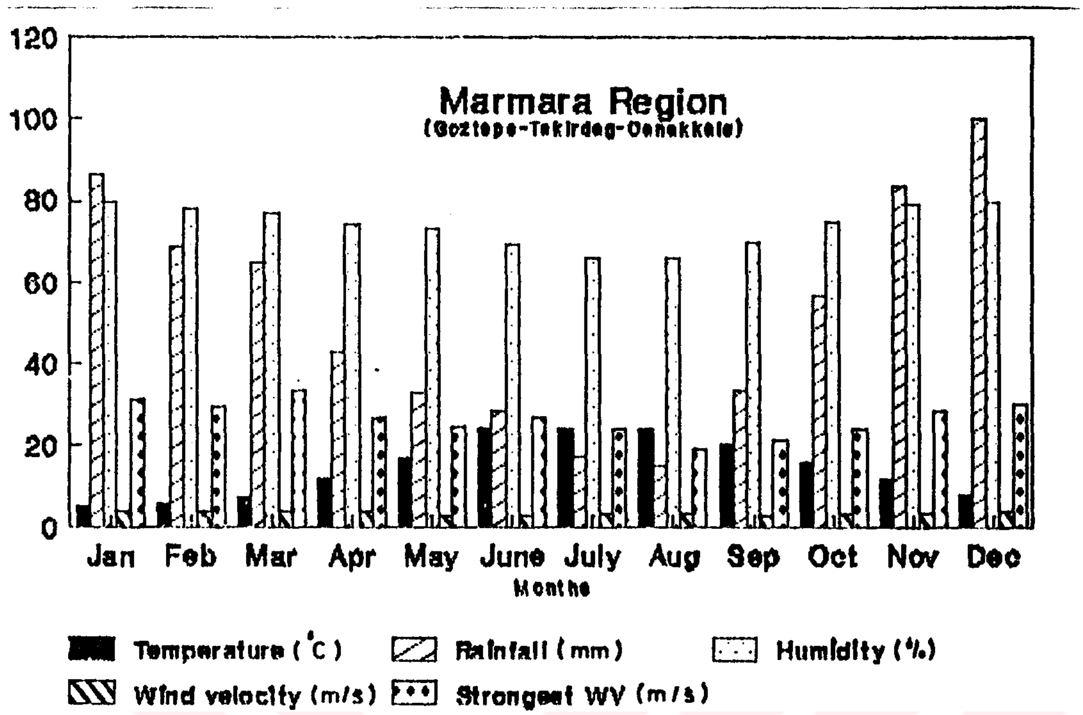


Figure 1.5 : Meteorological parameters through the over 50 years period (Based on data by DMIGM, Meteorological Monthly Bulletin, 1989).

sector are equal in both frequency and strength. In winter (December-March) during 1985-1987 years, the mean frequency was 35 % for each of these directions (Büyükay, 1989). The monthly wind velocity ranges between 2.9 and 4.2 m/sec with an annual mean of 3.6 m/sec. The strongest wind velocity is about 33.1 m/sec during the late winter (DMIGM, 1989).

The annual mean air temperature based on over 50 years period ranges from 5 °C in winter and 24 °C in summer with an average value of about 14.4 °C (DMIGM, 1989).

The annual mean rainfall over 50 years period is about 52.5 mm in average for three stations in the Marmara Region (Fig.

1.5). Rainfall occurs mostly during October through March, leading to a precipitation of 7 km^3/yr over the Marmara Basin (DMIGM, 1989). The mean evaporation is estimated as 11 km^3/yr (Özsoy *et al.*, 1988). These fluxes are negligible in comparison with the exchange flows of adjacent basins (Ünlüata *et al.*, 1990).

The monthly mean humidity which is also based on measurements during over 50 years period ranges from 66 to 80 % with an annual mean of about 74 % (Fig. 1.5).

1.4. OCEANOGRAPHY

The Marmara Sea shows a transitory character between Black and Aegean Seas, thus, the water column in the Marmara Sea consists of the two distinct layers displaying highly different properties, derived from their respective basins of origin, the Black and Mediterranean Seas (Latif *et al.*, 1990). Therefore, the physical oceanography of the Turkish Straits is closely related, by its very existence, to the variations in the hydrological regimes of the Black and Aegean Seas (Baştürk *et al.*, 1988, 1990; and Özsoy *et al.*, 1988). In general terms, the temperature of the upper layer undergoes greater changes in response to the surface heating/cooling (Ünlüata *et al.* 1990). In winter, from November till May, the surface layer becomes colder than the lower layer with temperatures decreasing to about 4 °C. After May, the temperature of near-surface levels increases to 24 °C as a result of radiative heating (Ünlüata *et al.*, 1990). The upper layer salinity varies within the range of 16-18 ppt in the Bosphorus and 23-28 ppt in the Dardanelles through the year (Fig. 1.6).

This upper layer has a high oxygen content, corresponding to near saturation or supersaturation (Fig. 1.7). On the other hand, the properties of the lower layer do not vary, except on the micro structure scale, due to lack of interaction with either the atmosphere or the upper layer. The potential temperature and salinity of the lower layer in the deeper part of the basin are in between 14.3-14.4 °C and 38.55 ppt respectively (Latif *et al.*, 1990). They pointed out that the water mass in the lower layer is renewed by the inflow having higher salinity water through the Dardanelles to the basin and the inflow is also a source of oxygenated water at various levels below the halocline to the basin. It is crucial in preventing the sea from becoming anoxic in the lower layer (Latif *et al.*, 1990).

The upper layer renewal time is about 4 months and lower layer an overall time scale of about 6 years (Latif *et al.*, 1990). The water mass in the eastern half of the sea has a salinity of 38.56 ppt and lower oxygen content of 0.8 ml/l between the depths of about 200-500 m. Baştürk *et al.* (1990) concluded that due to its permanently stratified character, sub-halocline water masses of the Marmara Sea are continuously depleted in dissolved oxygen.

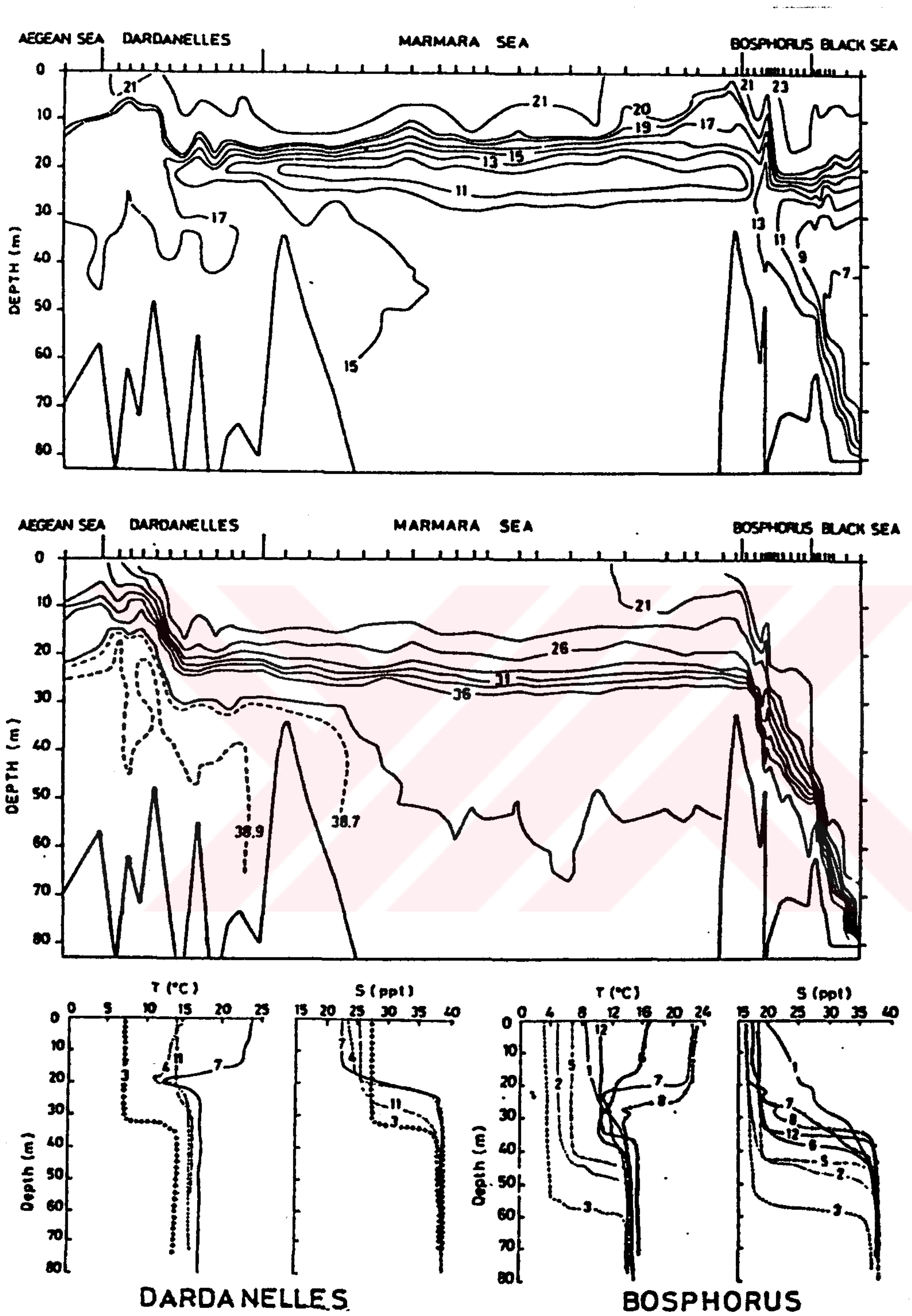


Figure 1.6 : The longitudinal variation of salinity and temperature transects in the Turkish Straits Systems during July, 1986 (from Ünlüata, *et al.*, 1990).

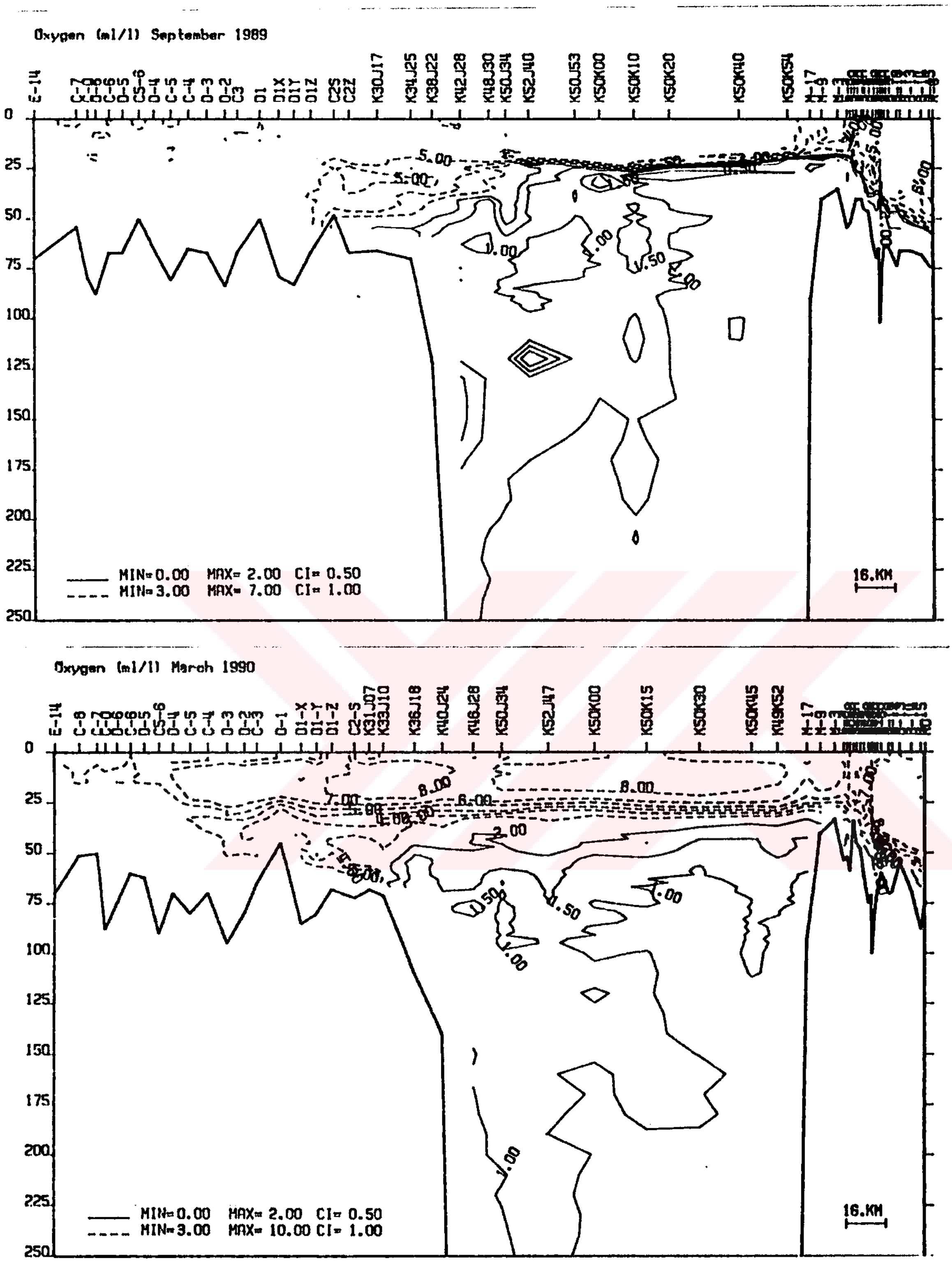


Figure 1.7 : Oxygen transects through the Sea of Marmara, from Bosphorus (st.K0) to the Aegean Sea (st.E14) (Reproduced from unpublished data of METU-IMS, 1989, 1990).

Oxygen-minimum layer located between 200-300 m depth interval is a permanent feature of the Marmara Sea. On the other hand, DO content of water masses deeper than 800 m decreased rapidly from 1.3-1.4 mg/l level to about 1.0-1.1 mg/l level during winter period of 1987 and then increased to its normal level within the following period.

The DO content of this layer increased continuously to 1.5-1.7 mg/l level after mid-1988 till the end of 1989 period. The existence of denitrification or ammonification processes dominating under low oxygen conditions within the subhalocline layer of the Marmara Sea has to be proved by field experiments (Baştürk *et al.*, 1990). Less saline (20-22 ppt) Black Sea waters inflowing through Bosphorus upper layer is underlain by more saline (≃38.9 ppt) bottom waters of Aegean origin inflowing through Dardanelles lower layer. These two water masses of different densities form a body of water which is permanently stratified at about 25-30 m depth (Baştürk *et al.*, 1990). Deep water masses of the Marmara Sea are oxygenated only by the influx of well-oxygenated Aegean Sea water masses. However, it has been noted (Ünlüata and Özsoy, 1986), that this influx of oxygenated waters through Dardanelles underflow is not sufficient to re-aerate and balance the oxygen consumption of organic matter that sinks into deep layers of the Marmara Sea. The result is the formation of water masses which are permanently depleted in oxygen content. Ünlüata and Özsoy (1986) and Özsoy *et al.* (1988) showed that some fraction of the inflowing Dardanelles bottom waters sinks down to 100-300 m and occasionally, down to the bottom depending on the meteorological and hydrographic conditions affecting the region. These water masses become depleted in dissolved oxygen as they are transported towards the northeastern basin of the Sea of Marmara. The largest oxygen deficiencies are observed within the sub-halocline water masses of the eastern basin due to the imposition of oxygen utilizations caused by the sinking particulate organic matter of allocthonous and authochthonous origin over already oxygen-depleted deep water masses (Baştürk *et al.*, 1990). Sub-halocline waters of the BMJ region receives not only the sinking organic particles produced within the photic zone, but also those introduced through the Bosphorus upper layer flow, domestic and industrial waste discharges of Istanbul Great Metropolitan Area. These inputs of organic matter are responsible factors for high oxygen deficiencies observed in this section of the Marmara Sea (Baştürk *et al.*, 1990).

In the shallow parts of the basin, the total suspended solid distribution is due to the general current system and to the meteorological conditions (Fig. 1.8). As seen on Figure 1.8, their concentrations generally exceed over 2 mg/l in around deep basinal areas, in the Bay of Bandırma and off Kocaburun Baştürk *et al.* (1988) reported that spatial variability of surface total suspended solid (TSS) levels indicate the dynamism of the BMJ region which greatly effects the surface distributions of TSS and other related parameters like Chl-*a* and humic materials. They also found that the surface distributions of TSS show some patchy characters in that region, but general distribution of TSS is closely related to the direction of the Bosphorus surface flow.

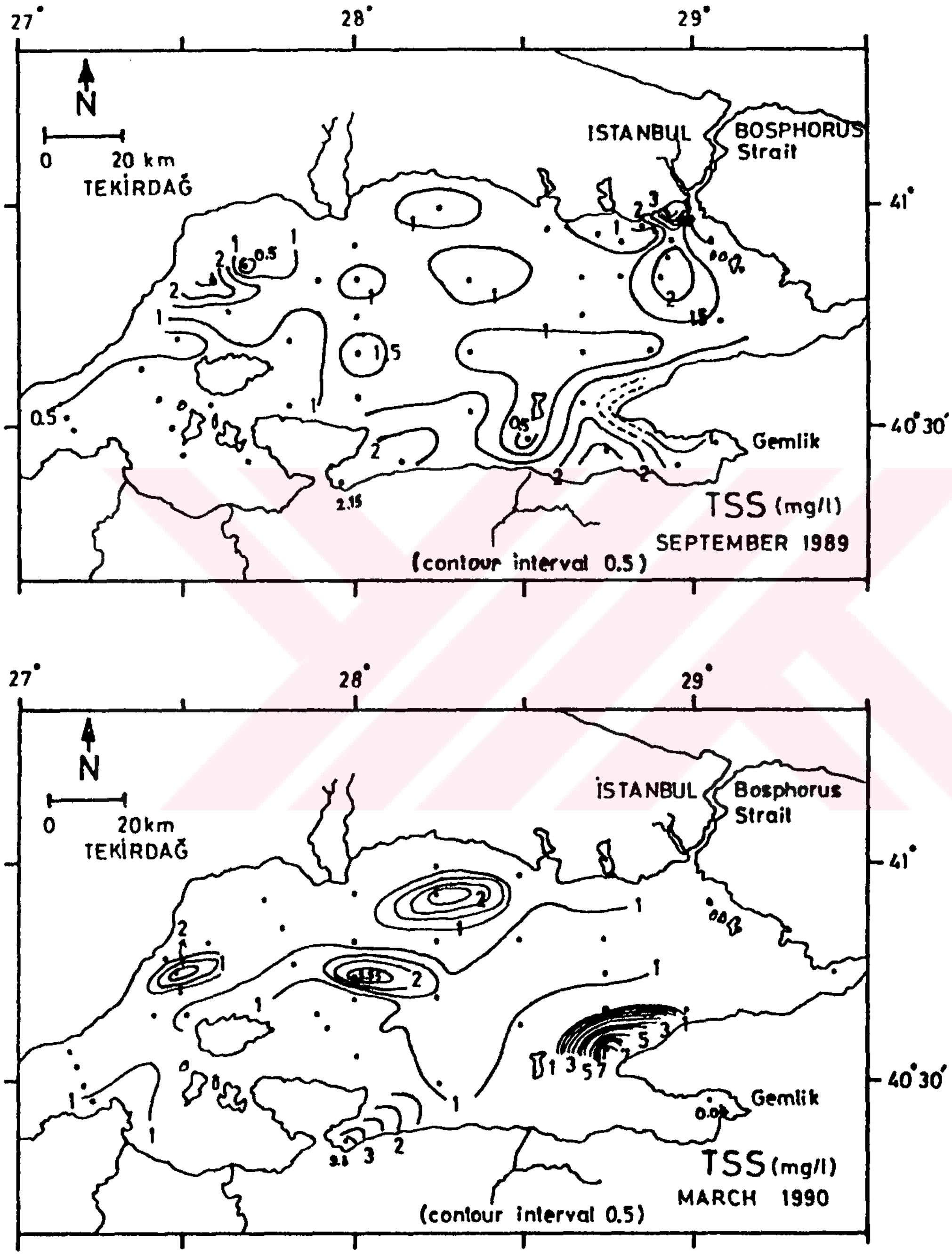


Figure 1.8 : Total suspended solid distribution in the surface water through the Sea of Marmara (Reproduced from unpublished data of METU-IMS, 1989, 1990).

1.5. PURPOSE OF STUDY AND PREVIOUS WORKS

The main purpose of this study was to document the types and modes of distribution of recent bottom deposits of the Sea of Marmara and its straits (Bosphorus and Dardanelles),in response to various geological, biological, chemical and physical oceanographic conditions prevailing in this region.

The physical and chemical oceanography of the Marmara Sea and its straits have been monitored by METU-IMS, since 1985. Numerous works have been reported on the physical (*e.g.*, Ünlüata and Özsoy, 1986; Özsoy *et al.*, 1986, 1988; De Filippi *et al.*, 1986; Oran, 1986; Sur, 1988; Oğuz and Sur, 1989; Latif *et al.*, 1990; Yenigün and Albek, 1990, and Ünlüata *et al.*, 1990), chemical (*e.g.*, Artüz and Baykut, 1986; Baştürk *et al.*, 1988, 1990; Göçmen, 1988; Bizsel, 1988; Kubilay, 1989; and Polat, 1989), biological (Demir, 1954; Tortonese and Demir, 1960; Caspers, 1968; Müller, 1985; Bingel and Ünsal, 1986; Ünsal and Uysal, 1988; Uysal, 1987, and Güre, 1990) aspects of the Marmara Sea and Turkish Straits.

However, surprisingly, little is known on the types and modes of distribution of Recent (mainly Late-Holocene) sediments and their geochemistry in this sea. Thus, the Sea of Marmara has increasingly received attention, also because it connects the world's largest anoxic basin (the Black Sea) in the world with an evaporitic basin (the Mediterranean Sea), as well as, it behaves like a trap for sedimentary materials under various physico-chemical conditions. Earlier works concern with the coastal morphology and shore deposition of the Sea of Marmara (Ardel and İnandık, 1957; Ardel and Kunter, 1957). The palynology of the deep-sea sediments from the western Marmara Basin were firstly investigated by Koreneva (1971). For the purpose of a sea-floor engineering survey, the surficial sediments from the Marmara-Bosphorus areas were analyzed for their grain-size distribution and the results are presented in DAMOC (1971). The sediment distribution maps available by the Turkish Navy Hydrographic Office (in Adatepe, 1988), reveal very limited information on the composition of sediments there. The mineralogy of shelf sediments from some selected stations in the northern Marmara Sea are investigated by Emelyanov (1972). Further studies included the sea floor sediments of the Beykoz Bay in Bosphorus (Bakkalsalihoğlu and Yüce, 1984), the deltaic sedimentation of Kocasu River (Algan and Akbulut, 1985) and the lagoonal sediments of Küçükçekmece (Algan, 1987).

Later, Stanley and Blanpied (1980) studied core sediments from the eastern Marmara Basin and discussed their results with reference to the water exchanges between the Black and Mediterranean Seas. Recent sediments of the Sea of Marmara was reviewed by Ergin and Evans (1988). Further data on geochemistry and micropalaeontology of the deep-sea sediment from the eastern Marmara Basin was introduced by Evans *et al.* (1989). Micropalaeontology of foraminifers in the deep-sea sediment cores from the eastern Marmara are outlined by Alavi (1986, 1988). Yemenicioğlu (1990) has recently studied the basin scale fate of mercury on both sediment and water samples from the Marmara Sea and Turkish Straits. The compositional distribution and the depositional processes of sediments from the northeastern and south-western parts of the Marmara Sea (including canyon regimes of Dardanelles and Bosphorus) were investigated by Ergin *et al.* (1991a). Further investigations on sedimentary and geochemical processes are from the northeastern Marmara (Ergin and Yörük, 1990; Ergin *et al.* 1991b). Information on the geology and modern sedimentation from the Golden Horn estuary can be found in works of Sayar (1977), Yalçınlar (1977), Meriç *et al.* (1988), and Ergin *et al.* (1990a).

Furthermore, sediment studies are concerned with the Late-Quaternary seismic stratigraphy in the Strait of Bosphorus (Okyar, 1987; Uluğ *et al.*, 1987 and Alavi *et al.*, 1989). Akal (1987) and DAMOC (1971) provided a preliminary knowledge on the Quaternary marine geology of the northeastern Marmara Sea using seismic reflection profiling. The geophysical studies in the Marmara Sea and its surroundings were also performed by many authors (Crampin and Üçer, 1975; Üçer et al., 1985; Evans *et al.*, 1985; Crampin and Evans, 1986; Eyidoğan, 1988; Ergün *et al.*, 1989 and Ergün, 1990). Recently, the geophysics of the Marmara Sea was reviewed by Adatepe (1988), but with no special reference to the areas of this study.

CHAPTER TWO

2. MATERIALS AND METHODS

Materials used in this study were collected by using both grab and corer devices and the sediment samples obtained were subjected to granulometric (grain-size analyses), petrographic (determination of sedimentary components in gravel and sand fractions of sediments by using binocular microscopy) and chemical (organic-carbon, carbonate and heavy metal analyses) investigations.

2.1. SAMPLING OF THE SURFACE SEDIMENTS

A total of 209 surface sediment samples were collected with a *Dietz LaFonde* grab during the 1988-1990 cruises of **R/V Bilim** in the Sea of Marmara. Stations of the sampling locations for whole Marmara Sea and its straits are shown in Fig. 2.1 and regional sampling locations are also shown in Fig. 2.2. Their coordinates are listed in Tables (3.1 to 3.6). Sediment samples immediately after their collection are placed into plastic bags and kept frozen until their further analysis in the laboratory.

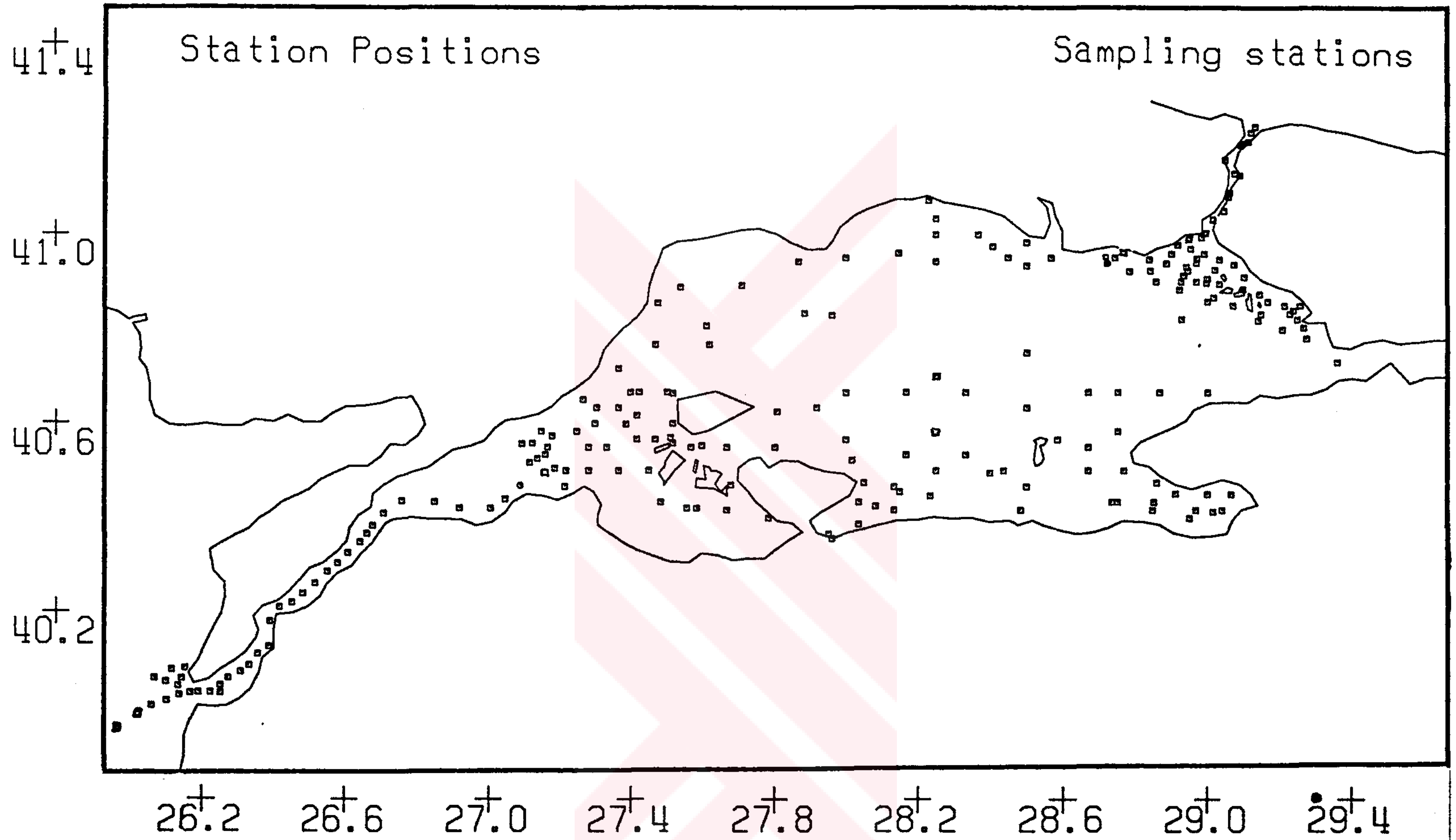


Figure 2.1 : Map showing sampling stations of the surface and core sediments from the Sea of Marmara and its Straits (Bosphorus and Dardanelles).

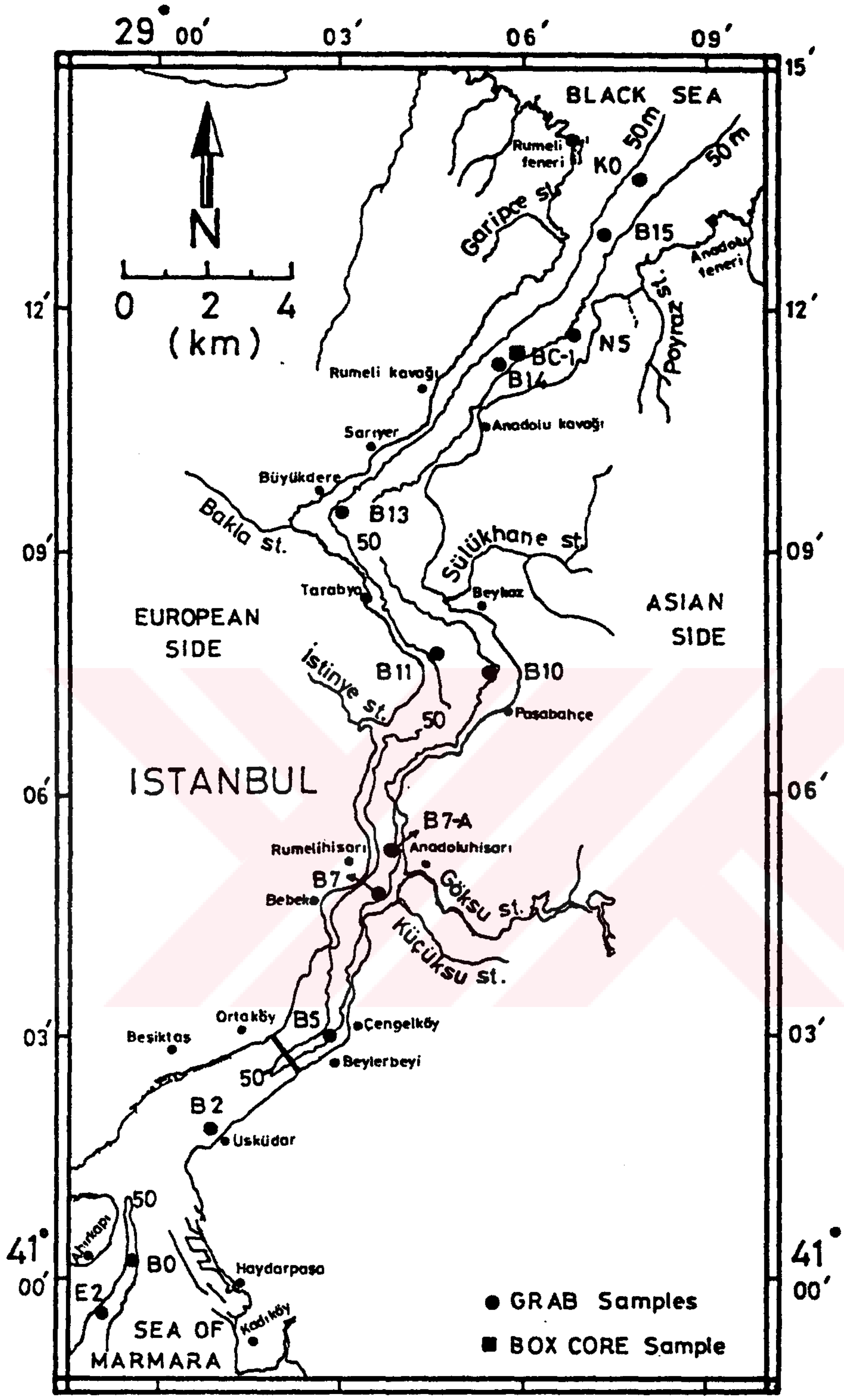


Figure 2.2 : Regional Maps showing sampling stations of the surface and core sediments.

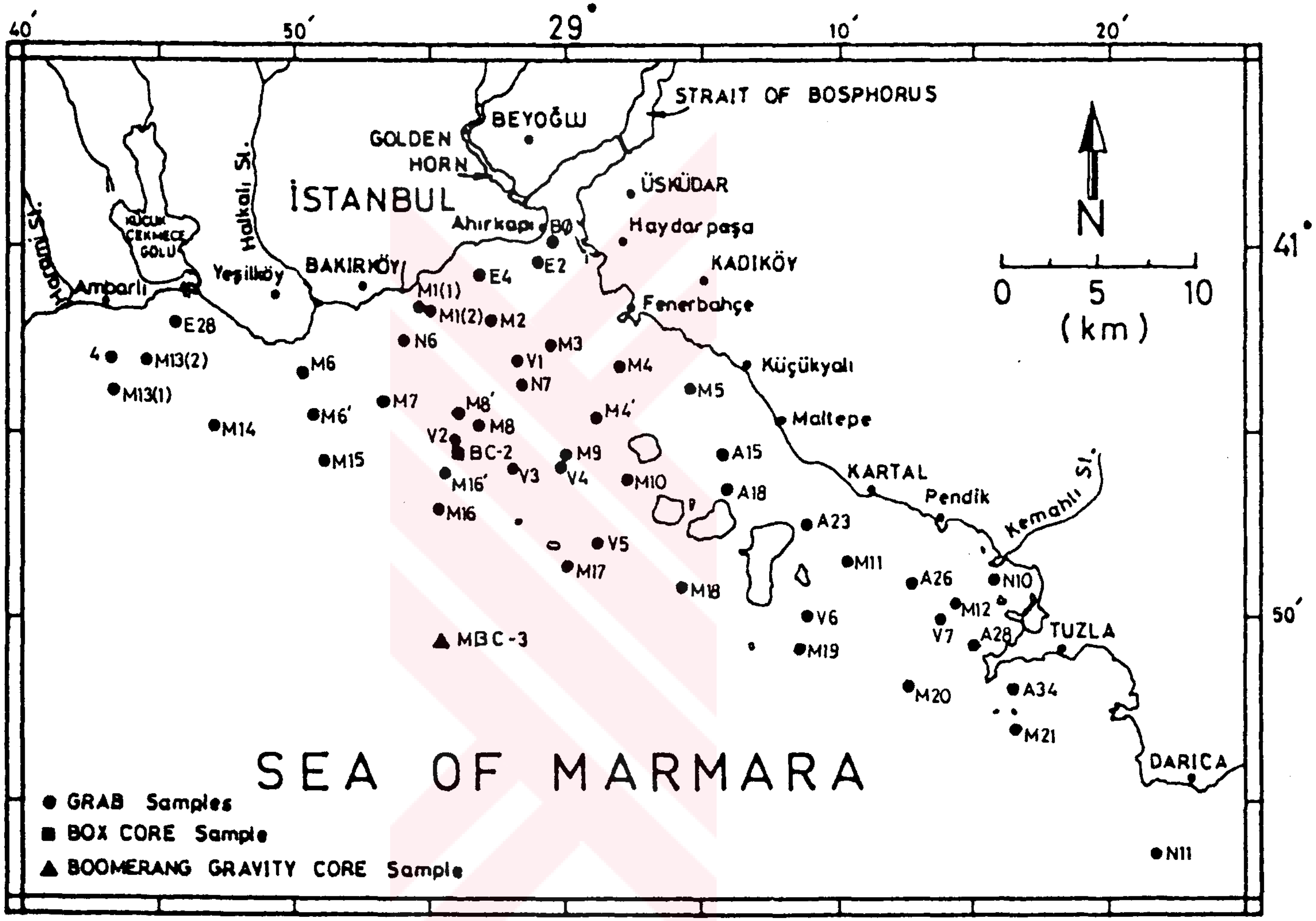


Figure 2.2 : Continued (b).

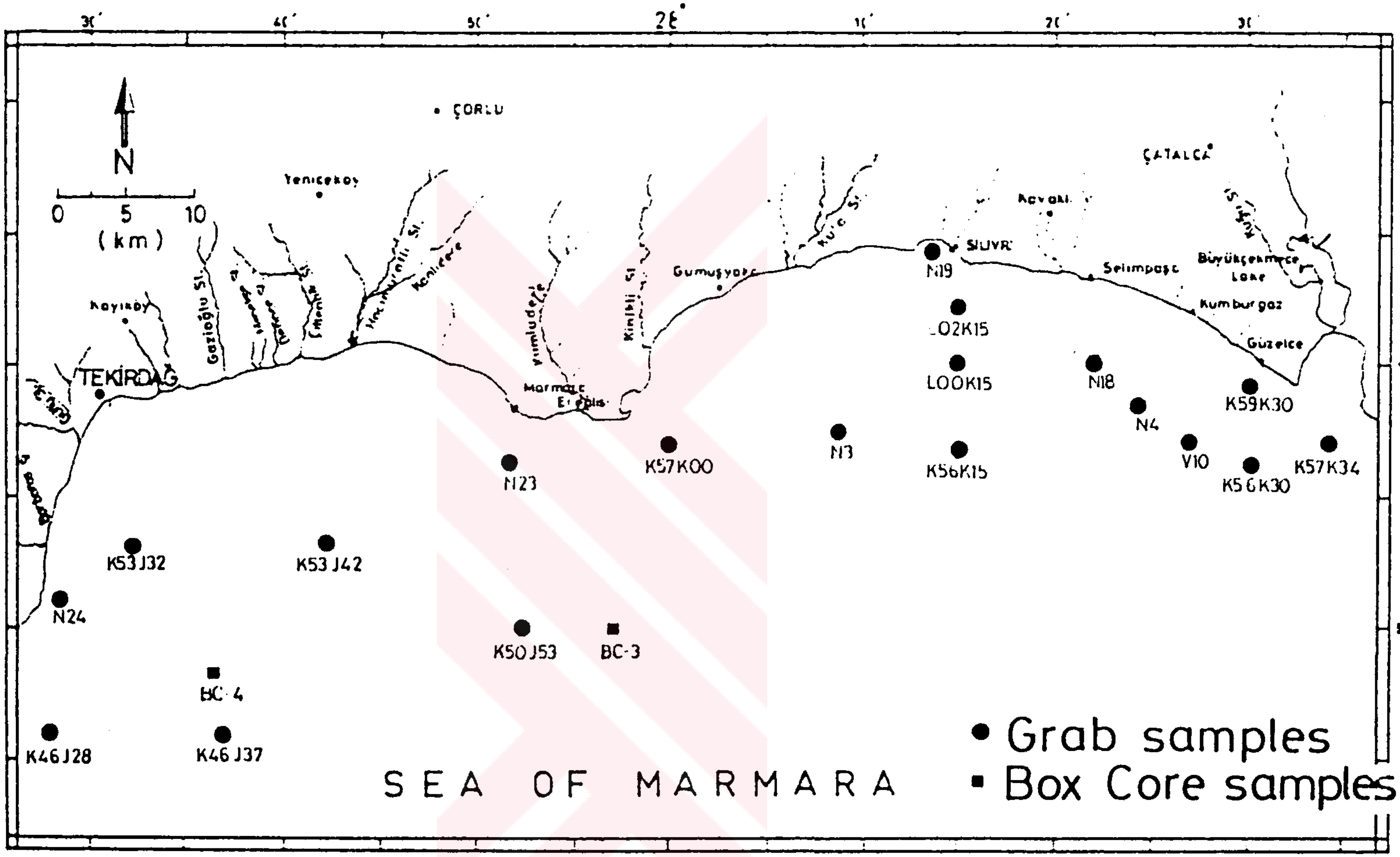
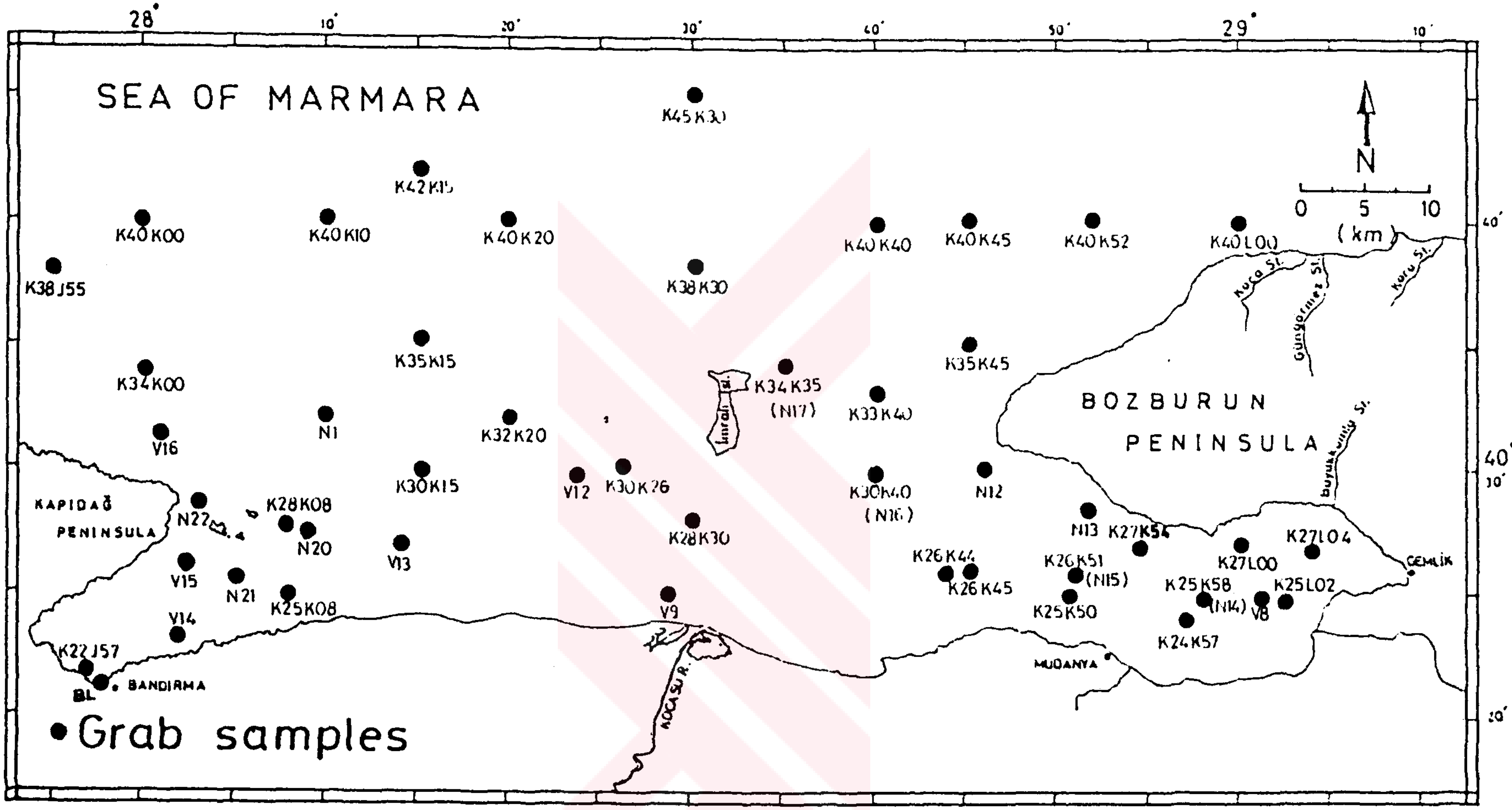


Figure 2.2 : Continued (c).



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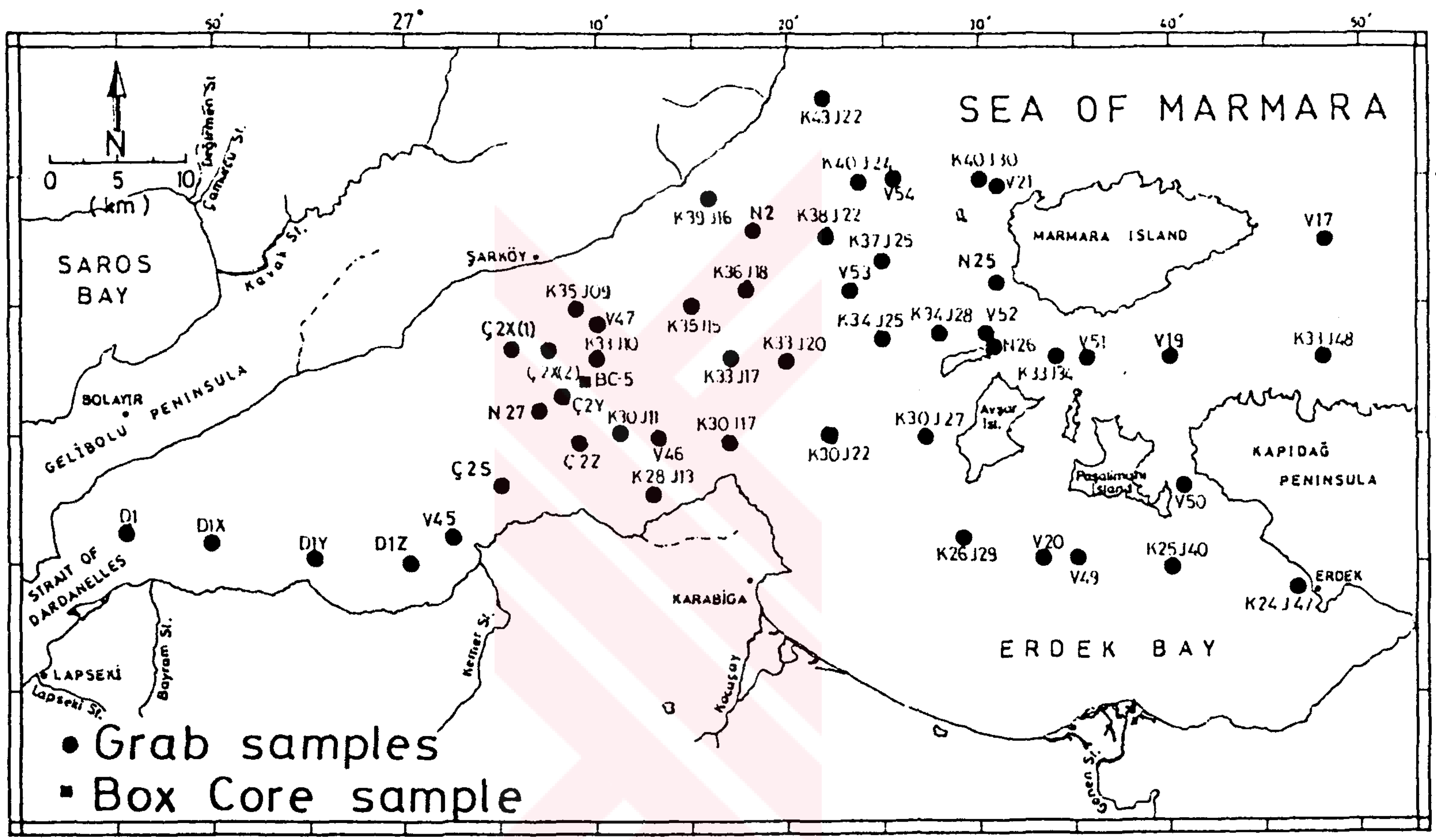

Figure 2.2 : Continued (e).

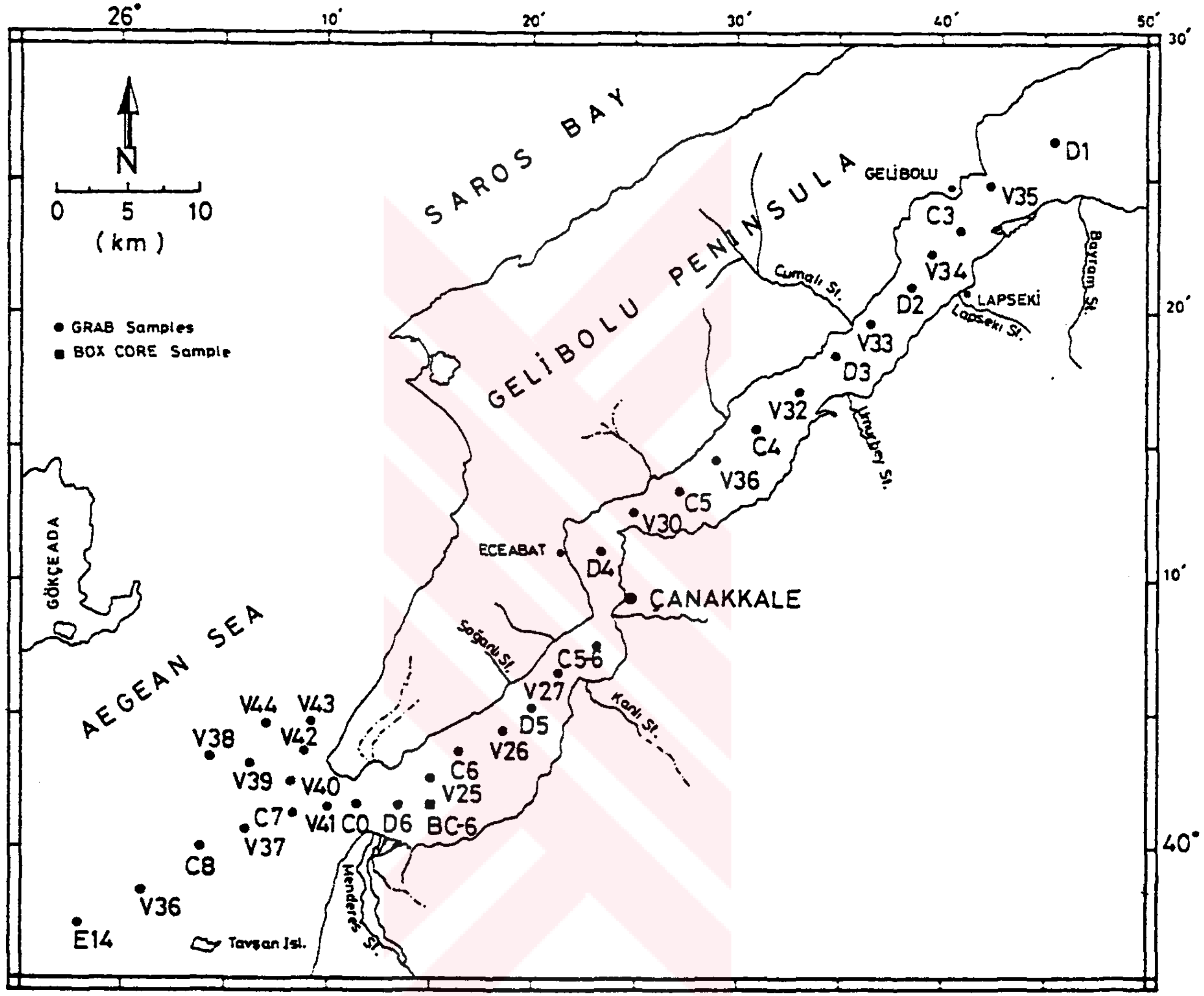

Figure 2.2 : Continued (f).

Also, at the time of sediment sampling, many other parameters, such as salinity, density, temperature, dissolved oxygen, TSS, nutrients, Chl-α, and humic matter are measured in the water column of stations.

2.2. SAMPLING OF THE CORE SEDIMENTS

In 1984, three boomerang gravity cores were collected from the eastern Marmara Basin and results from two of these cores (M1 and M4) were already presented in Ergin and Evans (1988) and Evans *et al.* (1989). The third core (MBC-3, about 80 cm long) was analyzed in this work. In addition, sediment samples are obtained at six stations with an **Soutar Box** Corer (Ocean Instruments Mark III; approximately 50 cm^3), during the **134-13** leg cruise of **R/V Knorr** in the Sea of Marmara and Turkish Straits. All the cores are kept frozen and, in the laboratory, are split at 2 cm intervals. The locations, coordinates and the water depths of coring stations are shown in Fig. 2.3 and Table 2.1).

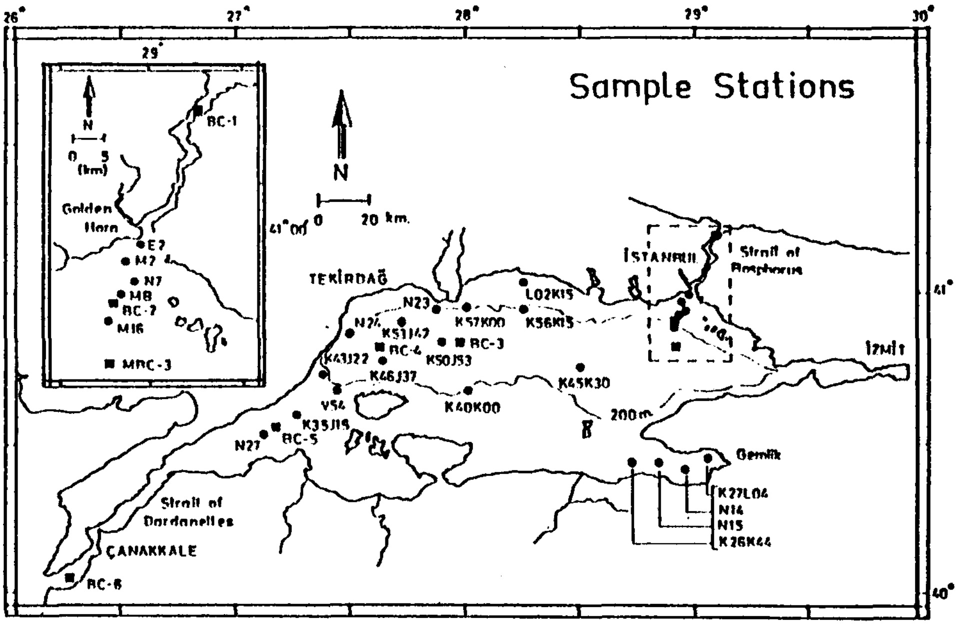

Figure 2.3 : Map showing the locations of surface and core sediments used for geochemical analysis.

Table 2.1 : Core locations with water depths (m) and lenghts (cm) of the sediments recovered.

Core St.	Water Depth	Latitude	Longitude	Core Length
BC-1	54	41°11'29"	29°05'55"	18
BC-2	64	40°54'48"	28°56'03"	46
MBC-3	1200	40°49'15"	28°55'36"	80
BC-3	1226	40°49'48"	27°57'35"	54
BC-4	1106	40°48'26"	27°36'35"	58
BC-5	65	40°32'02"	27°09'37"	48
BC-6	74	40°01 37	26°15 09	28

2.3. LABORATORY PROCEDURES

The laboratory works include petrographic (*i.e.*, grain-size, microscopy) and chemical (organic carbon, carbonate, and heavy metals) studies on the both surface and core sediment samples. Estimation of the sedimentary components in sand and gravel fractions was done using binocular microscope.

2.3.1. GRAIN SIZE ANALYSES

Grain-size analyses were performed using the wet/dry sieving and pipette methods according to the standard procedures outlined by Folk (1974). Representative subsamples were separated into coarse and fine fractions by means of wet-sieving through a 63 μ mesh-size sieve using distilled water. Washing of the samples was continued until there was no sediment passing through the screen. The material passing through the sieve (smaller than 63 μ; silt and clay) was temporarily stored in a beaker of suitable size for the subsequent pipette analysis. The material retained on the sieve (63 μ) was transferred to the small evaporation dish and oven-dried at about 105 $^{\circ}$C overnight, for dry-sieving. During the dry-sieving, the coarse material (>63 μ) was further divided into different size classes with 1/3 Ø intervals using set of standard sieves.

The sediment fraction (silt and clay) that passes through the 63 μ-sieve was obtained during the wet-sieve process. For the pipette analysis, 10 ml of dispersing agent [which was previously prepared by dissolving of 35.70 gram of sodium hexametaphosphate and 7.94 gram of sodium carbonate in distilled water and diluted to one liter volume (Guy, 1969)] was added to the sample from the previous step and agitated by stirring rod. Then it was allowed to end flocculation of sediment for 24 hours. From this, 20 ml of suspension was obtained with a pipette, with successive withdrawals at 1/2 Ø intervals from 4 to 6 Ø and at full Ø intervals from 6 to 9 Ø with times and depths of withdrawal (Table 2.2).

Table 2.2 : Withdrawal intervals of pipette (from Folk, 1974).

Diameter (Ø)	Withdrawal Depth (cm)	Withdrawal Time at 20° C	Withdrawal Volume (ml)
4	20	20s	20
4.5	20	1m 56s	20
Restirring of sample			
5	10	1m 56s	20
5.5	10	3m 49s	20
6	10	7m 44s	20
7	10	31m 00s	20
8	10	2h 03m 00s	20
9	5	4h 06m 00s	20

The weight percentage distributions obtained from the sieve and pipette analysis of the studied samples were given in Tables 3.1 to 3.6. The textural classification of the sediment samples was based on the distribution of the proportions of gravel, sand and mud (silt+clay) using a triangular diagram (Shepard, 1954 and Folk, 1974). The resulting grain size percentages for each fraction were plotted and the boundary values [percentages and ratios for gravel (0.01, 5, 30, 80 %), sand (10, 50, 90%), sand to mud ratio (1:9, 1:1, 9:1) and silt to clay ratio (1:2, 2:1)] were contoured at those given intervals (Folk, 1974). Consequently, the grain size distribution or related lithofacies maps of the surficial Marmara sediments for each province were prepared by the applying of mapping technique (Folk, 1974 and Lisitzin, 1986) and illustrated in composite maps (Figs. 3.3, 3.4, 3.5, 3.6 and 3.10).

2.3.2. ORGANIC CARBON DETERMINATION

Organic carbon measurement was done 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 sulphuric acid. This method has successfully been applied to marine sediments (Gaudette *et al.*, 1974), although several other techniques are known for organic carbon determination (Bush, 1970; Mills and Quinn, 1979; Froelich, 1980; Krom and Berner, 1983; Hedges and Stern, 1984; Van-Iperen and Helder, 1985; Sandstrom *et al.*, 1986; Kristensen and Andersen, 1987; and Lee and Macalady, 1989). The wet-oxidation method used in this study is not affected by carbonates, but other reducing substances may interfere (El-Wakeel and Riley, 1957). As shown by Gaudette *et al.* (1974), the chloride effect correction is within the experimental errors. However, the recent studies have shown that the existence of great amount of $CaCO_3$ may produce some difficulties in the organic carbon determinations (Emerson and Hedges, 1988).

Oven-dried (60 °C), and powdered sediment samples (0.3 gr) were placed into the 500 ml of Erlenmayer flasks. Exactly 10 ml of 1 *N* $K_2Cr_2O_7$ solution is added to the sample and were mixed by swirling the flask, then 20 ml of concentrated H_2SO_4 (Merck 95-98 % extra pure) were added. The mixture was allowed to stand for 30 minutes. Three standardization blanks without sediment were run with each new batch of samples. After 30 minutes, the solution is diluted to 200 ml volume with distilled water, and 10 ml H_3PO_4 (Merck 85 % extra pure), about 0.2 gr NaF, and 15 drops of diphenylamine indicator were added to the solution. The solution is back titrated with 0.5 *N* ferrous ammonium sulfate solution. This titration process ends up until the solution color changes from an opaque green-brown to green and to brilliant green with adding few drops of ferrous ammonium sulfate solution approaching to the end point, then solution color becomes grayish blue. After the adding one drop of ferrous solution its color suddenly changes to brilliant-green. Hence, the titration process is finished at that end point.

During this work, duplicated analysis were performed for all samples and the results were given as averages of two analysis with the other parameters.

The percentages of organic-carbon were calculated by the following formula;

$$\% \text{ org.C} = 10 * (1-T/S) * [\ 1.0\ N * (0.003) * 100/W\ ]$$

where ;

T = Volume of ferrous solution in ml consumed by sample titration

S = Volume of ferrous solution in ml consumed by blank titration

(The T/S factor will cancel out the effect of the ferrous solution normality)

0.003 = 12/4.000 = meq weight of carbon

1.0 *N* = normality of $K_2Cr_2O_7$

10 = volume of $K_2Cr_2O_7$ (ml)

W = weight of sediment sample in grams

Analytical procedure were performed with duplicated samples and the validity of this method was checked by analysis of the pure standard sucrose ($C_{12}H_{22}O_{11}$, BDH). The calibration curves (Fig. 2.4) were prepared for comparison of the results. The reproducibility of this method was checked by analyzing of three different samples by using seventeen subsamples for each sample. Their results were illustrated in Fig. 2.5.

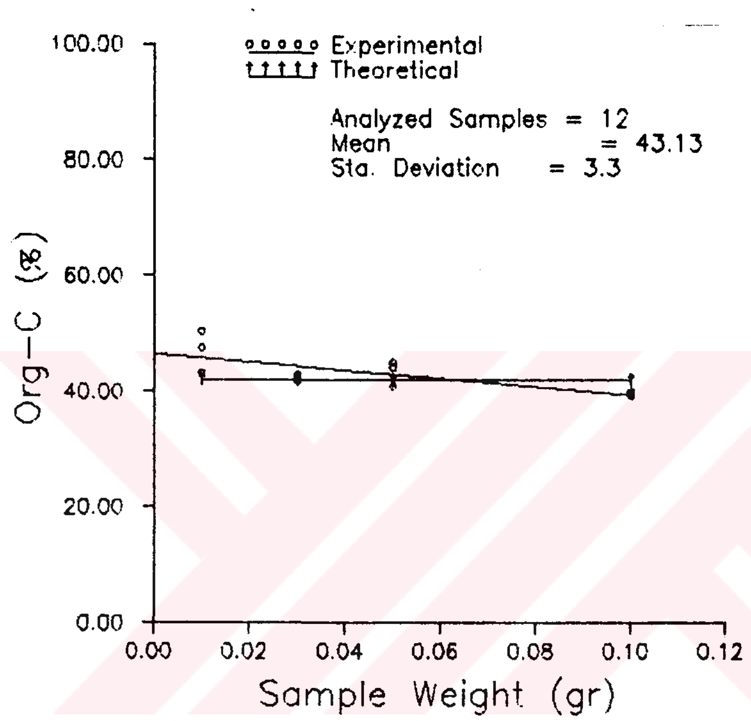

Figure 2.4 : Calibration curves for SUCROSE for comparison of the experimental and theoretical results.

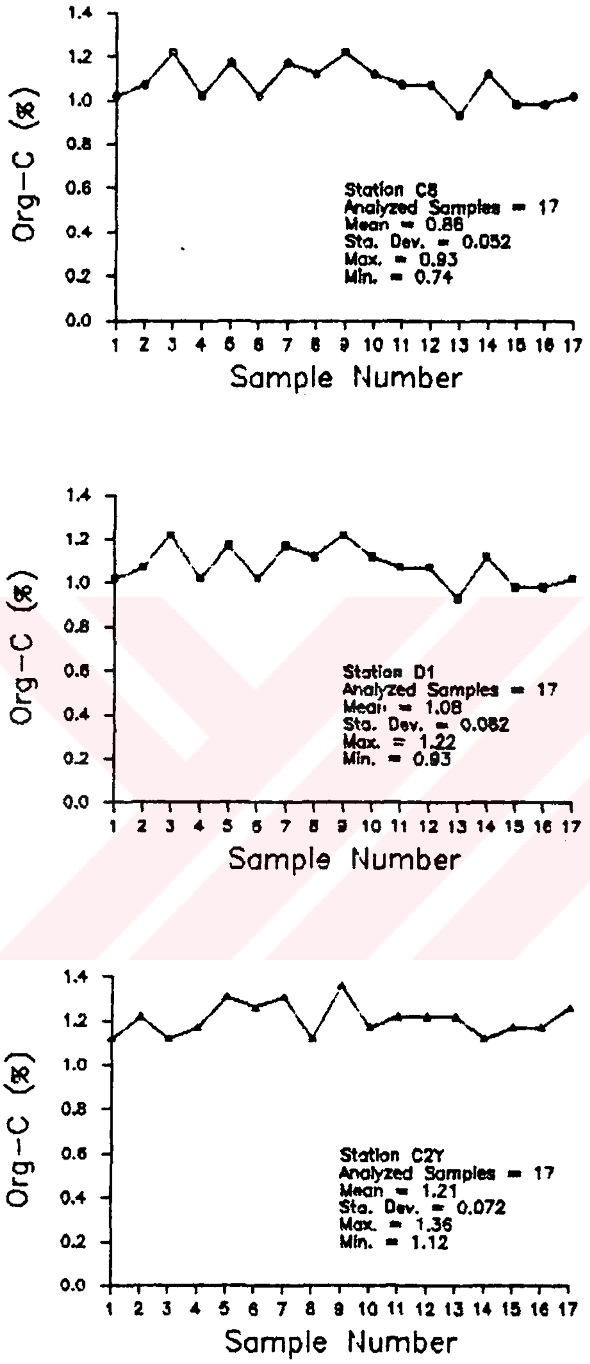

Figure 2.5 : Reproducibilty of the organic carbon measurements checked with three different samples.

2.3.3. CARBONATE DETERMINATION

The carbonate content in the bulk sediment samples was determined by gasometric method which is a modified "Scheibler" gasometer system (Müller, 1967). This method is based on the volumetric determination of CO_2 released by acidification of the oven-dried (60 °C) and pre-weighed samples (0.5 gr) with 10 ml of HCl (10 %) solution. The evolving of CO_2 from the acidification processes of samples with the HCl acid produces an over pressure exerting water to rise up in the scaled columnar barometric tube. Analytical procedure were checked by using the powdered extra pure carbonate ($CaCO_3$, Merck) with known quantities. Two calibration curves are tested for the effects of different temperatures (Fig. 2.6), were prepared to control the analytical procedure. Each determination was duplicated during the course of this study. The carbonate percentages were then found by comparing the displacement of liquid level in the digitized tube in vertical position caused by evolved CO_2 from the samples with those evolved by pure carbonate bearing standards. The accuracy of this method (38.8±1.6%) was checked with the sample (C2X(1), after about 15 times repetition with different weights (Fig. 2.7).

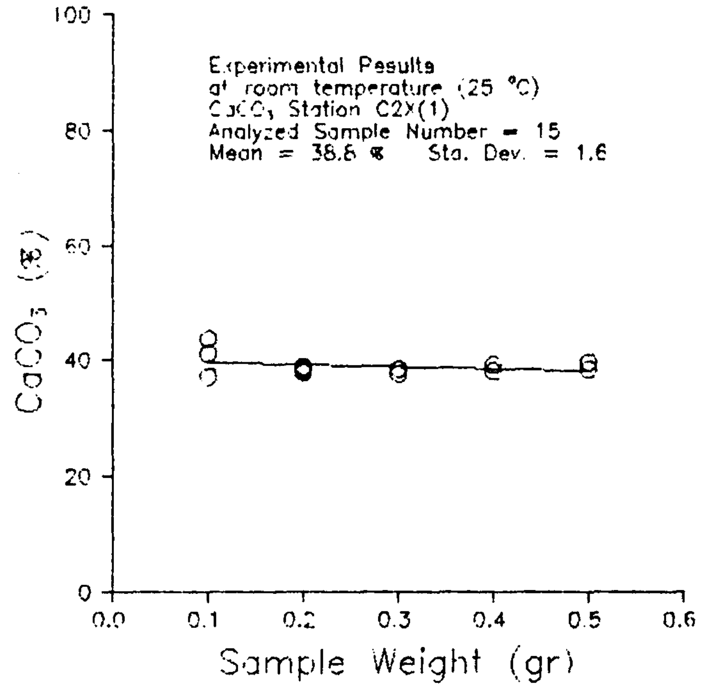

Figure 2.6 : **Calibration curves for $CaCO_3$ determinations at different room temperature (23 and 25 °C).**

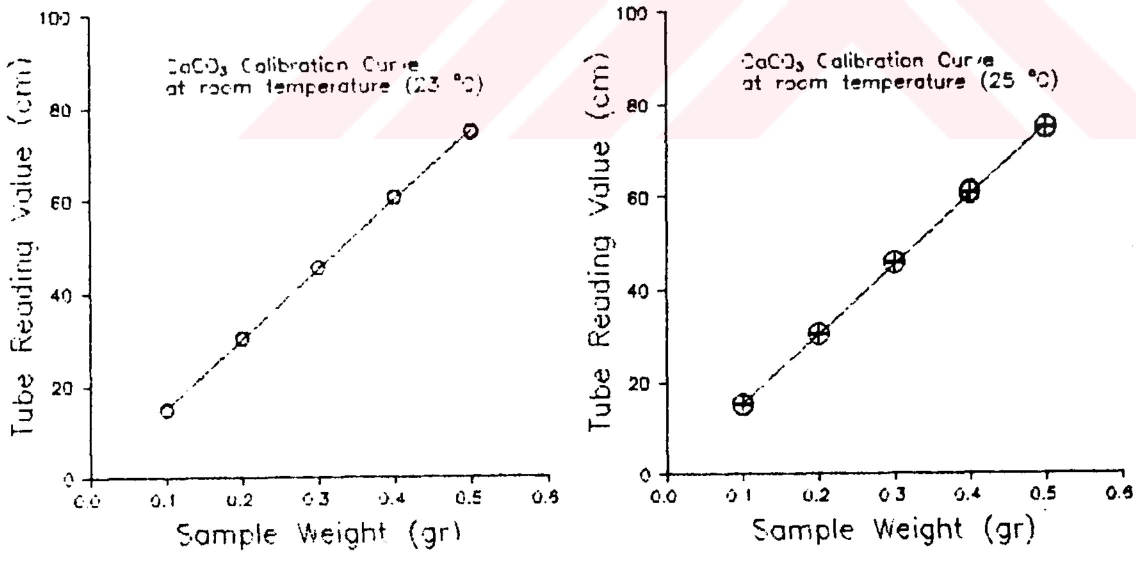

Figure 2.7 : **Reproducibility of the method for carbonate determinations checked with the sample [C2X(1)] of different weights.**

2.3.4. HEAVY METAL ANALYSES

A representative portion of frozen sediment sample was oven-dried at about 60 °C and then crushed into fine powder. The powdered sample (0.5 gr) was transferred into a teflon (PTFE) beaker to digest with the combined HNO_3 (Merck 65 % extra pure) and HF (Merck 38-40 % extra pure) acids. 10 ml of nitric acid was added to each ground sediment sample and let stand for about half an hour at room temperature. Afterwards, the samples are placed onto hot plate to heat the mixture at 160±5 °C for 8 hours. After heating the sediment/acid mixture in teflon beakers 15 ml of hydrofluoric and 15 ml of nitric acids were added and the beakers are covered with teflon watch-glass and heated again for about 8 hours at 160±5 °C. Then, teflon caps were removed and teflon beakers having samples and acid mixture were let stand for another two hours at the 160±5 °C until to dryness they appeared jelly-like. Later on the teflon beakers were let stand to cool at room temperature and after cooling, the digested samples were transferred into 50 ml of volumetric flasks, by adding distilled water to make up to volume of 50 ml. This complete digestion procedure has successfully been used and recommended by many laboratories (Chester and Hughes, 1967; Agemian and Chau, 1976; UNEP/IAEA, 1986; Loring, 1987; Loring and Rantala, 1988).

The digested sediment samples were analyzed for Fe, Mn, Ni, Zn, Cr, Co, Cu, and Pb using an atomic absorption spectrophotometer (Varian Techtron AA6, 1150/1250) with flame. The analytical calculations were done by employing standard calibration curves. Some representative examples of the calibration curves obtained during analysis were also illustrated on Fig. 2.8.

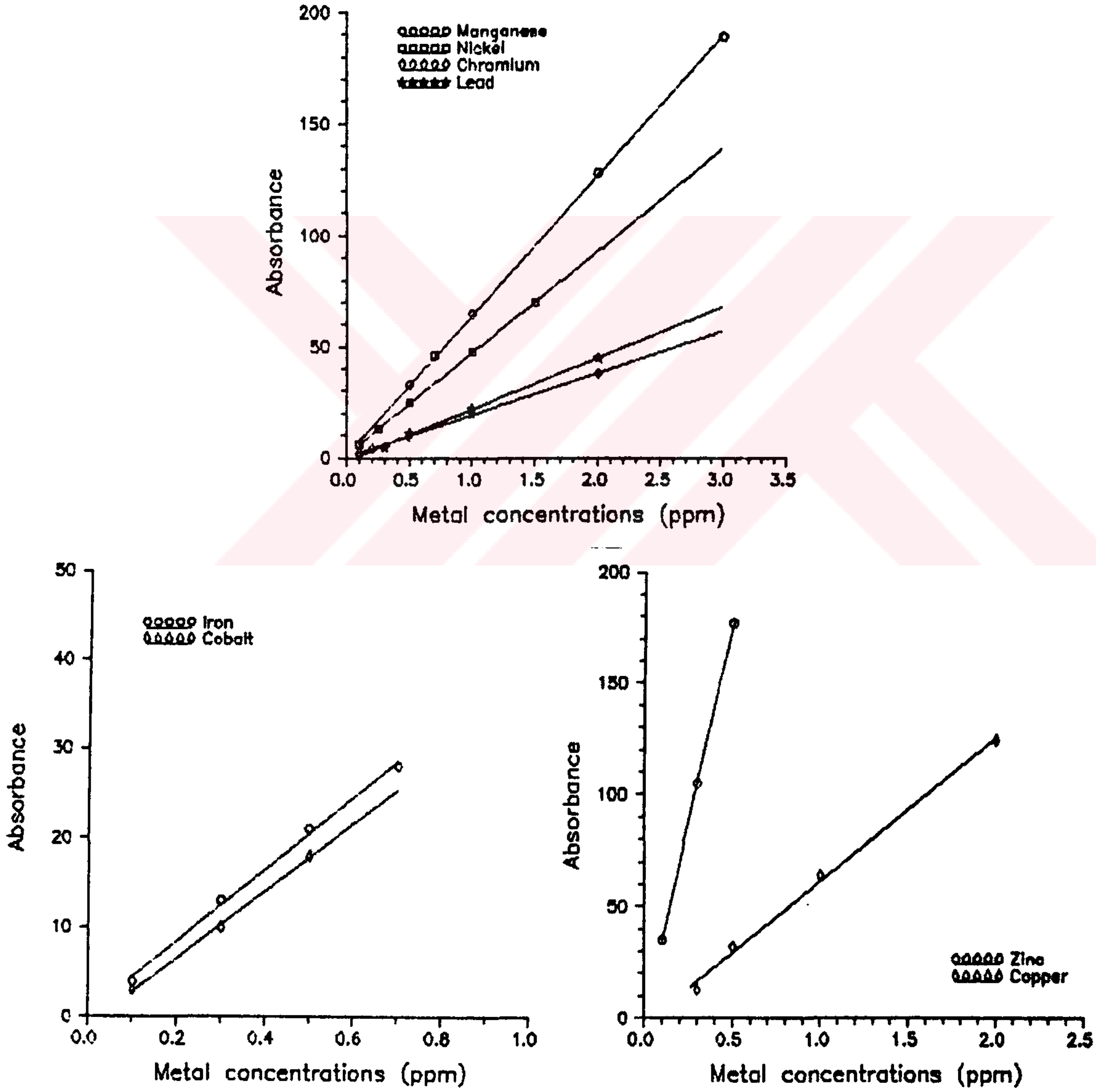

Figure 2.8 : Calibration curves for the studied heavy metal concentrations.

The analytical precision of this method was assessed by carrying out replicate determinations on ten subsamples of BC-3 (52-54 cm depth in core) for which sufficient material was available. The results with their standard deviation values. are given in Table (2.3)

Table 2.3 : Replicate analyses of subsamples from Core BC-3 (52-54 cm depth in core). Data in µg/g, except for iron in % .

SET #	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Set1	4.87	4285	124	87	139	16	37	40
Set2	4.74	4192	124	79	139	16	37	35
Set3	4.16	3920	121	99	118	15	39	52
Set4	4.13	4001	119	99	118	18	39	52
Set5	4.11	3838	117	92	123	18	38	58
Set6	4.16	4042	119	99	118	21	39	46
Set7	3.91	4457	123	96	131	15	39	54
Set8	3.88	4426	125	95	126	19	39	46
Set9	3.91	4818	127	92	131	12	37	46
Set10	3.86	4306	125	93	126	18	39	46
Mean	4.17	4229	122	93	127	17	38	48
SD	0.36	295	3	6	8	3	1	7

Additionally, three subsamples from different intervals of each core were analyzed in duplicate to check the precision of the analytical procedure. The results obtained are given in Tables (3.11 to 3.17).

The validity and precision of this method were controlled by using BCR reference materials CRM-142 (light sandy soil), EPA-286 (Electroplating Sludge) and EPA-386 (Shale-I) which were analyzed in the same way. The results obtained for the standard materials are given in Tables (2.4, 2.5 and 2.6).

Table 2.4 : Results of metal analysis of the standard (BCR) sample CRM-142 (Light sandy soil). Data in μg/g, except for iron in %.

SET #	Fe	Fe_2O_3	Mn	Ni	Zn	Cr	Co	Cu	Pb
Set1	2.49	35.6	595	31.2	92.0	84.4	7.1	25.7	39.4
Set2	2.15	30.7	566	27.6	80.7	76.1	7.0	26.0	37.2
Set3	1.94	27.7	583	30.0	78.4	68.7	6.2	25.8	37.9
Set4	1.83	26.1	621	28.0	86.7	69.7	9.8	25.9	40.2
Set5	1.89	27.0	595	29.1	73.5	75.8	9.1	26.7	38.2
Set6	1.70	24.3	633	31.9	88.3	76.2	9.1	26.7	40.0
Set7	1.90	27.1	606	26.8	84.6	84.4	9.0	26.7	39.1
Set8	1.93	27.6	586	29.6	86.8	79.2	9.1	26.7	39.0
Set9	2.14	30.6	612	28.5	85.3	73.6	9.1	26.6	37.5
Set10	1.95	27.9	602	30.2	96.2	80.8	9.0	26.7	38.7
Mean	1.99	28.5	600	29.3	85.3	76.9	8.5	26.4	38.7
SD	0.22	3.1	19	1.6	6.5	5.4	1.2	0.4	1.0
BCR (CRM-142, Light sandy soil) (certified value)									
Mean		(28.0)	(569)	29.2	92.4	(74.9)	(7.9)	27.5	37.8
SD				2.5	4.4			0.6	1.9
Acc. Meth.		1.8	5.5	0.3	-7.7	2.7	7.6	-4.0	2.4

Note : Values in parentheses are not certified

Table 2.5 : Results of metal analysis of the standard sample EPA-286 (Electroplating Sludge). Data in μg/g, except for iron in %.

SET #	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Set1	3.01	285	422	13877	5447	9	653	24
Set2	3.65	303	406	10039	5681	12	651	61
Set3	3.46	293	433	12239	4126	9	653	61
Set4	3.72	286	411	12103	4978	6	658	17
Set5	3.48	331	443	11792	5614	9	634	70
Mean	3.46	300	423	12010	5169	9	650	47
SD	0.28	19	15	1367	645	2	9	24
EPA-286 (certified value)								
Mean	36243	311	512	13810	9212	ND	884	1282
SD	2529	24	34	810	436	-	67	54

ND : not detected

Table 2.6 : Results of metal analysis of the standard sample EPA-386 (Shale Sludge). Data in μg/g, except for iron in %.

SET #	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Set1	1.83	317	32	89	31	9	52	32
Set2	2.12	364	29	85	32	12	55	39
Set3	1.97	293	29	71	25	12	53	48
Set4	2.17	327	25	81	29	9	53	46
Set5	1.86	422	32	88	25	9	50	62
Mean	1.99	345	29	83	28	10	53	45
SD	0.15	50	3	7	3	2	2	11
EPA-386 (certified value)								
Mean	22200	357	ND	100	ND	ND	67	ND
SD	1820	50	-	9	-	-	5	-

ND : not detected

It has been found that there exists a good agreement between the heavy metal concentrations obtained in this study and those values reported by the supplier of Reference Materials (BCR and EPA samples).

CHAPTER THREE

3. RESULTS AND DISCUSSIONS

3.1. COMPOSITION AND DISTRIBUTION OF THE SURFACE SEDIMENTS

Textural, petrological and chemical compositions and their distributions of surficial sediments will be discussed in detail on regional basis and given brief conclusions at the end of the each subject in this section.

3.1.1. TEXTURE AND PETROLOGY OF THE SURFACE SEDIMENTS

3.1.1.1. REGIONAL DISTRIBUTION

THE STRAIT OF BOSPHORUS (BS) : The surficial sediments of the Bosphorus Strait are dominated usually by the coarse-grained materials (gravel and sand) and the percentages of the sand and gravel showed wide variations, between about <1 and 84 % (mean: 40 %) for the gravel and 15 to 69 % (mean: 41 %) for the sand fractions. The amounts of mud fractions were 1-71 %, (mean; 19 %) (Table 3.1).

Gravel fraction is principally composed of the biogenous materials, which are represented mainly by the molluscan shell fragments of various pelecypods species, (*Mytilus*

Table 3.1 : Composition of surface sediments from the Strait of Bosphorus.

STA. NAME	DEPTH (m)	LAT.	LON.	G	S	Z	C	M	S/M	Z/C	Z/M	org.C	$CaCO_3$	SEDIMENT TEXTURE	GENETIC TYPE
E2	55	405936	285900	22	58	10	10	20	2.9	1.0	0.5	0.90	36	gmS	Biogenous
B0	52	410012	285933	65	29	3	3	6	4.8	1.0	0.6	1.09	28	msG	Terrigenous
B2	45	410150	290050	44	50	4	2	6	8.9	1.8	0.6	0.51	52	msG	Biogenous
B5	64	410300	290249	43	52	3	2	5	11.1	1.3	0.6	0.37	55	sG	Biogenous
B7	74	410445	290335	10	58	16	16	32	1.8	1.0	0.5	0.73	3	gmS	Terrigenous
B7-A	69	410517	290346	62	33	3	2	5	6.4	1.4	0.6	0.37	45	msG	Biogenous
B10	74	410730	290525	32	60	4	4	8	8.0	1.0	0.5	0.39	48	msG	Biogenous
B11	66	410745	290434	31	21	24	24	48	0.4	1.0	0.5	1.37	21	mG	Terrigenous
B13	66	410928	290300	81	17	1	1	2	8.7	0.8	0.3	1.18	61	G	Biogenous
B14	69	411120	290536	84	15	1	0	1	10.4	6.1	0.9	0.30	88	G	Biogenous
BC-1	54	411129	290555	4	68	15	13	28	2.4	1.2	0.5	0.37	28	(g)mS	Terrigenous
N5	38	411142	290650	11	58	18	13	31	1.9	1.3	0.6	0.93	17	gmS	Terrigenous
B15	88	411254	290720	73	26	1	0	1	27.0	4.7	0.8	0.22	46	sG	Biogenous
K0	70	411336	290758	<1	29	46	25	71	0.4	1.8	0.6	1.07	2	(g)sM	Terrigenous
Avg.	63			40	41	11	8	19	6.8	1.8	0.6	0.70	38		
Std.	13			28	18	12	8	20	6.6	1.5	0.1	0.37	23		

G: Gravel g: Gravelly S: Sand Z: Silt M: Mud

(g): Slightly gravelly s: sandy C: Clay m: muddy

galloprovincialis, *Modiolus barbatus*, *Mysella bidendata*, *Pitar rudis and Corbula gibba*, *Gafrarium minima*, *Venus ovata* with the subordinate amounts of *Ostrea edulis* (Güre, 1990 and Mutlu, 1990). The latter is especially dominant at stations B10, B11, and B13 (Fig. 2.2a). Other biogenous materials include the calcareous worm tubes, gastropods (*Triphora sp.* and *Gibbula sp.*) and some calcareous algae (only at st. B0). The occurrences of the biogenic constituents in the Bosphorus sediments was also discussed by some other authors (Caspers, 1968; Meriç *et al.*, 1988; Güre, 1990; Mutlu, 1990 and Ergin *et al.*, 1991a). In particular, the subrounded and partially well-rounded pelecypod shell fragments together with the pebble-sized rock fragments are found at sts.: B2, B5, B7, B7-A and B15 (Fig. 2.2a). Microscopic investigations strongly suggest that the majority of these samples have originated from the calcareous skeletal remains of benthic organisms, generally appear as fragmented, reworked, oxidized, and altered by various physical, chemical, and also by biological processes. Some molluscs shells especially of *Mytilus*, *Cardium papillosum* (Güre, 1990) are bored by some other living organisms. Some other stations (KO, N5, B11, B7, BO) (Fig. 2.2a) show the abundant terrigenous materials most probably indicating active coastal erosion and supply from the land or/and processes of strong reworking and redistribution on the bottom of this strait. Most of the terrigenous components are derived from the metamorphic (especially schist, quartzite) and sedimentary (mudstones, shale and limestone) rock fragments with some mica flakes. Cherts with their typical reddish-brown color commonly occur as well-rounded and sometimes encrusted by calcite. Coal and slug particles with some wood- and plant-tissues are also found in sediment samples, derived directly or indirectly from the land-based sources.

The sand fractions of the Bosphorus surface sediments had wide variety in their compositions. Their terrigenous fractions are dominated by quartz and other light and dark colored minerals as well as rock fragments (especially chert and schist). The terrigenous grains are commonly subrounded and partially well-rounded at stations E2, B14, B15 (Fig. 2.2a). The sand fractions also contained appreciable amounts of materials. Most of them are made up of the pelecypod shells, with less extent of the gastropods (*Turritella sp.*).

Some authors (Demir, 1954; Uysal, 1970 and Hasanoğlu, 1975) stated that the distributions of biogenics are favored by the specific conditions in temperature, salinity, and the bottom substratum (hard-sandy-gravel). Other biogenous constituents are, in equal amount of occurrences, made of the calcareous worm tubes, algae, bryozoans, and ostracods, with minor amounts of sponge spicules (st. B0) (Fig. 2.2a), polychaetes (stations B7-A, E2) (Fig. 2.2a), and some foraminiferas (commonly *Ammonia beccarii sp.* and *milioline sp.*) with less extent of agglutinated type of forams. There are very little echinoid spine and plates throughout the strait even with the absence at stations B15, B14, and B13 (Fig. 2.2a). However, absence of the Mediterranean Echinoderms in the bottom sediments of Bosphorus was also reported by Tortonese and Demir (1960). Some biogenous and terrigenous materials are found throughout the strait which were partly well-oxidized having reddish-brown color (probably stained by iron-oxide) and polished reworked surfaces (stations B2 and B15) (Fig. 2.2a).

Fig. 3.1 shows the bottom relief of the Bosphorus Strait. Taking the topographic irregularities into consideration, it is obvious that the strong variations in the sediment distribution becomes prominent.

Here the bottom currents are measured to be approximately 60 cm/sec, at about 7 m above the sea floor (METU-IMS, 1985). Since the dominant bottom currents (more 10-20 cm/sec) are

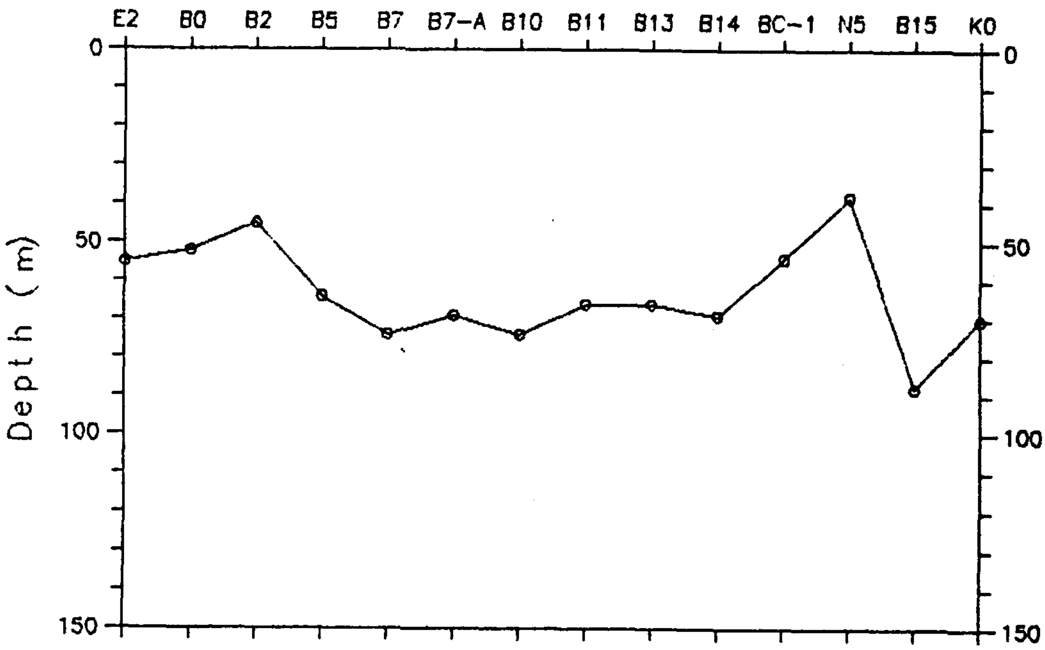

Figure 3.1 : **Depth profile along the Strait of Bosphorus.**

usually capable of eroding and removing finer material, then, the presence of the highly abundant coarse materials (gravel and sand, Fig. 3.2) and the undulated bottom topography especially at stations BO, B7-A, B13, B14 and B15, most probably resulted from the effects of strong bottom currents (>75 cm/s, at 60 m water depth, at the northern exit of the Bosphorus, METU-IMS, 1991 unpublished ADCP raw dat) in strait's channel. The presence of coarse-grained clastic sediments along the shores of this strait may also reflect, in part, the erosional effect at the coast by the prevailing currents. While the coarser particles settle with the decreasing energy of turbulence, only a small fraction of the finer sediments are entrapped in the

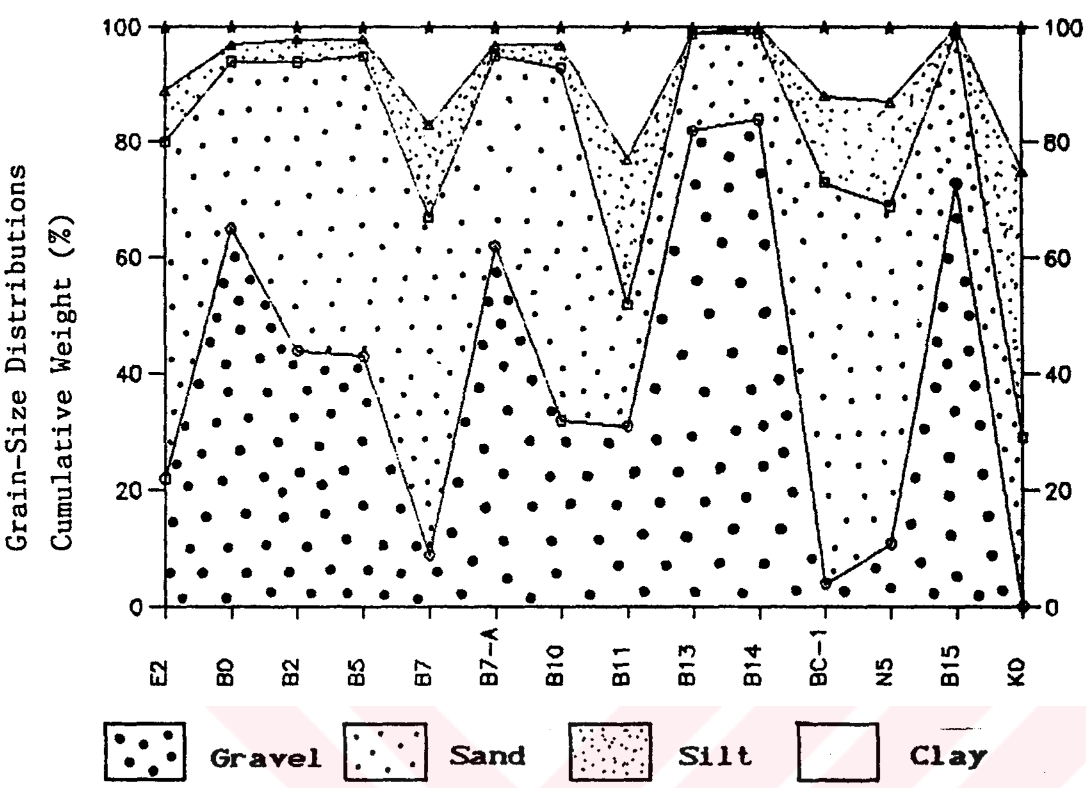

Figure 3.2 : Distribution of grain-size along the Strait of Bosphorus.

inlets (Passega, 1977). The finer particles (very-fine sand and mud) may be winnowed out and transported away by the strong bottom currents, leaving the coarse particles as lag deposits along the strait. It thus appears, that most of the coarse-grained fractions of the surficial Bosphorus sediments, could be the products of such reworking and redistribution processes of the older deposits. Therefore, the distribution of the surface sediments in the Strait of Bosphorus seem to be controlled by the dominant water-flow regimes in this region. For example, finer clastic sediments with over 20 % mud fraction (silt and clay) were deposited at stations B7, B11, BC-1, N5 and KO (Fig. 3.2 and Fig. 2.2a); where the hydraulic energy is believed to be rather low. However, the presence of the coarse fractions of benthic origin (mostly from the molluscan shell fragments) can not be explained by the hydrodynamically-controlled sedimentation processes.

JUNCTION OF THE BOSPHORUS STRAIT WITH THE SEA OF MARMARA (BMJ) : In the Bosphorus Strait and the Sea of Marmara Junction, gravel and sand fractions varied between 0 and 65 % and 1 to 80 % respectively. Mud is present in amounts from 2 to 99 % of bulk sediment (Table 3.2).

The gravel fractions are generally composed of the biogenous materials which are represented by the molluscan shell fragments (pelecypod) with subordinate amounts of freshly broken echinoid fragments (at sts; N11, and V6) (Fig. 2.2b). In addition, cherts and well-rounded quartz grains (st. M15), as well as calcareous worm tubes are found (st. M9). Samples from stations E4, M1(1), M1(2), M4, M4', M5, M7, N6, V1, A15, A18 and A34, from depths between 13 and 60 m, constituted 11 to 49 % gravel mostly of biogenic origin. In the vicinity of Princes Islands, the sediment texture is characterized by the coarse grained materials (Fig. 3.3). At these stations, with the exception of A34 (where pelecypod is dominant), gravel fractions of the sediments are principally composed of the branching skeletal remains of the encrusting *melobesid* calcareous algae (e.g. *Lithothamnium*) with the subordinate amounts of molluscs shell fragments, dominantly pelecypod.

Table 3.2 : Composition of the surface sediments from the junction of the Bosphorus Strait with the Sea of Marmara.

STA. NAME	DEPTH (m)	LAT.	LON.	G	S	Z	C	M	S/M	Z/C	Z/M	org.C	$CaCO_3$	SEDIMENT TEXTURE	GENETIC TYPE
B0	52	410012	285933	65	29	3	3	6	4.8	1.0	0.6	1.09	28	msG	Terrigenous
A15	25	405436	290612	39	29	21	11	32	0.9	1.9	0.7	0.68	69	mG	Biogenous
A18	25	405303	290600	41	33	18	8	26	1.3	2.3	0.7	1.73	63	msG	Biogenous
A23	55	405223	290844	<1	2	44	54	98	0.0	0.8	0.5	0.84	14	(g)M	Terrigenous
A26	65	405100	291256	19	9	40	32	72	0.1	1.3	0.6	1.66	22	gM	Terrigenous
A28	60	404916	291502	1	80	11	8	19	4.2	1.4	0.6	0.92	63	(g)mS	Biogenous
A34	13	405733	291600	30	68	1	1	2	29.8	1.2	0.5	0.52	90	gS	Biogenous
BC-2	64	405448	285603	<1	12	49	39	88	0.1	1.3	0.6	1.14	12	(g)sM	Terrigenous
E2	55	405936	285900	22	58	10	10	20	2.9	1.0	0.5	0.90	36	gmS	Biogenous
E4	25	405932	285700	11	30	33	26	59	0.5	1.3	0.6	1.60	47	gM	Biogenous
E28	28	405818	284544	7	31	40	22	62	0.5	1.8	0.6	1.20	23	gM	Terrigenous
KC4	75	405618	284308	0	4	41	55	96	0.0	0.8	0.4	1.16	15	M	Terrigenous
M1(1)	22	405842	285500	23	24	28	25	53	0.5	1.1	0.5	1.70	59	gM	Biogenous
M1(2)	22	405842	285454	23	19	30	28	58	0.3	1.1	0.5	2.16	55	gM	Biogenous
M2	66	405812	285712	2	14	40	44	84	0.2	0.9	0.5	1.87	12	(g)sM	Terrigenous
M3	35	405730	285930	<1	42	35	23	58	0.7	1.5	0.6	1.06	13	(g)sM	Terrigenous
M4	25	405648	290204	16	27	31	26	57	0.5	1.2	0.5	1.47	35	gM	Biogenous
M4'	25	405530	290118	28	18	22	32	54	0.3	0.7	0.4	1.49	52	gM	Biogenous
M5	13	405609	290430	49	12	20	19	39	0.3	1.1	0.5	1.49	60	mG	Biogenous
M6	27	405648	285030	1	21	39	39	78	0.3	1.0	0.5	1.23	24	(g)sM	Terrigenous
M6'	80	405524	285030	<1	17	37	46	83	0.2	0.8	0.4	0.94	16	(g)sM	Terrigenous
M7	37	405618	285306	21	37	18	24	42	0.9	0.7	0.4	1.42	56	gM	Biogenous
M8	66	405524	285642	<1	21	45	34	79	0.3	1.3	0.6	1.04	15	(g)sM	Terrigenous
M8'	50	405554	285624	<1	11	50	39	89	0.1	1.3	0.6	1.35	12	(g)sM	Terrigenous
M9	40	405424	285956	30	28	23	19	42	0.7	1.2	0.5	1.04	39	mG	Biogenous
M10	40	405345	290200	48	44	4	4	8	5.5	1.2	0.5	0.37	10	msG	Terrigenous
M11	65	405130	291012	7	43	19	31	50	0.9	0.6	0.4	1.04	33	gM	Biogenous
M12	56	405024	291418	3	43	26	28	54	0.8	0.9	0.5	0.90	26	(g)sM	Terrigenous
M13(1)	79	405618	284312	<1	4	43	53	96	0.0	0.8	0.4	1.06	15	(g)M	Terrigenous
M13(2)	67	405700	284430	<1	5	45	50	95	0.1	0.9	0.5	1.16	17	(g)M	Terrigenous
M14	90	405518	284700	1	24	33	42	75	0.3	0.8	0.4	0.90	17	(g)sM	Terrigenous
M15	71	405400	285124	20	31	25	24	49	0.6	1.0	0.5	0.73	16	gM	Terrigenous
M16	250	405300	285517	<1	15	40	45	85	0.2	0.9	0.5	1.09	14	(g)sM	Terrigenous
M16'	72	405400	285536	0	9	47	44	91	0.1	1.1	0.5	1.18	12	M	Terrigenous
M17	90	405130	290000	<1	21	35	44	79	0.3	0.8	0.4	1.04	15	(g)sM	Terrigenous
M18	90	405100	290418	<1	25	29	46	75	0.3	0.6	0.4	1.02	18	(g)sM	Terrigenous
M19	94	404906	290830	1	6	33	60	93	0.1	0.6	0.4	1.17	15	(g)M	Terrigenous
M20	85	404800	291230	0	3	36	61	97	0.0	0.6	0.4	1.14	14	M	Terrigenous
M21	85	404648	291630	0	2	41	57	98	0.0	0.7	0.4	1.14	12	M	Terrigenous
N6	23	405730	285400	17	38	20	25	45	0.9	0.8	0.4	1.38	64	gM	Biogenous
N7	60	405624	285806	<1	10	51	39	90	0.1	1.3	0.6	1.31	11	(g)sM	Terrigenous
N10	27	405100	291530	4	21	45	30	75	0.3	1.5	0.6	1.00	25	(g)sM	Terrigenous
N11	219	404348	292140	1	3	54	42	96	0.0	1.3	0.6	1.00	9	(g)M	Terrigenous
V1	60	405656	285812	16	30	23	31	54	0.6	0.7	0.4	1.55	55	gM	Biogenous
V2	65	405448	285600	<1	9	47	44	91	0.1	1.1	0.5	0.76	15	(g)M	Terrigenous
V3	60	405400	285806	<1	17	50	33	83	0.2	1.5	0.6	1.10	12	(g)sM	Terrigenous
V4	40	405354	285948	10	64	15	11	26	2.5	1.4	0.6	0.37	33	gmS	Biogenous
V5	70	405200	290106	<1	6	44	50	94	0.1	0.9	0.5	1.07	13	(g)M	Terrigenous
V6	80	404954	290854	<1	5	33	62	95	0.1	0.5	0.3	1.15	14	(g)M	Terrigenous
V7	60	405000	291348	17	69	6	8	14	5.1	0.7	0.4	0.44	72	gmS	Biogenous
MBC-3	1200	404915	285600	<1	1	25	74	99	0.0	0.3	0.3	1.05	10	C	Terrigenous
Avg.	83			11	24	31	33	65	1.4	1.0	0.5	1.13	29		
Std.	163			16	19	14	17	28	4.2	0.4	0.1	0.36	21		

G: Gravel g: Gravelly S: Sand Z: Silt M: Mud

(g): Slightly gravelly s: sandy C: Clay m: muddy

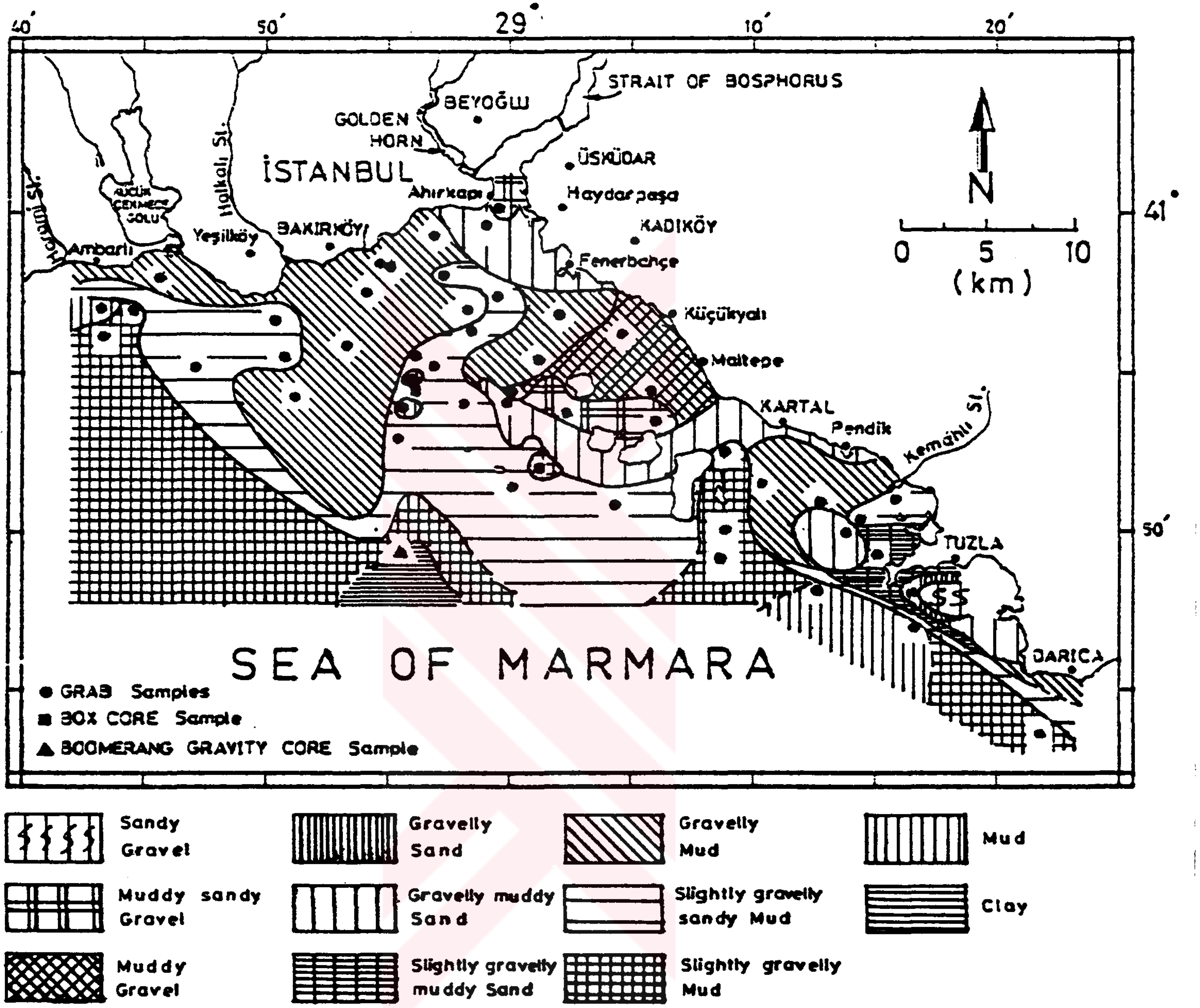

Figure 3.3 : Distribution of grain-size in the surface sediments from the junction of the Bosphorus Strait with the Sea of Marmara (based on Folk, 1974).

Tortonese and Demir (1960) also reported that the bottom surrounding the Prince Islands were covered by the coralligeneous sediments. This type of bottom was defined by Müller (1985) as the original substratum of bioclastic sand and detritic mixture, which was abundantly covered and cemented together by calcareous *Rhodopyceae*, chiefly *Lithothamnium calcareum*, *L. fruticolusum* and *Lithophyllum racemus*. On the other hand, the presence of these coralligeneous massifs maybe elucidated as the results of the environmental changes (warm-cold) which must be occurring not only in ancient times, but also in Recent time in the eastern Mediterranean Sea (Bacescu, 1985; Bellan-Santini, 1985). Matson (1989) stated that the abundant terrigenous sediment input or high water turbidity precludes the development and maintenance of coral reefs. These plants encrust the sea-bed with their calcified fronds in the photic zone (Müller, 1985). The plants produce a variety of ecological niches for grazing epibenthic forms and attached filter-feeders. This is reflected in the composition of the benthic foraminiferal assemblages. These are dominated by species of *Elphidium* and sessile forms (*e.g.*, *Cibicides* and various *Discorbids*) together with several species of miliolids and arenaceous forms. The prevalence of the coralligeneous sediment on the Anatolian side of the shelf, between the Princes Islands and the coast can be attributed to more steady-state hydrographic conditions and a limited amount of terrigenic supply. There is no major river reaching the coast in this area and the present hydrographic data suggest that it is less affected by the outflow of brackish waters from the Black Sea (Özsoy *et al.*, 1988).

The sand fractions are commonly dominated by the terrigenous materials mostly composed of lithic and mineral grains (quartz, mica, chert and metamorphic rocks with some local occurrences of coal, slug, tar balls and plant-wood remains). The biogenous components in sand are made of a large variety of organism remains, such as of calcareous algae, foraminifera, molluscs (dominantly pelecypod), and to a lesser extend of calcareous worm tubes, echinoid-spine and -plates, ostracods, fecal pellets bryozoans, siliceous sponge spicules, and polychaetes. These skeletal remains of benthic organisms especially foraminifers are concentrated in the finer sand fractions (125-250 μ) of sediments. Davies and Gorsline (1976) stated that in regions where the biological productivity is high, so the biogenous sediment accumulate in high amounts. It has been known that the Junction of the Sea of Marmara and Bosphorus is one of the most productive areas in the Marmara Sea (Baştürk *et al.*, 1990).
The presence of various shallow-water species of the foraminifers in large quantities (especially *Textularia*, *Ammonia*, *Elphidium*, various *Miliolids* and *Discorbids*) at depths down to 1200 m suggests that significant downslope movements of the shallow- water bottom sediments is probably originated from the shallower parts of the shelf of European and Asian marginal areas in this section of Marmara Sea.
Fecal pellets are found at the most samples, with a

predominance at stations BC-2, M6, M8', M12 and M18 as associated with high percentages of mud (54 to 89 %). They mostly appear in elongated and partly spherical to elliptical shape usually in form of micro-crystalline aggregates with yellowish to olive-green color, when viewed with the binocular microscope. Their concentrations in the surface sediments but also throughout the core BC-2 suggest recent formation and the presence of some well-rounded forms may attest to the reworking of the sea-floor. These excretionary materials are also found in sediments from deeper waters and basinal sediments. Their occurrences were also reported by Evans *et al.* (1989). In the study area, they are produced by benthic organisms most probably by the polychaetes which predominate the benthos in the relatively deeper areas of the shelf as can also be confirmed by the findings of Caspers (1968); and Ünsal and Uysal (1988). Their presence indicates a marine setting typified by large fluxes of freshwater, terrestrial organic matter and high rates of sediment accumulation (Pimmel and Stanley, 1989). However, in the deeper parts of the shelf, the biogenous fraction of most of the samples is dominated by the benthic foraminifers (*Bulimina*, *Globulimina*, *Bolivina*, *Uvigerina*, *Chilostomella*, and also *Melonis sp.*) followed by some planktonic foraminifera species (*Globigerina quinqueloba*, *Globigerinoides ruber* and also some *Globorotalia Sp.*) occur at most places. The species are adapted to high productivity conditions and their transportation by the undercurrent must have led to increased deposition in these areas (Alavi, 1988).

Pyrite and pyritization are common associations of some foraminiferal tests, especially the *Bolivina* and also *Bulimina sp.* Some genera do characteristically occur in areas of high nutrient concentration (*Bulimina* and *Bolivina sp.*) such as marine sewer outfalls where nutrient levels are raised to unnatural highs (Haq and Boersma, 1981). The other important biogenous constituent is the sponge spicule which is dominantly found at two stations KC4 and V4. Davies and Gorsline (1976) found that the correlation between the accumulation of siliceous sediments and areas of high productivity is enhanced because the preservation of siliceous shells appears to be better in the sediments rich in organic matter. The occurrences of high silicate contents in the water column of st. 45C during 1986-1989 period (Baştürk *et al.*, 1990) confirms this. The molluscs shell fragments were commonly reworked, broken and some of them (especially *Turritella sp.*) were stained partly with reddish-brown color. Minor amounts of bryozoa were found only at the stations M6', M7, M9, M11, M12, M13(1), M13(2), M14, N11 and V7. Here also, echinoid plates and spine as well as calcareous worm tubes were characteristic of these, the worm tubes were most abundant at stations; M9 and V4.

In general, the sediment texture of the southern Bosphorus canyon/valley is marked by the slightly gravelly sandy mud facies [(g)sM] which are abundant at the both European and Asian sides of the BMJ. The grain size of sediments showed an increasing tendency toward the fine material (slightly gravelly sandy mud facies) in the down-canyon direction, both along the nearly north-south trending axis and the east-west trending side walls (Fig. 3.3). For example, here, the mud fractions increase from 20 % at the head of canyon (E2) to 85 % in downcanyon (M16) and to 99 % in the deep basin (MBC-3), or decrease in the vice versa direction. (Table 3.2). This downcanyon-fining or upcanyon-coarsening of the grain size of sediments (Fig. 3.3) can best be explained in accordance with the changes in the topography and the intensity of undercurrents acting upon that in this region. It is evident that the inflowing Marmara undercurrents to the Black Sea attain their high velocities as approaching to the Strait of Bosphorus, where the maximum current speeds were measured (METU-IMS, 1985, 1990 and 1991). Thus, a coarsening of the sediments must be expected towards the entrance of the strait, which is confirmed in this study. Occasional near-shore increments of mud are characteristic on the western (off Yeşilköy, Küçükçekmece Lake and also Ambarlı) and eastern shelf regions (*i.e.*, Pendik Bay which is bordered to the east by the Tuzla Peninsula and to the west by the Princes Islands). In these areas (sts. M6, M6', E28, KC4, M13(1), M13(2), M14, A23, A26 and N10) (Fig. 2.2b), sediments contained exceptionally high mud concentrations ranging from 54 to 98 % (Table 3.2).

NORTHERN SHELF OF THE SEA OF MARMARA (NSM) : The surficial sediments of the northern Marmara shelf, are marked by generally high mud percentages, with an average of about 84

% (Table 3.3). A gravelly-sandy mud facies at nearshore passes into gravelly mud, and further offshore, into mud. This is typical offshore-decrease in the mean-grain size of sediments, as expected. Off Ereğli and Gümüşyaka coasts, in the central part of the northern Marmara shelf, a zone of gravelly-muddy sand appears. This region seems to represent a canyon-like feature (Offshore Ereğli Canyon) (Fig. 3.4).

Here, the gravel fraction decreases from (19 %) in the nearshore shallow-waters to (<1 %) in offshore deep-waters. The molluscan shell fragments makes up the most of the gravel fraction principally composed of pelecypods and gastropods with a minor amounts of calcareous worm tubes, bryozoa and echinoid fragments. Exceptionally, the sample at station N23 contained biogenic constituents in high abundances. These skeletal shell fragments were generally subrounded and iron-stained. Some well-rounded and partially-subrounded yellowish-green-gray, smooky and transparent quartz and quartzite particles are also found in this fraction. The sand or sandy facies are widely distributed at stations; K57K00 (41 %), N4 (49 %) and N19 (51 %), associated with some gravel and mud portions (Fig. 3.4 and Table 3.3). This at stations N4, V10 and K56K30, and partly stained by iron oxides/hydroxides. Mica flakes, metamorphic rock fragments, and organic debris (mostly tar ball and coal particles) are occasionally found in this fraction. The occurrences of well-rounded quartz grains at these stations may indicate that these sediments are reworked

Table 3.3 : Composition of the surface sediments from the northern shelf of the Sea of Marmara.

STA. NAME	DEPTH (m)	LAT.	LON.	G	S	Z	C	M	S/M	Z/C	Z/M	org.C	$CaCO_3$	SEDIMENT TEXTURE	GENETIC TYPE
N24	180	405118	272830	0	4	49	47	96	0.0	1.0	0.5	0.81	9	M	Terrigenous
K46J28	760	404600	272800	0	1	35	64	99	0.0	0.5	0.4	1.20	9	M	Terrigenous
K53J32	390	405318	273218	<1	10	27	63	90	0.1	0.4	0.3	1.06	10	(g)sM	Terrigenous
BC-4	1106	404826	273635	<1	<1	33	67	100	0.0	0.5	0.3	1.14	8	C	Terrigenous
K46J37	700	404600	273700	<1	<1	26	74	100	0.0	0.4	0.3	1.16	9	(g)M	Terrigenous
K53J42	480	405330	274230	0	1	23	76	99	0.0	0.3	0.2	1.23	10	C	Terrigenous
N23	67	405630	275200	<1	14	41	44	85	0.2	0.9	0.5	0.81	12	(g)sM	Terrigenous
K50J53	855	405000	275300	0	1	16	83	99	0.0	0.2	0.2	1.04	10	C	Terrigenous
BC-3	1226	404948	275735	<1	<1	23	77	100	0.0	0.3	0.2	1.00	10	C	Terrigenous
K57K00	75	405700	280000	19	41	15	25	40	1.0	0.6	0.4	0.97	36	gmS	Biogenous
N3	77	405736	280848	<1	9	32	59	91	0.1	0.5	0.3	1.14	16	(g)sM	Terrigenous
N19	12	410415	281350	0	51	24	25	49	1.0	1.0	0.5	0.57	10	mS	Terrigenous
L02K15	56	410200	281500	<1	2	37	61	98	0.0	0.6	0.4	1.37	13	(g)M	Terrigenous
L00K15	61	410000	281500	26	15	18	41	59	0.2	0.5	0.3	1.23	20	gM	Terrigenous
K56K15	320	405630	281500	<1	3	33	64	97	0.0	0.5	0.3	1.64	14	(g)M	Terrigenous
N18	61	410000	282200	<1	<1	34	66	100	0.0	0.5	0.3	1.22	13	(g)M	Terrigenous
N4	64	405830	282424	16	50	13	21	34	1.5	0.6	0.4	0.57	16	gmS	Terrigenous
V10	100	405700	282700	16	19	27	38	65	0.3	0.7	0.4	0.68	20	gM	Terrigenous
K59K30	53	405900	283000	<1	<1	44	56	100	0.0	0.8	0.4	1.47	12	(g)M	Terrigenous
K56K30	85	405600	283000	<1	29	28	42	70	0.4	0.7	0.4	0.85	15	(g)sM	Terrigenous
K57K34	60	405700	283400	<1	13	46	40	86	0.2	1.1	0.5	1.13	15	(g)sM	Terrigenous
Avg.	323			4	12	30	54	84	0.2	0.6	0.4	1.06	14		
Std.	372			8	16	10	18	21	0.4	0.2	0.1	0.27	6		

G: Gravel g: Gravelly S: Sand Z: Silt M: Mud
(g): Slightly gravelly s: sandy C: Clay m: muddy

or transported by rolling of the particles, probably due to the prevailing under-currents. The sand fractions contained minor amounts of biogenous constituents and only those here concentrated in the coarse-sand fraction. The biogenous constituents are mostly composed of skeletal remains of benthic organisms, which are dominated by hyaline type of benthic foraminifers (*Uvigerina*, *Bulimina* and *Bolivina sp.*) and of pelecypods. The other biogenous components are shells of ostracods (dominant at st. N18), gastropods (dominant at st. LOOK15), calcareous worm tubes, bryozoans and also sponge

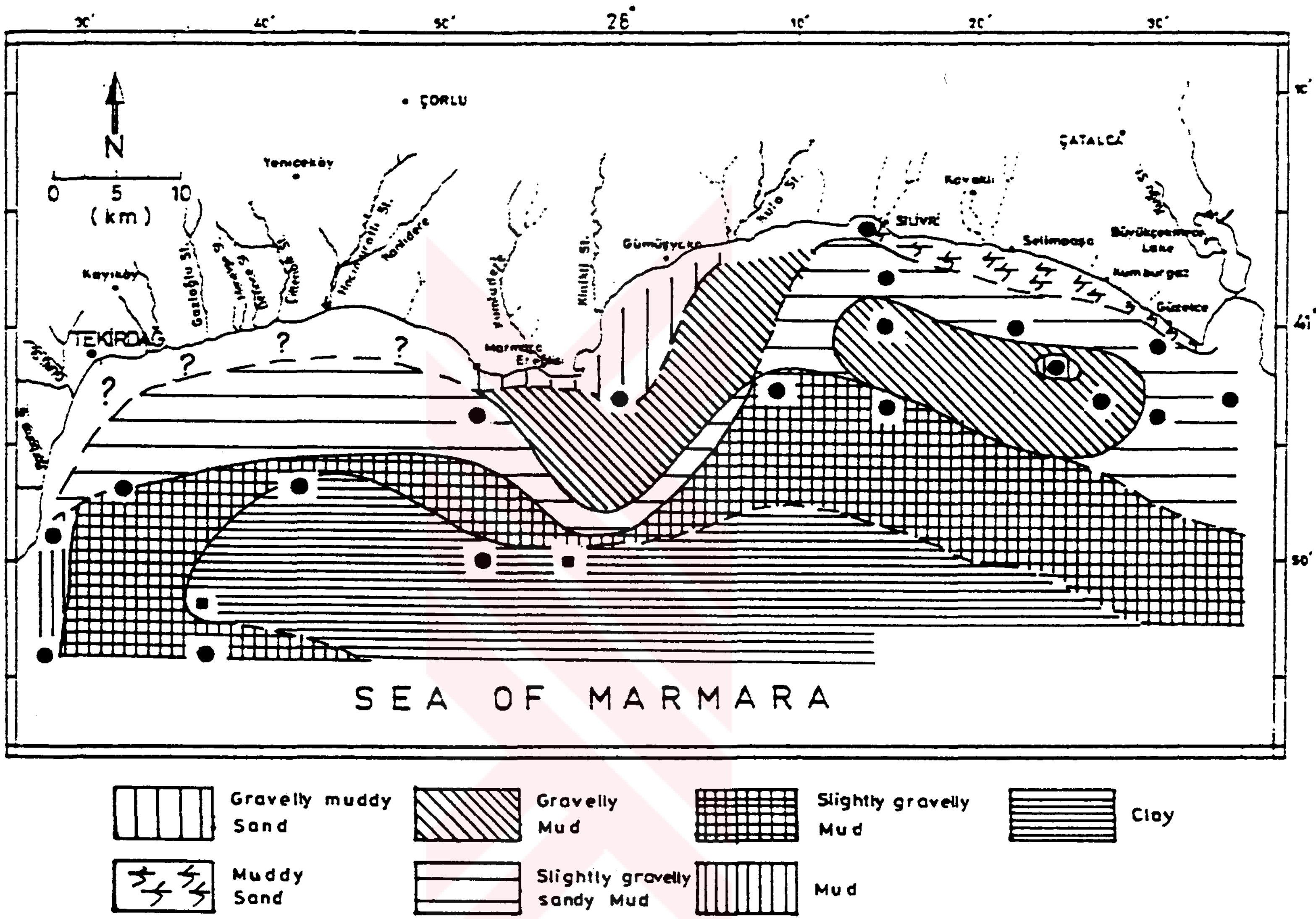

Figure 3.4 : Distribution of grain-size in the surface sediments from the northern shelf of the Sea of Marmara (based on Folk, 1974).

spicules. Polychaete also occurs but only at station N24. Pteropod shells are also found in some deeper stations (K56K15, BC-3; Fig. 2.2c). In sand fraction, pyritization was commonly observed within the shell of hyaline type of foraminifers (especially *Ammonia*, *Bolivina* and *Bulimina sp's*). These are frequently occurring at sts.; N19, L02K15 and L00K15, with decreasing tendency in abundances towards the deeper water stations (Fig. 2.2c). Since those species belong to shallow water environments (Haq and Boersma, 1981), therefore they are probably transported by turbidity currents and gravity slumping down the slope of the northern shelf. At two stations; BC-3 and K50J53 (water depths are 1226 and 855 m, respectively) the sand fraction was fully composed of hyaline type of foraminifers and of pelecypods shells and some of them were stained by oxidized iron colors. The authigenic pyrite occurrences are dominantly found at station BC-3.

The mud fraction of the sediments usually exceeds 80 %, with the exception of stations K57K00 (40 %), N19 (49 %), L00K15 (59 %), N4 (34 %), V10 (65 %) and K56K30 (70 %) (Table 3.3). The samples with mud contents with more than 96 % are confined to stations N24 and K46J28. Mud facies with slightly-gravelly sand is concentrated in the western and eastern parts of the inner shelf in this area (Fig. 3.4). The slightly-gravelly mud facies is distributed in deeper-water areas, with exception of stations; K53J42, K50J53, BC-3 and BC-4, this might be caused by the turbidity currents and also down-slope movements of coarser materials towards the deeper areas. Clay fraction ranged between 75 and 83 %; it is highest in abundance at stations from deeper-waters of the study area (480 and 1226 m).

In general, the northern Marmara shelf and upper slope is characterized by the deposits which are dominated by terrigenous materials and with subordinate of biogenous constituents. The sediments are mostly made of the siliceous, detrital clastics derived from the river runoff and coastal erosion. The sediments deposited in the deeper water areas are largely pelagic in character, namely their lithogenous material is composed of fine-grained particles From the above results, it appears that the texture of the sediments of the northern shelf of Marmara Sea was related to the bottom topography and environmental conditions.

SOUTHERN SHELF OF THE SEA OF MARMARA (SSM) : On the southern shelf of Marmara Sea, the surface sediments were generally composed of muddy facies (mud percentages ranged between 7 and 100 % with an average value of 81 %) associated with some gravel and sand portions on the average 4 and 15 %, respectively (Table 3.4).

The gravel fraction is commonly comprised of biogenous materials which are principally derived from the skeletal remains of benthic organisms belonging to molluscan shell fragments, mainly of pelecypods with the minor amounts of gastropod shell fragments (especially *Turritella sp.*). Some

Table 3.4 : Composition of surface sediments from the southern shelf of the Sea of Marmara.

STA. NAME	DEPTH (m)	LAT.	LON.	G	S	Z	C	M	S/M	Z/C	Z/M	org.C	$CaCO_3$	SEDIMENT TEXTURE	GENETIC TYPE
K38J55	76	403800	275500	0	24	31	45	76	0.3	0.7	0.4	0.85	13	sM	Terrigenous
K40K00	101	404000	280000	<1	65	10	25	35	1.9	0.4	0.3	0.44	10	(g)mS	Terrigenous
K34K00	50	403400	280000	9	57	14	20	34	1.7	0.7	0.4	0.56	32	gmS	Biogenous
V16	48	403124	280100	9	54	20	17	37	1.5	1.2	0.5	0.44	29	gmS	Terrigenous
N22	38	402830	280300	9	44	38	19	57	0.8	2.0	0.7	0.52	11	gM	Terrigenous
V15	50	402600	280210	<1	5	46	49	95	0.1	0.9	0.5	0.85	7	(g)M	Terrigenous
V14	50	402312	280206	2	3	39	56	95	0.0	0.7	0.4	0.95	6	(g)M	Terrigenous
K22J57	32	402200	275700	<1	22	48	30	78	0.3	1.6	0.6	1.34	4	(g)sM	Terrigenous
BL	10	402124	275736	5	59	24	12	36	1.6	2.0	0.7	1.13	10	gmS	Terrigenous
N21	46	402530	280500	0	3	43	54	97	0.0	0.8	0.4	1.00	7	(g)M	Terrigenous
K25K08	53	402500	280800	2	7	39	52	91	0.1	0.7	0.4	1.14	9	(g)M	Terrigenous
N20	46	402718	280900	2	16	39	43	82	0.2	0.9	0.5	0.86	19	(g)sM	Terrigenous
K28K08	50	402800	280800	<1	4	39	56	95	0.0	0.7	0.4	1.09	8	(g)M	Terrigenous
N1	55	403200	281000	4	76	8	12	20	3.9	0.7	0.4	0.35	10	(g)mS	Terrigenous
K40K10	100	404000	281000	<1	6	26	68	94	0.1	0.4	0.3	1.11	14	(g)M	Terrigenous
K42K15	190	404200	281500	0	2	31	67	98	0.0	0.5	0.3	1.14	13	C	Terrigenous
K35K15	68	403500	281500	27	4	19	50	69	0.1	0.4	0.3	1.04	18	gM	Terrigenous
K30K15	56	403000	281500	<1	2	25	73	98	0.0	0.3	0.3	1.28	9	(g)M	Terrigenous
V13	50	402648	281406	<1	1	33	66	99	0.0	0.5	0.3	0.90	9	(g)M	Terrigenous
K40K20	130	404000	282000	<1	2	24	74	98	0.0	0.3	0.2	1.11	14	(g)M	Terrigenous
K32K20	60	403200	282000	27	2	18	53	71	0.0	0.3	0.3	1.14	18	gM	Terrigenous
V12	50	402942	282354	9	30	21	40	61	0.5	0.5	0.3	0.59	34	gm	Biogenous
K30K26	50	403000	282612	28	7	20	45	65	0.1	0.5	0.3	1.04	21	gM	Terrigenous
V9	10	402500	282901	<1	2	32	66	98	0.0	0.5	0.3	1.10	6	(g)M	Terrigenous
K28K30	60	402800	283000	1	29	25	45	70	0.4	0.5	0.4	0.89	14	(g)sM	Terrigenous
N17	72	403400	283500	<1	7	35	58	93	0.1	0.6	0.4	0.95	18	(g)sM	Terrigenous
K38K30	120	403800	283000	11	25	22	42	64	0.4	0.5	0.3	0.89	18	gM	Terrigenous
K45K30	496	404500	283000	0	1	18	81	99	0.0	0.2	0.2	1.21	11	C	Terrigenous
K40K40	370	404000	284000	0	1	20	79	99	0.0	0.3	0.2	1.28	10	C	Terrigenous
K33K40	150	403300	284000	4	33	23	40	63	0.5	0.6	0.4	0.85	12	(g)sM	Terrigenous
N16	36	403000	284000	22	71	5	2	7	9.9	2.7	0.7	0.26	76	gS	Biogenous
K26K44	67	402600	284400	0	1	29	70	99	0.0	0.4	0.3	1.31	8	C	Terrigenous
K26K45	64	402600	284500	0	1	30	69	99	0.0	0.4	0.3	1.27	8	C	Terrigenous
N12	48	403000	284600	7	77	5	11	16	4.8	0.4	0.3	0.30	36	gmS	Biogenous
K35K45	219	403500	284500	0	2	30	68	98	0.0	0.4	0.3	1.01	13	C	Terrigenous
K40K45	320	404000	284500	0	1	24	75	99	0.0	0.3	0.2	1.01	12	C	Terrigenous
K40K52	200	404000	285200	0	2	29	69	98	0.0	0.4	0.3	1.90	13	C	Terrigenous
K40L00	154	404000	290000	2	14	35	50	85	0.2	0.7	0.4	1.18	13	(g)sM	Terrigenous
N13	64	402830	285130	<1	1	29	70	99	0.0	0.4	0.3	1.07	8	(g)M	Terrigenous
N15	74	402600	285100	0	1	23	76	99	0.0	0.3	0.2	1.26	7	C	Terrigenous
K25K50	65	402500	285048	<1	1	29	70	99	0.0	0.4	0.3	1.17	8	(g)M	Terrigenous
K27K54	100	402706	285436	<1	1	20	79	99	0.0	0.3	0.2	1.46	6	C	Terrigenous
N14	104	402500	285800	0	<1	22	78	100	0.0	0.3	0.2	1.22	7	C	Terrigenous
K24K57	107	402400	285700	0	1	24	75	99	0.0	0.3	0.2	1.31	7	C	Terrigenous
K27L00	81	402700	290000	<1	1	29	70	99	0.0	0.4	0.3	1.11	7	(g)M	Terrigenous
K27L04	70	402700	290400	<1	1	32	67	99	0.0	0.5	0.3	1.14	7	(g)M	Terrigenous
K25L02	69	402500	290230	<1	1	32	67	99	0.0	0.5	0.3	1.12	7	(g)M	Terrigenous
V8	80	402448	290100	<1	1	30	68	99	0.0	0.4	0.3	1.29	7	(g)M	Terrigenous
Avg.	97			4	16	27	54	80	0.6	0.6	0.4	1.01	14		
Std.	91			7	23	10	21	26	1.6	0.5	0.1	0.32	12		

G: Gravel g: Gravelly S: Sand Z: Silt M: Mud

(g): Slightly gravelly s: sandy C: Clay m: muddy

of them seem to be reworked and, thus, can be regarded as relict in nature. Encrustation by calcite and borings by dwelling organisms are also observed within those organisms occasionally. Branched forms of calcareous algae were most commonly found at stations K34K00 and N16. Other stations were poor in calcareous algae. The echinoid shell fragments are observed in samples from stations V15, K25K08, K40K10, K40K20, K33K40, and N13 (Fig. 2.2d). Barnacles and calcareous worm tubes are occurred as attached on the molluscan shell fragments in gravel fraction. Of the terrigenic detritus, encrusted quartz and quartzite grains by calcite are generally found in well-rounded and partly-subangular form, in most samples (especially at stations; K40K00, K34K00, N1, K38K30 and K33K40) (Fig. 2.2d).

The sand percentage ranged between less than 1 and 77 %, with an average value of about 15 %. This fraction is generally composed of biogenous materials (up to 90 %), based on visual estimation. These biogenic materials are represented by hyaline type of (*Globigerina*, *Globorotalia*, *Ammonia*, *Elphidium*, *Bolivina*, *Bulimina*, *Uvigerina*, *Valvulineria*, *Nonionella*, *Dentilina sp's.*, and some agglutinated type of (*Textularia sp.*) and porcelaneous type of foraminifers (*Triloculina sp.* and *Miliolina sp.*), and pelecypods. Some of the benthic and planktonic foraminiferal tests (especially *Bolivina*, *Bulimina*, *Elphidium*, *Ammonia* *Globigerina* and also *Globorotalia sp's.*) were commonly pyritized (st. K40L00) as observed under the microscope.

Some foraminifera tests, especially of *Elphidium* and *Ammonia sp's.* are abundant in most samples from which are located on the inshore areas and characterized by the inner shelf sediments. Of other biogenous constituents, gastropods (mainly *Turritella sp.*), ostracods, pteropods, calcareous algae are characteristic, mostly in samples from two stations N16 and K34K00, where the salinity fluctuations are less (METU-IMS, 1985 to 1991, unpublished raw data) and the input of the terrigenous materials is low. The worm tubes, bryozoans, echinoid spine and plates, sponge spicules, and fecal pellets are found at stations K38J55 and K40K52. The molluscan shell fragments are generally not fresh and seem to be reworked in most cases, they are encrusted with calcite and, partly, are bored by dwelling organisms. The worm tubes are also attached on those. Some shell fragments especially molluscan and foraminiferal tests are stained by reddish brown color of oxidized iron. Terrigenous materials are dominated by quartz and quartzite grains which are generally well-rounded, to partly-subrounded with subangular form. Metamorphic rock fragments (schist) mica (mostly in the Bays of Gemlik and Bandırma), sandstone fragments and organic debris are parts of the terrigenous constituent in the sand fraction. Organic debris are mainly associated with the jelatinous and fibreous plant- and wood-tissues with minor amounts of tarballs, and slug particles. Those are mostly found off the Kocasu river mouth (st. V9; Fig. 2.2d) and in the Bays of Gemlik and Bandırma. The pyrite occurrences are also common in those stations. The organic debris and pyrite occurrences off the Kocasu river mouth are reported by Algan and Akbulut (1985).

The gravelly mud facies is characteristic on the mid-shelf of this area (Fig. 3.5). Clay fractions are highly abundant in samples from the offshore stations but also in deeper parts of the Bay of Gemlik (gravel <1 %). The surface sediments are dominated by mud exceeding 78 % in the Bay of Bandırma and exceptionally, the sediments off Bandırma Harbour consisted of about 36 % of mud (Table 3.4).

In conclusion, the surface sediments from the southern Marmara shelf contain predominantly mud with some gravel and sand portions mainly derived from the molluscan shell fragments and tests of foraminifers. The remains of bryozoans and calcareous algae are missing at most places but echinoid spines and plates are frequent. Therefore, the skeletal remains of molluscs and echinoids in nearly all of the samples in this studied region are most probably of indigenous origin. The presence of mica flakes in the sediments in most samples reflect influences from land-based sources (Ternek *et al.*, 1987). 1 to 5 % mica in the Marmara sediments was already reported by Emelyanov (1972). Obviously, the lithogenic fraction of the southern Marmara sediments receive great amounts of materials from the land via rivers or/and coastal erosion. Apart from this, terrigenous materials may also come from the reworking of pre-existing bottom deposits and surface-exposed submarine

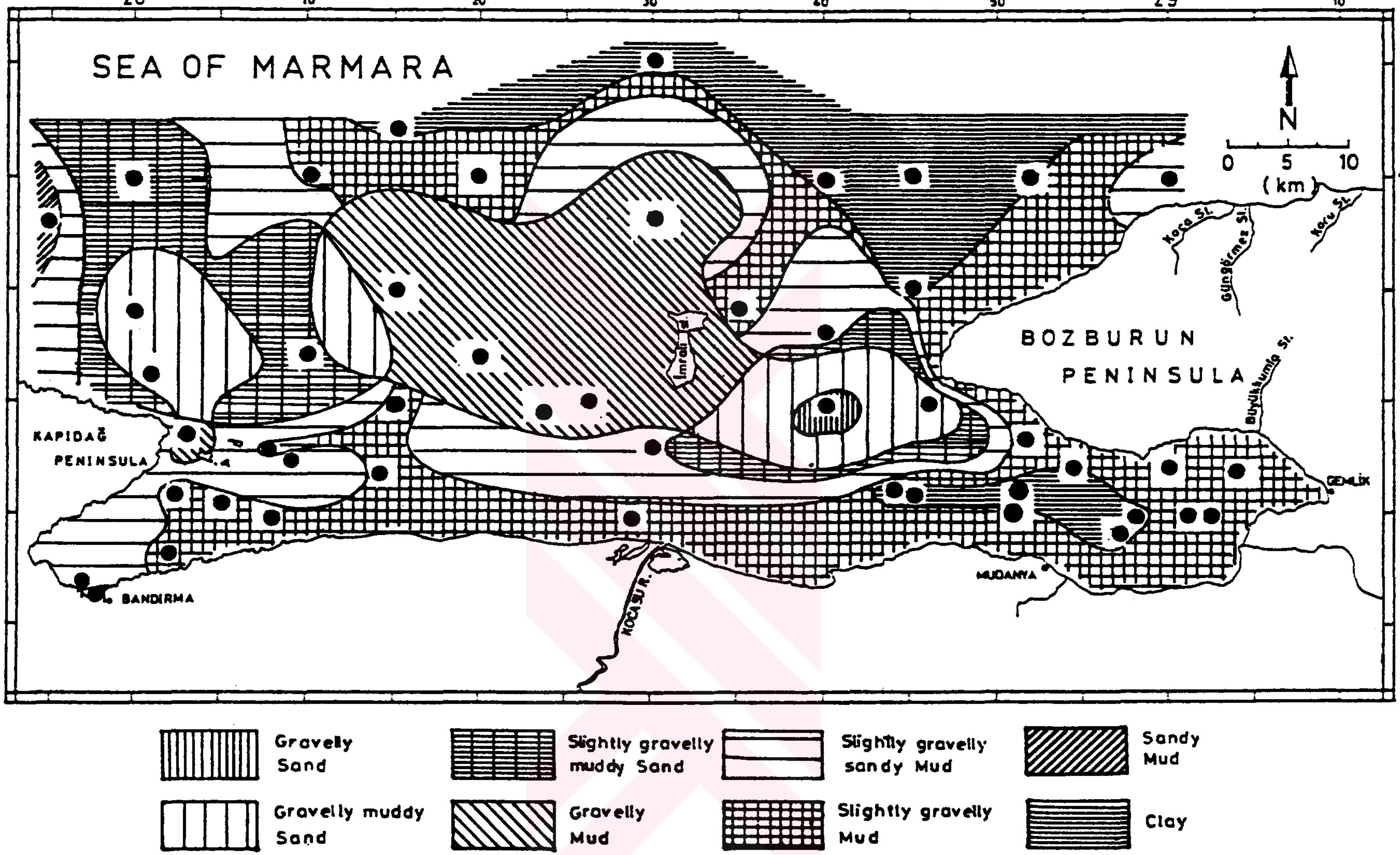

Figure 3.5 : Distribution of grain-size in the surface sediments from southern shelf of the Sea of Marmara (based on Folk, 1974).

rocks. The molluscan shells and foraminiferal tests are common biogenic constituents of the sand fraction in the area but below the halocline, molluscs are less common than foraminifers. The presence of the typical shallow-water species of foraminifers (such as *Textularia*, *Ammonia*, *Elphidium*, *Discorbids* and *Miliolids sp's.*) in deeper water stations support that point of downslope sediment movement. The foraminiferal assemblages are dominated by taxa tolerant of low-oxygen conditions and planktonic foraminifera (*Globigerina sp.*) occur at most places. This is the only species of planktonic foraminifers which consistently occurs in the Sea of Marmara (Alavi, 1986). These species are characteristic from the continental slope and outer shelf sediments (Haq and Boersma, 1981). Isolated occurrences of tests of other planktonic species (*e.g. Globigerinoides ruber*) at some localities suggest that they must be transported to the Sea of Marmara by the penetration of the subsurface Mediterranean waters into the this area. Because it is the most abundant epi-pelagic planktonic form reported in the Aegean and Mediterranean Seas (Parker, 1958; Thunell, 1978 and Alavi, 1980). A branch of this current hugs the southern slope and the outer shelf as it flows towards the Bosphorus (Özsoy *et al.*, 1988).

JUNCTION OF THE SEA OF MARMARA WITH THE DARDANELLES STRAIT (MDJ) : The surface sediments from the Sea of Marmara and Dardanelles Strait Junction are mainly composed of mud-size materials, (concentrations vary from 26 to 100 % with an mean value of 87 %) with minor amounts of gravel and sand fractions (Table 3.5) especially at sts.; D1, N27, K28J13, K30J27, K24J47, K40J30 and V54 (Fig 2.2e). Exceptionally, only two stations (V17 and V51) showed sand facies with the less amounts of gravel and mud (Fig. 3.6). This might reflect the downslope-movements of the coarser sedimentary particles.

The gravel fractions of the sediments from this part of the Sea of Marmara mainly constitute molluscan shell fragments, especially of pelecypods and gastropods including *Turritella sp.* Particular occurrences of echinoid spines and plates even in smaller concentrations are observed at, stations (C2X(1), K28J13, K35J15, and V53; Fig. 2.2e). The echinoderm population in the Sea of Marmara, in general, is believed to have originated recently, after migration from the Aegean or respectively Mediterranean Sea. Thus, they are scarce in the Sea of Marmara (Tortonese and Demir, 1960). The gravel fractions have minor amounts of calcareous algae (found only at stations C2X(1), V46 and V50, in branched forms), worm tubes, and polychaete (mainly observed at station K35J15). Müller (1985) has also reported the presence of luxuriantly-developed pre-coralligen community along the western shores of the Marmara Sea and near to the northern entrance of Dardanelles, usually in water depths between 16 and 20 m. Here, the original substratum of coarse bioclastic sand and detritic mixture was abundantly covered and cemented by calcareous *Rhodophyceae* -chiefly *Lithothamnium calcareum*,

Table 3.5 : Composition of the surface sediments from the junction of the Sea of Marmara with the Dardanelles Strait.

STA. NAME	DEPTH (m)	LAT.	LON.	G	S	Z	C	M	S/M	Z/C	Z/M	org.C	$CaCO_3$	SEDIMENT TEXTURE	GENETIC TYPE
D1	44	402612	264536	2	23	40	35	75	0.3	1.1	0.5	0.85	16	(g)sM	Terrigenous
D1X	81	402600	265100	13	28	30	29	59	0.5	1.0	0.5	0.63	21	gM	Terrigenous
D1Y	84	402512	265512	10	22	40	28	68	0.3	1.4	0.6	0.75	22	gM	Terrigenous
D1Z	64	402512	270024	0	1	61	38	99	0.0	1.6	0.6	1.21	10	M	Terrigenous
V45	66	402624	270248	<1	2	49	49	98	0.0	1.0	0.5	0.95	10	(g)M	Terrigenous
C2S	68	402806	270524	<1	5	43	52	95	0.1	0.8	0.5	1.06	11	(g)M	Terrigenous
N27	68	403100	270700	<1	10	51	39	90	0.1	1.3	0.6	1.00	10	(g)sM	Terrigenous
C2X(1)	60	403324	270542	5	28	36	31	67	0.4	1.2	0.5	0.70	37	gM	Biogenous
C2X(2)	68	403330	270730	13	1	34	52	86	0.0	0.7	0.4	0.97	10	gM	Terrigenous
C2Y	67	403130	270818	<1	1	46	53	99	0.0	0.9	0.5	1.04	10	(g)M	Terrigenous
C2Z	67	402948	270900	0	1	44	55	99	0.0	0.8	0.4	1.06	10	M	Terrigenous
K28J13	53	402800	271300	2	13	44	41	85	0.1	1.1	0.5	0.94	12	(g)sM	Terrigenous
K30J11	68	403018	271118	<1	1	46	53	99	0.0	0.9	0.5	1.11	10	(g)M	Terrigenous
BC-5	65	403202	270937	<1	1	43	56	99	0.0	0.8	0.4	0.84	10	M	Terrigenous
K33J10	71	403300	271000	<1	1	39	60	99	0.0	0.7	0.4	1.06	10	(g)M	Terrigenous
V47	66	403424	271500	<1	1	40	59	99	0.0	0.7	0.4	0.78	10	(g)M	Terrigenous
K35J09	70	403500	270900	9	1	42	48	90	0.0	0.9	0.5	0.99	10	gM	Terrigenous
V46	66	403000	271312	<1	1	44	55	99	0.0	0.8	0.4	0.95	10	(g)M	Terrigenous
K30J17	66	403000	271700	<1	1	37	62	99	0.0	0.6	0.4	0.99	9	(g)M	Terrigenous
K33J17	74	403300	271700	0	1	36	63	99	0.0	0.6	0.4	0.99	10	M	Terrigenous
K35J15	84	403500	271500	<1	1	38	61	99	0.0	0.6	0.4	0.94	10	(g)M	Terrigenous
K39J16	55	403900	271600	<1	1	57	42	99	0.0	1.4	0.6	0.80	11	(g)M	Terrigenous
N2	78	403800	271818	9	2	33	56	89	0.0	0.6	0.4	0.98	10	gM	Terrigenous
K36J18	110	403600	271800	0	5	41	54	95	0.1	0.7	0.4	0.99	10	M	Terrigenous
K33J20	69	403300	272000	0	1	34	65	99	0.0	0.5	0.3	1.01	8	M	Terrigenous
K30J22	59	403000	272200	<1	1	35	64	99	0.0	0.5	0.4	1.14	6	(g)M	Terrigenous
K38J22	122	403800	272200	<1	1	36	63	99	0.0	0.6	0.4	0.87	9	M	Terrigenous
V53	88	403554	272312	<1	1	29	70	99	0.0	0.4	0.3	0.90	9	(g)M	Terrigenous
K34J25	70	403400	272500	<1	3	27	70	97	0.0	0.4	0.3	1.09	7	(g)M	Terrigenous
K30J27	62	403000	272700	2	43	17	38	55	0.8	0.4	0.3	0.70	15	(g)sM	Terrigenous
K26J29	54	402600	272900	12	38	15	35	50	0.7	0.4	0.3	0.61	7	gM	Terrigenous
V20	46	402514	273318	1	2	30	67	97	0.0	0.4	0.3	0.93	6	(g)M	Terrigenous
V49	43	402512	273500	2	5	28	65	93	0.0	0.4	0.3	1.07	6	(g)M	Terrigenous
K25J40	42	402500	274000	3	8	29	60	89	0.1	0.5	0.3	1.14	14	(g)M	Terrigenous
K24J47	29	402400	274700	<1	18	49	33	82	0.2	1.5	0.6	1.51	7	(g)sM	Terrigenous
V50	25	402812	274036	34	28	13	25	38	0.7	0.5	0.3	0.98	50	mG	Biogenous
V19	68	403300	274000	<1	6	36	57	93	0.1	0.6	0.4	0.80	9	(g)M	Terrigenous
V51	64	403312	273548	<1	73	9	18	27	2.7	0.5	0.3	0.37	13	(g)mS	Terrigenous
K33J34	64	403300	273400	<1	7	35	58	93	0.1	0.6	0.4	0.80	10	(g)M	Terrigenous
N26	70	403330	273100	<1	3	32	65	97	0.0	0.5	0.3	1.00	9	C	Terrigenous
V52	70	403412	273036	<1	3	31	66	97	0.0	0.5	0.3	1.05	9	(g)M	Terrigenous
N25	65	403600	273000	<1	2	33	65	98	0.0	0.5	0.3	1.02	7	(g)M	Terrigenous
V21	86	403948	273100	<1	3	31	66	97	0.0	0.5	0.3	0.85	9	(g)M	Terrigenous
K40J30	88	404000	273000	<1	11	23	66	89	0.1	0.3	0.3	0.94	11	(g)sM	Terrigenous
K43J22	70	404300	272200	0	1	49	50	99	0.0	1.0	0.5	0.99	11	M	Terrigenous
K40J24	150	404000	272400	0	6	34	60	94	0.1	0.6	0.4	0.82	13	M	Terrigenous
V54	126	404000	272524	2	28	24	46	70	0.4	0.5	0.3	0.69	23	(g)sM	Terrigenous
K37J25	100	403700	272500	0	<1	32	68	100	0.0	0.5	0.3	1.11	8	C	Terrigenous
K34J28	75	403400	272800	<1	1	42	57	99	0.0	0.7	0.4	0.97	11	(g)M	Terrigenous
V17	64	403729	274822	<1	65	17	18	35	1.9	0.9	0.5	0.46	10	(g)mS	Terrigenous
K33J48	70	403300	274800	<1	2	31	67	98	0.0	0.5	0.3	1.09	9	(g)M	Terrigenous
Avg.	71			2	10	36	52	88	0.2	0.7	0.4	0.93	12		
Std.	22			6	16	11	14	18	0.5	0.3	0.1	0.19	7		

G: Gravel g: Gravelly S: Sand Z: Silt M: Mud

(g): Slightly gravelly s: sandy C: Clay m: muddy

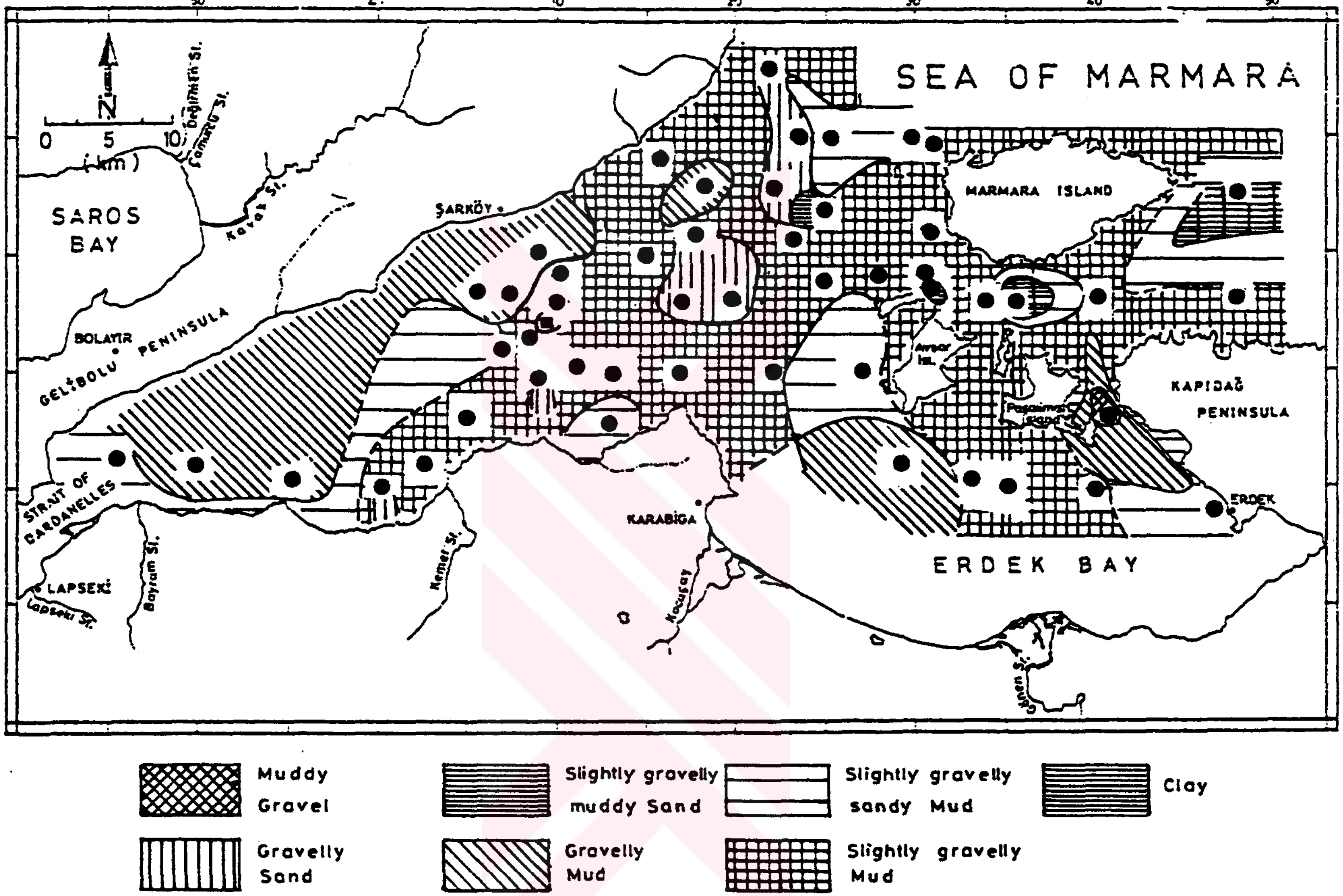

Figure 3.6 : Distribution of grain size in the surface sediments from the junction of the Sea of Marmara with the Dardanelles Strait (based on Folk, 1974).

L. fruticolusum and *Lithophyllum racemus*- supporting, in their turn, a surprisingly-rich settlement of sciaphilous soft algae, dominated by *Phyllophora nervosa* and its epiphytes, such as *Sphaerococus coronopifolius*, *Gelidiella nigrescencs* and *Polysiphonia sp.* More recently, Ergin *et al.* (1991a) reported the occurrences of coralgal communities from the Junction of the Sea of Marmara and Dardanelles Strait. Of the shell fragments, especially those of pelecypods seem to be reworked, freshly broken and bored by dwelling organisms (*i.e.*, relict). The terrigenous materials in pebble size were generally associated with encrusted, and gray-colored quartz and quartzite grains. Some of them are well-rounded and partially-subrounded. Tarballs and slug particles are the anthropogenic substances rarely found.

The sand fraction is dominated by both biogenous and terrigenous materials. The biogenous materials are usually enriched in the coarse-sand fraction (>500 μ), whilst fine-sand is dominated by the terrigenous materials.
The biogenous materials are mostly represented by molluscan shell fragments (especially pelecypods). The other biogenic constituents concentrated in the fine-sand (500-63 μ) are represented by the benthic and planktonic foraminifers (*Uvigerina*, *Bulimina*, *Bolivina*, *Ammonia beccarii*, *Elphidium*, *Textularia*, *Triloculina*, *Quinqueloculina*, *Globigerina*, *Globorotalia*, *Miliolina sp's.*), and pelecypods with subordinate amounts of gastropods. The molluscan shell fragments generally appeared to be reworked and, thus,

believed to be relict. The presence of typical shallow-water species of foraminifers in the deeper water samples may indicate that those are probably transported by the downslope movements of bottom either directly or indirectly under the influence of bottom currents action. The other important biogenic constituents are ostracods, pteropods (mostly found at st. BC-5), echinoid spine and plates, sponge spicules, bryozoans and calcareous worm tubes and algea. Fecal pellets which generally have micro-granular structures being cylindrically-elongated, and yellowish-green in color are commonly observed at most places (mainly found at stations K30J27 and K26J29). Terrigenous fractions of sand are mainly composed of quartz and quartzite grains with subordinates of metamorphic rock fragments and mica flakes (dark-brown). These terrigenous materials are typical in the surrounding land masses of the study area (Ternek *et al.*, 1987). These terrigenic grains were generally rounded to subrounded in form and encrusted with calcite in yellowish-green color. The well-rounded forms were common in samples from D1Y and V17. The occurrences of authigenic pyrite and pyritization are common in most samples but more abundantly at stations C2Z(2), K28J13, BC-5, and K30J27. Here, their occurrences are principally concentrated within the foraminiferal tests. Organic debris, principally plant- and wood-tissues is also observed at most places but are frequently found at sts: D1Z, V45, C2S, C2X(2), C2Y(2), C2Z(2), K33J10, V47, K35J09 V46, K30J17, K33J17, K39J16, and K24J47 (Fig. 2.2e).

In general, lithofacies map shows a wide range of distribution in the Marmara-Dardanelles Juncture (Fig. 3.6). It has been found that mud is dominant facies with the subordinates of gravel and sand fraction. Fig. 3.6 also shows that this mud facies may have high gravel and sand percentages which are concentrated in the narrower parts of the sea (strait existence towards the Marmara Sea) and in nearshore waters around the islands. This facies type was also observed in the western and central parts of the Erdek Bay. The surficial sediments have relatively high sand fractions at eastern part off Erdek. This is in agreement with the data of Ergin *et al.* (1988). The mud concentrations along the canyon axis show varying silt to clay ratios reflecting local differences in the depositional conditions, although mud in this canyon must have its source from the nearby land-masses (*i.e.*, river runoff, coastal erosion) most probably supplied during the early spring and late summer. The increased clay percentages in the down-canyon direction must have been resulted from changes in intensity of the down-canyon flow of undercurrent, from the shallow waters of the strait (high energy conditions) to the deeper waters of the basin (low energy conditions). Fig. 3.6 also shows that gravelly mud facies are concentrated on the north-western shelf of the MDJ. The muddy gravel facies occurred only at st. V50. In short, the above discussions suggest that the high- to low-energy conditions prevail in the Sea of Marmara and the Strait of Dardanelles Junction which are influenced by the bottom topography and the undercurrent flows acting upon this.

JUNCTION OF THE DARDANELLES STRAIT WITH THE AEGEAN SEA (DAJ) :
The surface sediments in the Dardanelles Strait exhibit a wide variety of grain-size mixture, ranging from boulder to clay-size, as a result of the irregular bottom topography in this strait (Fig. 3.7), a fact which is similar to that observed in the the Bosphorus Strait.

The sand fractions make up the important portions of bulk sediments (average 47 %) and contain mud and gravel fractions from 1 to 97 % and from 0 to 95 % respectively (Table 3.6).

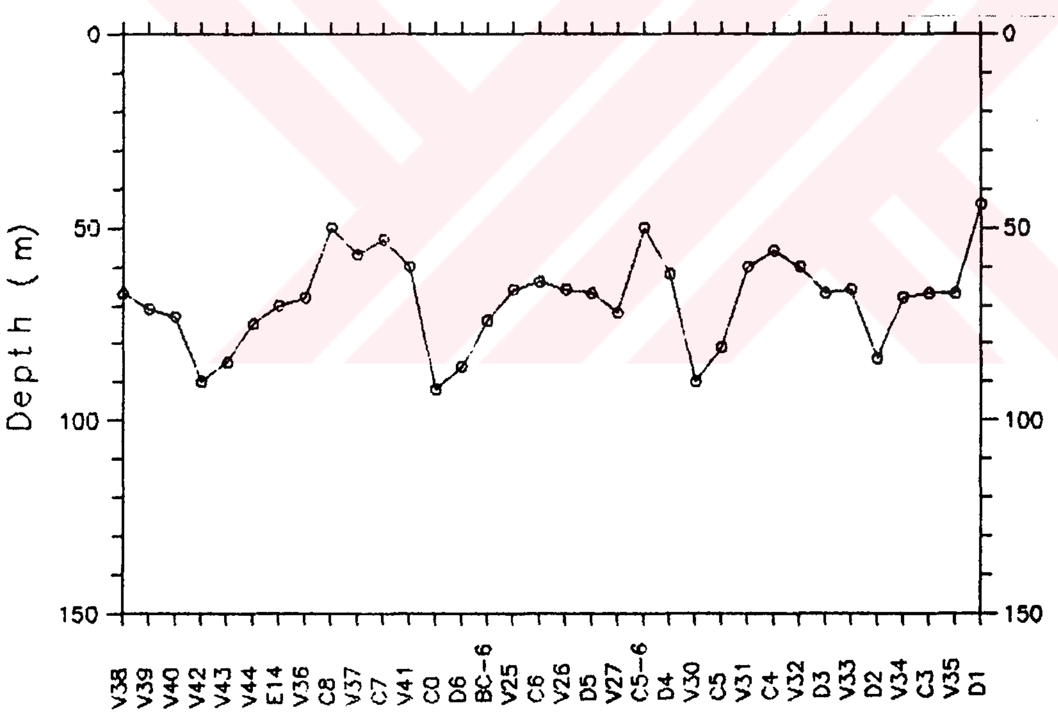

Figure 3.7 : Depth profile along the Strait of Dardanelles and its junction with the Aegean Sea.

Table 3.6 : Composition of surface sediments from the junction of the Dardanelles Strait with the Aegean Sea.

STA. NAME	DEPTH (m)	LAT.	LON.	G	S	Z	C	M	S/M	Z/C	Z/M	org.C	CaCO	SEDIMENT TEXTURE	GENETIC TYPE
V38	67	400330	260418	45	50	2	3	5	10.4	0.7	0.4	0.27	83	sG	Biogenous
V39	71	400306	260612	47	47	2	4	6	8.6	0.5	0.3	0.32	73	msG	Biogenous
V40	73	400236	260812	30	55	6	9	15	3.7	0.7	0.4	0.35	54	gmS	Biogenous
V42	90	400330	260842	15	68	6	11	17	4.0	0.6	0.4	0.25	36	gmS	Biogenous
V43	85	400448	260918	6	72	10	12	22	3.3	0.8	0.4	0.35	26	gmS	Terrigenous
V44	75	400436	260706	14	76	3	7	10	8.0	0.5	0.3	0.20	36	gmS	Biogenous
E14	70	395706	255806	8	63	14	15	29	2.1	1.0	0.5	0.51	28	gmS	Terrigenous
V36	68	395848	260112	1	72	15	12	27	2.7	1.3	0.6	0.37	35	(g)mS	Biogenous
C8	50	400000	260348	4	78	9	9	18	4.2	1.1	0.5	0.88	68	(g)mS	Biogenous
V37	57	400042	260618	15	70	7	8	15	4.7	0.9	0.5	0.25	41	gmS	Biogenous
C7	53	400124	260824	28	57	6	9	15	3.9	0.7	0.4	0.46	43	gmS	Biogenous
V41	60	400136	261012	17	80	1	2	3	30.7	0.6	0.4	0.13	30	gS	Biogenous
C0	92	400142	261130	6	76	10	8	18	4.1	1.3	0.6	0.49	14	gmS	Terrigenous
D6	86	400142	261330	3	75	12	10	22	3.4	1.3	0.6	0.51	19	(g)mS	Terrigenous
BC-6	74	400137	261509	<1	2	51	47	98	0.0	1.1	0.5	0.19	15	(g)M	Terrigenous
V25	66	400236	261512	0	16	48	36	84	0.2	1.3	0.6	1.05	10	sM	Terrigenous
C6	64	400330	261630	0	11	54	35	89	0.1	1.5	0.6	1.13	8	sM	Terrigenous
V26	66	400418	261836	<1	20	48	32	80	0.2	1.5	0.6	0.90	8	(g)sM	Terrigenous
D5	67	400506	262000	<1	29	45	26	71	0.4	1.7	0.6	0.90	6	(g)sM	Terrigenous
V27	72	400636	262124	1	62	20	17	37	1.7	1.1	0.5	0.56	7	(g)mS	Terrigenous
C5-6	50	400730	262318	<1	57	23	20	43	1.3	1.1	0.5	0.80	5	(g)mS	Terrigenous
D4	62	401042	262330	95	4	<1	<1	1	5.3	1.0	0.5	0.12	50	G	Biogenous
V30	90	401230	262506	3	96	<1	<1	1	108.2	0.5	0.3	0.10	27	(g)S	Terrigenous
C5	81	401306	262712	13	70	9	8	17	4.2	1.1	0.5	0.53	15	gmS	Terrigenous
V31	60	401418	262900	<1	21	44	35	79	0.3	1.3	0.6	0.80	10	(g)sM	Terrigenous
C4	56	401536	263106	<1	22	45	34	78	0.3	1.3	0.6	1.04	9	(g)sM	Terrigenous
V32	60	401706	263312	0	16	49	34	84	0.2	1.4	0.6	0.85	9	sM	Terrigenous
D3	67	401812	263454	12	43	28	17	45	1.0	1.6	0.6	0.66	37	gM	Biogenous
V33	66	401930	263636	5	52	21	22	43	1.2	1.0	0.5	0.66	14	gmS	Terrigenous
D2	84	402054	263836	<1	48	29	23	52	0.9	1.2	0.6	0.61	12	(g)sM	Terrigenous
V34	68	402200	263942	<1	10	45	45	90	0.1	1.0	0.5	0.88	12	(g)sM	Terrigenous
C3	67	402300	264048	<1	29	39	32	71	0.4	1.2	0.5	0.85	16	(g)sM	Terrigenous
V35	67	402436	264236	<1	29	36	35	71	0.4	1.0	0.5	0.73	16	(g)sM	Terrigenous
D1	44	402612	264536	2	23	40	35	75	0.3	1.1	0.5	0.85	16	(g)sM	Terrigenous
Avg.	68			11	47	23	19	42	6.5	1.1	0.5	0.57	26		
Std.	12			19	26	18	14	31	18.5	0.3	0.1	0.30	20		

G: Gravel g: Gravelly S: Sand Z: Silt M: Mud
(g): Slightly gravelly s: sandy C: Clay m: muddy

The coarsest sediments with the maximum gravel and sand percentages are found near the meandering Nara Passage (Sts.; D4 and V30; Fig. 2.2f) and the junction of the Dardanelles with the Aegean Sea, where also surface and bottom currents reach their maximum velocities (up to 160 cm/sec, METU-IMS, 1991 unpublished raw data). The role of channel geometry, bottom topography and associated hydrodynamic regime on the sediment distribution in this strait was already discussed in Ergin *et al.* (1991a). In such narrowing and shoaling channels, finer-grained bottom materials are usually ledged or current-swept (Kelling and Stanley, 1972) as a result of the high flow velocities (Leopold *et al.*, 1964). From stations D4 and V30 towards the both northeast (except stations D3, V33, and D2) and southwest (st. BC-6), the silt fraction of the sediments (Fig. 3.8) are comparatively increases markedly due to the topography-related decreasing hydraulic energy, with the exception of D4, and V30, where the energy conditions are comparatively high.

As shown in Fig. 3.8, the surface sediments again increase in their mean grain size, from station BC-6 towards the Aegean Sea exit, where coarse sediments are prominent. One may infer from the Figs. 3.7 and 3.8, the undulated bottom topography, suggests that the coarser-materials are deposited at highs and the finer ones at the lows or flat parts between these elevations.

As it has been known, the grain size, current velocity and their relationship to various bedforms are prominent in many fluviatile environments (Simons *et al.*, 1965). Otherwise, on a plane bedform, the prevailing bottom currents in the

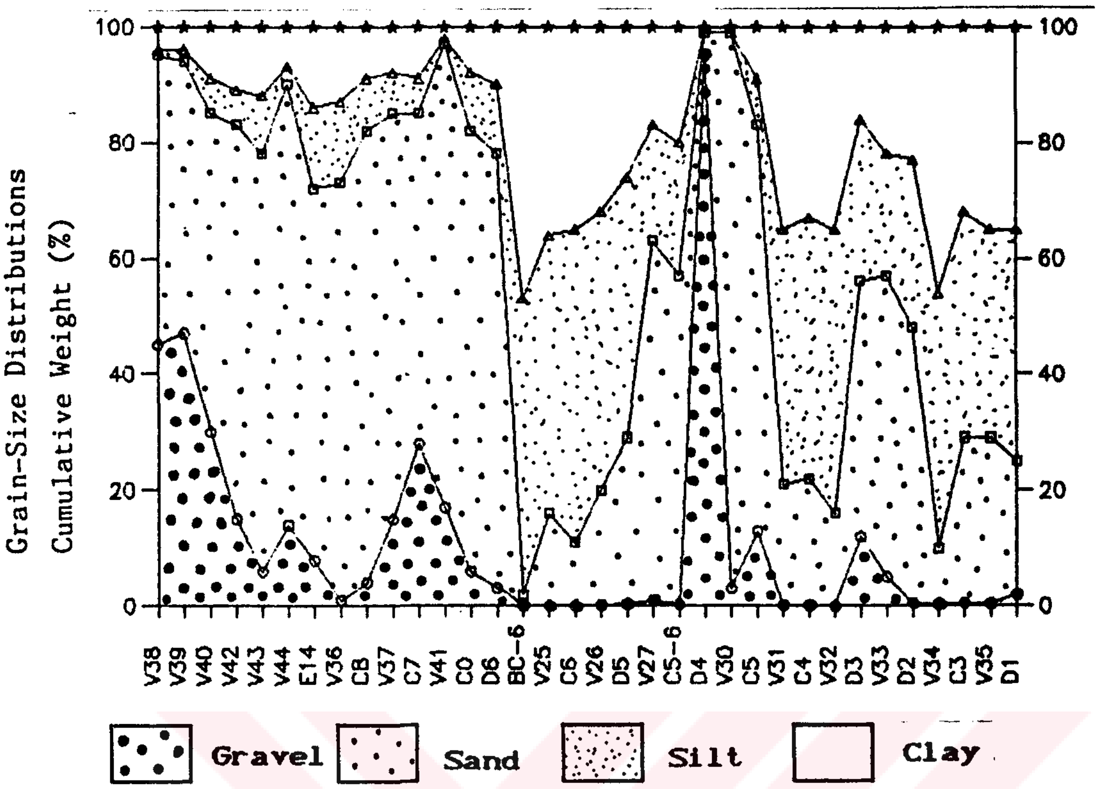

Figure 3.8 : Distribution of grain-size in the surface sediments from the junction of the Dardanelles Strait with the Aegean Sea.

channel (10-40 cm/sec) -in accordance with the Hjulstrom's diagram (Fig. 3.9)- would rather suggest accumulation only of coarser-grained sediments and consequently erosion and removal of finer-grained materials.

At the south-western Aegean exit of the strait, the surface sediments are rich in sand, with some additionally gravel and mud portions. Microscopic studies of the gravel fractions of sediments revealed that molluscan shell fragments (mainly pelecypods, gastropods) in reworked form, echinoids, bryozoans, barnacles, calcareous worm tubes, and

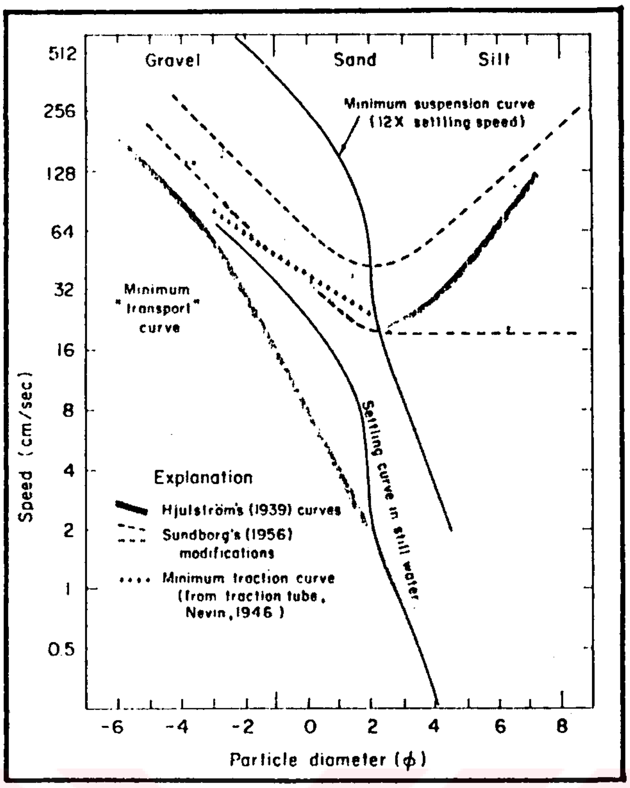

Figure 3.9 : Hjulstrom's Diagram (from Friedman and Sanders, 1978).

coralline algae are the common biogenous components. The terrigenous components are dominated by the organic debris (abundantly plant remains, coal, slug particles, and tarballs), quartz grains partly encrusted with calcite, and metamorphic rock fragments. It has also been found that biogenous components were more abundant than the terrigenous ones.

The sand fraction is dominated by the terrigenous materials mostly comprised of rounded quartz grains, and metamorphic rock fragments and organic debris (especially wood- and plant-tissues), with minor amounts of mica flakes and pyrite. Again here, pyritization within the foraminiferal tests is commonly observed at most places. The biogenous materials

are composed of molluscan shell fragments (pelecypods and gastropods) and benthic and planktonic foraminifers (*Uvigerina*, *Globigerina*, *Globorotalia*, *Elphidium*, *Ammonia*, *Bolivina*, *Bulimina*, *Textularia*, *Quinqueloculina*, *Triloculina*, and *Miliolina sp's.*), with subordinate amounts of ostracods, bryozoans (abundant at stations D3, V27, D5, V40, V39, and V38; Fig. 2.2f), echinoid-spine and -plates, sponge spicules, calcareous worm tubes (very common at st. C3), and fecal pellets (only at st. D1). The presence of the calcareous algae in both sand and gravel fractions is a prominent feature in this region. It is highly abundant at the junction of the Strait of Dardanelles with the Aegean Sea (Sts.; V41, C7, V37, C8, V36, E14, V44, V43, V42, V40, V39 and V38; Fig. 2.2f). In particular, a ridge- or bank-like bottom feature at some stations (C7, V37, V40) was characteristic for the calcareous algal communities.
The coralline algae is present both as nodules (up to 2 cm in diameter), and as calcified-branching fragments (mainly of the encrusting *melobesid* algae *Lithothamnium* with subordinate amounts of pelecypods and gastropods shells. Even in less amounts, living species of *Lithothamnium* are found. Examples of such coralline-algal sediments are well known from other regions elsewhere in the Mediterranean (Caulet, 1972; Goedicke, 1972; Milliman *et al.*, 1972; Campbell, 1982; and Alavi *et al.*, 1989) and are usually restricted to areas of shallow water depths, sandy and rocky bottoms. Although both warm and cold conditions may favor the growth of coralline algae (Flugel, 1978), most of these

organisms live in waters of tropical and subtropical zones with relatively warm and saline marine characteristic (Brandon, 1973). At the sampling stations (V41 to V38), surface water temperatures reflected great seasonal variations (8-23 °C) with salinities between 27 and 39 ppt, and oxygen contents from 4.5 to 7 ml/l. The subsurface temperatures were comparatively uniform in a narrow range from 12 to 17 °C and the salinities were nearly stable at 38-39 ppt. Oxygen concentrations did not differ much (5-7 ml/l) from that in the surface (Özsoy *et al.*, 1986; 1988; and from unpubl. data files of METU-IMS, 1990 and 1991). In this region, the bottom currents are usually less than 5 cm/sec (Sur, 1988). On the other hand, the absence of the coralline algae in bottom sediments within the channel probably indicates occurrences of high energy under-currents which can restrict the algal growth (UNEP/IUCN, 1988). Marked occurrences of echinoid fragments in the samples from southwest are represented by the high sand and gravel percentages of the sediments, which provide best living conditions for the echinoderms in this region (Demir, 1954). Sediment samples also contain diverse assemblages of benthic foraminifers which are characteristic of carbonate shelf environments around the Mediterranean Sea. These assemblages are often rich in a variety of rotaliids and miliolids (Alavi, 1989). Biological studies on sediment samples revealed that the pelecypods species *Galommatacea* and *Nucula sulcate*, and the gastropods *Cerithiospidae* and *Pyramidellidae* are completely restricted to the Dardanelles whereby the *Galommatacea* tended to increase in density towards the Marmara Sea, whilst *Nucula* was homogeneously distributed along the strait (Güre, 1990).

3.1.1.2. COLOR AND ODOR

"The color of sediments is mainly controlled by the chemical environment under which a certain sediment has been deposited Apart from this, mineralogical composition and amount of organic matter are the major factors responsible for the color of a sediment. Among the minerals the iron minerals are most important. Sediments having iron in oxidized form (Fe^{+3}) are generally brown to red in color, thus having iron in reduced form (Fe^{+2}) are gray to green. Thus, in general, brown- to red-colored sediments are an indication of deposition in an oxidizing environment, and gray colored sediments suggest deposition in a reducing environment. Gray- and dark-colored sediments (especially muds) generally possess high organic matter contents, which also points to deposition in a reducing environment. A green color in sediments is generally due to the presence of minerals such as chlorate and glauconite" (Reineck and Singh, 1975).

Initial studies of the gray or green colors of marine sediments are attributed to the presence of adsorbed organic matter, and yellow or brown colors to the presence of iron oxy-hydroxides in the sediments. Red or brown hues are attributed to oxidized (ferric) environments, green to green-gray colors to more reducing conditions (ferrous iron), however, both of these colors can be derived by the reversible oxidation or reduction of iron-rich smectites (Lyle, 1983). The depth to the brown-green transition provides a rapid way to estimate redox conditions in the sediments and a measure of the rate of depositional flux and consumption of organic carbon in sediments on a regional basis (Lyle, 1983). The brown-green transition in marine sediments is a measure of the rate at which oxidants are consumed within the sediment during organic carbon oxidation. This transition from brown to green in marine sediments marks the depth at which the nitrate in pore waters has been reduced and the Fe(III) reduced to Fe(II). Thin Fe(III)-bearing layers (brown color) occur under waters of high primary productivity (high organic carbon flux to sediments) or on topographic features that have higher sedimentation rates than surrounding areas (Lyle, 1983).

Surficial wet sediments from the Sea of Marmara and Turkish Straits, were generally greenish-gray to dark green and occasionally brown colors were also observed by naked-eye on board. Emelyanov (1972) has also pointed out that sediments from geosynclinal areas in the Mediterranean (including the Marmara Sea) are usually gray in color. Besides, in most cases, slightly greenish-gray to brown and also reddish-brown colors were observed in the upper sediment layers, especially at the top of cores but also insome surficial sediments (sts. K27L00, K27L04, V8, BC-3, BC-4, BC-5, BC-6) (Fig. 2.2b to 2.2f).

In the upper 15 cm of the cores, sediments showed reddish-brown (from pale-yellowish brown to dark yellowish-brown) colors attributable to oxidation of iron and the notation ranges. There was no odor which could be evidence for H_2S-formation of anoxic depositional environment, although along the Strait of Bosphorus and elsewhere in the Sea of Marmara, sediment samples were generally marked by fish- and/or sewage-odor. As a whole, it seems that the majority of the sediments must have been deposited under oxic conditions, although it seems that anoxic conditions might have been developed usually after some time of burial of sediments. The early diagenetic reactions or the redox state of the sediment may be partly reflected by the color of the sediments.

3.1.1.3. CONCLUSION

The surface sediments from the investigated area (the Sea of Marmara and its straits) are associated with wide variations of percentages in their grain-size ranging from 0 to 95 % for gravel (mean: 8 %) (including pebbles), from about <1 to 98 % for sand (mean: 23 %) and from 0 to 98 % for mud (silt and clay) (mean: 69 %). The surficial distribution of sediments from the Sea of Marmara is illustrated in Fig. 3.10.

Biogenic gravel fractions are principally composed of the molluscan shell fragments of various pelecypod species (such as; *Mytillus galloprovincialis*, *Modiolus barbatus*, *Corbula gibba*, *Gafrarium minima* and *Venus ovata* with the subordinate

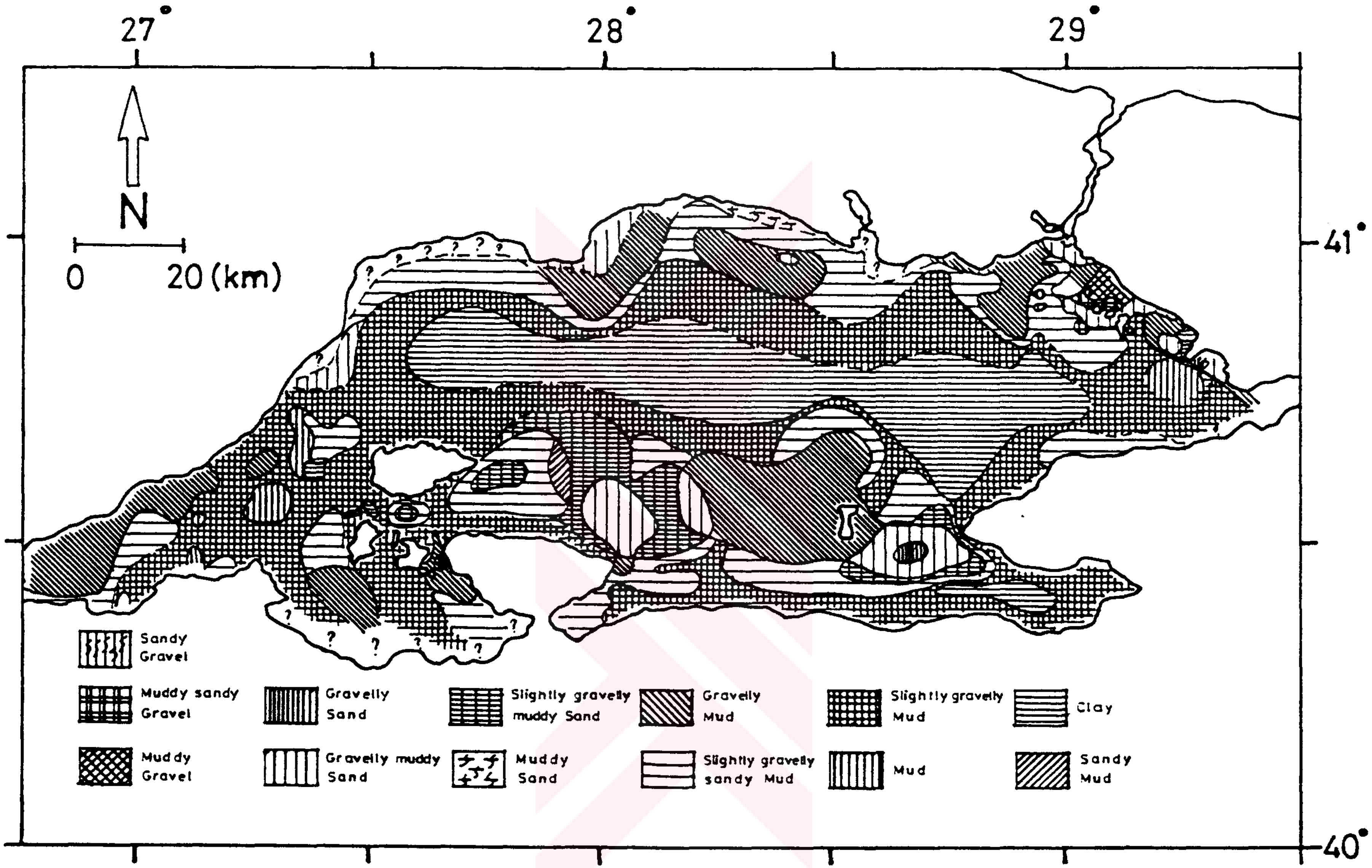

Figure 3.10 : Lithofacies map of the Sea of Marmara. Sediment classification according to grain size using Folk's (1974) scheme.

amounts of *Ostrea edulis*). The gravelly sediments from the marginal parts of BMJ, DAJ and some stations from MDJ [C2X(1), V46, and V50] were made up mainly of calcareous *Rhodophyceae* chiefly *Lithothamnium calcareum*, *L. fruticolusum* and *Lithophyllum racemus*. The occurrences of the coralligenous sediment on those regions can be attributed to more calm conditions on hydrography and a limited amount of terrigenic supply.

The sand portions of surface sediments from the Sea of Marmara and its straits generally vary inversely with depth, but relatively high sand contents (>30 %) are found in near-shore areas and along the Bosphorus and Dardanelles Straits, as well as, in their open-sea junctions. This fraction is mainly composed of terrigenous materials with subordinate amounts of biogenous ones. Terrigenous components include subrounded and partially well-rounded quartz grains, mica flakes, and metamorphic (schist and quartzite), basic/ ultrabasic, and sedimentary rock fragments and also organic debris (wood-, plant-tissues in mostly fibreous form, coal, slug and tarball particles). Emelyanov (1972) found that the quartz to feldspar ratio is usually less than 1 and plagioclase, hornblende, epidote, zoisite are typical.
The mineral grains and various kinds of rock fragments may most probably be originated from different petrographically different provinces or outcrops from surrounding land masses of the Sea of Marmara (Fig. 1.4).

The mud-sized particles (mostly silty clays) are predominantly concentrated in the offshore (10 km away from the coast) areas and especially in deep basins of the Sea of Marmara (Fig. 3.11). Mud (silt and clay) contents range from 0 to 100 % and increase-decrease significantly (Table 3.7) with water depth; the highest concentrations occur in the deepest parts of the Marmara Sea and the Bay of Gemlik.

Table 3.7 : The correlation coefficient matrix of the various parameters measured in the surficial sediments from the Sea of Marmara and the Straits of Bosphorus and Dardanelles (N=216, p=0.05, r=0.14).

	Depth	Gravel	Sand	Silt	Clay	Mud	org.C	$CaCO_3$
Depth	1.00	-.15	-.22	-.02	.36	.24	.09	-.18
Gravel	-.15	1.00	.25	-.61	-.59	-.69	-.25	.71
Sand	-.22	.25	1.00	-.64	-.83	-.87	-.60	.48
Silt	-.02	-.61	-.64	1.00	.48	.79	.47	-.58
Clay	.36	-.59	-.83	.48	1.00	.92	.53	-.65
Mud	.24	-.69	-.87	.79	.92	1.00	.58	-.72
org.C	.09	-.25	-.60	.47	.53	.58	1.00	-.24
$CaCO_3$	-.18	.71	.48	-.59	-.65	-.72	-.24	1.00

The surficial wet sediment samples from the Bosphorus- and Dardanelles-Straits and Marmara Sea, were generally greenish-gray to dark green and occasionally brown colors occured. Besides, in most cases, slightly greenish-gray to brown and also reddish brown colors were observed in the uppermost layers of sediments in form of thin films, especially in the top sections of the core samples but also

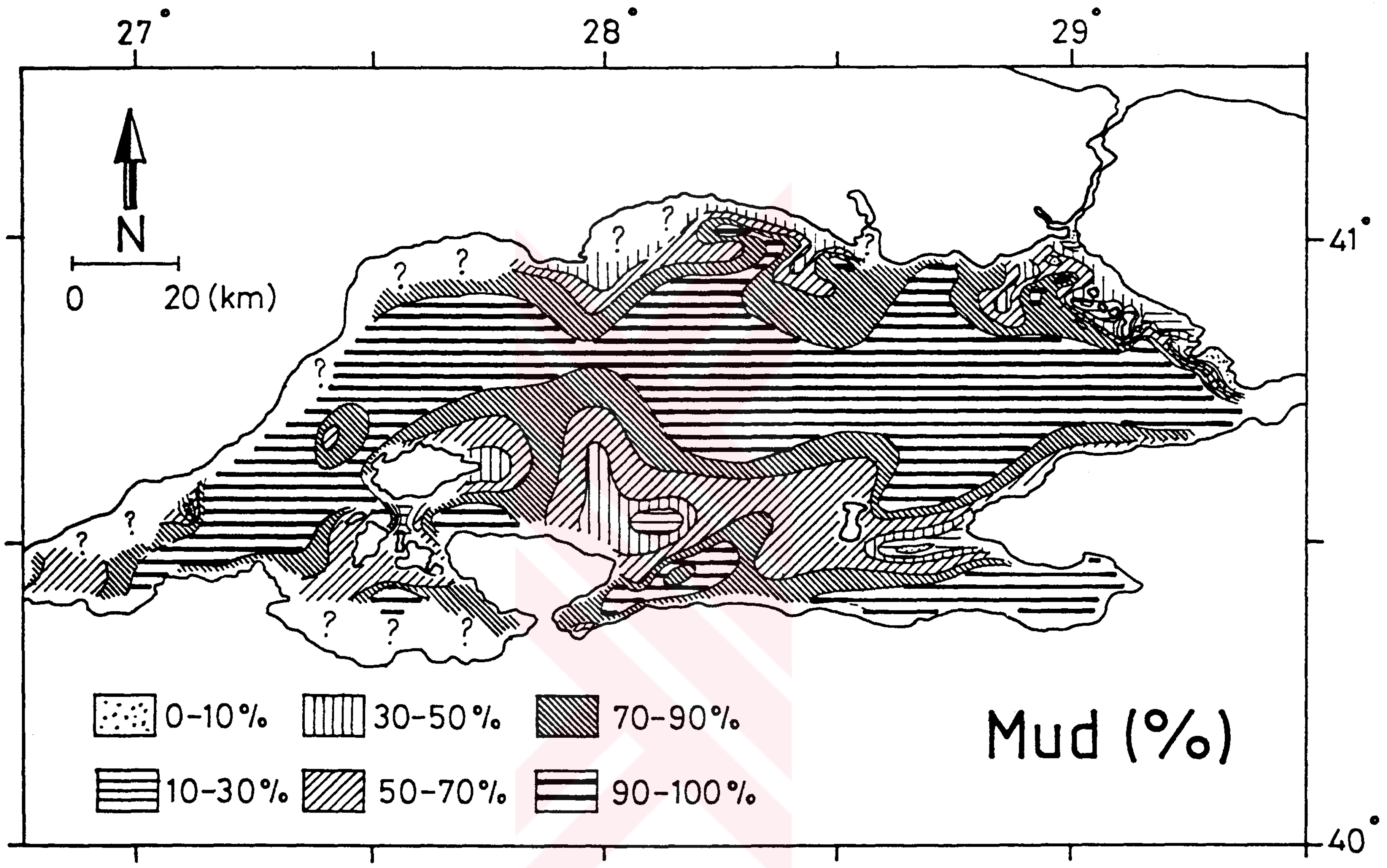

Figure 3.11 : Mud distribution map in the surface sediments from the Marmara Sea.

the surficial sediments (sts. K27L00, K27L04, V8, BC-3, BC-4, BC-5, and BC-6) (Fig. 2.2b to 2.2f). As a whole, it seems that the majority of the sediments must have been deposited under oxic conditions, although anoxic conditions might be developing locally after some time of burial of the sediments.

The moisture content of the studied sediments ranges from 23 to 137 % with an average of 80 % (Appendix 1.1). The high moisture percentages are usually related to the presence of clay fractions in the samples, especially in the deep basins and Gemlik Bay. Emelyanov (1972) also showed that sediments from geosynclinal areas in the Mediterranean (including the Marmara Sea) had a moisture content ranging from 24 to 81 %. The high absorbance capacity of the clay minerals explains the moisture contents of the studied samples.

3.1.2. GEOCHEMISTRY OF THE SURFACE SEDIMENTS

In this section, geochemistry the distribution of organic carbon, carbonate and heavy metal concentrations in the surficial sediments will be discussed in detail on the regional basis and given brief conclusions at the end of in each subsection.

3.1.2.1. ORGANIC CARBON

Numerous studies have shown (Bordovskiy, 1965; Trask, 1968; Gross *et al.*, 1972; and Romankevich, 1984) that the organic carbon contents of sediments change with a number of parameters. The sedimentary organic carbon associated with high primary productivity rates was generally high in sediments due to oxygen deficiency and the high sedimentation rates (Ibach, 1982). Organic matter in the Recent Marmara sediments has been a subject of intensive investigations during the last few years (METU-IMS, 1985 to 1991). In the Sea of Marmara, the local and seasonal changes in the surface primary productivity, depth of halocline, meteorological conditions, rate oxygen utilization, and influxes from the Black Sea *etc.* are the main factors controlling the distribution of organic carbon (Baştürk *et al.*, 1988; Ünlüata and Özsoy, 1986; Polat, 1989).

3.1.2.1.1. REGIONAL DISTRIBUTION

THE STRAIT OF BOSPHORUS (BS) : The organic carbon contents of the Bosphorus sediments ranged from 0.22 to 1.37 % with an average of 0.70 % by dry weight, being normally high in the fine-grained (<63 μ) sediments (1.37 and 1.07 % at stations; B11 and K0, respectively), but low in the coarse-grained (>63 μ) sediments (0.22-0.93 %, with the exception of stations; B0, B11 and B13, those exceed 1 %) (Table 3.1 and Fig. 3.12).

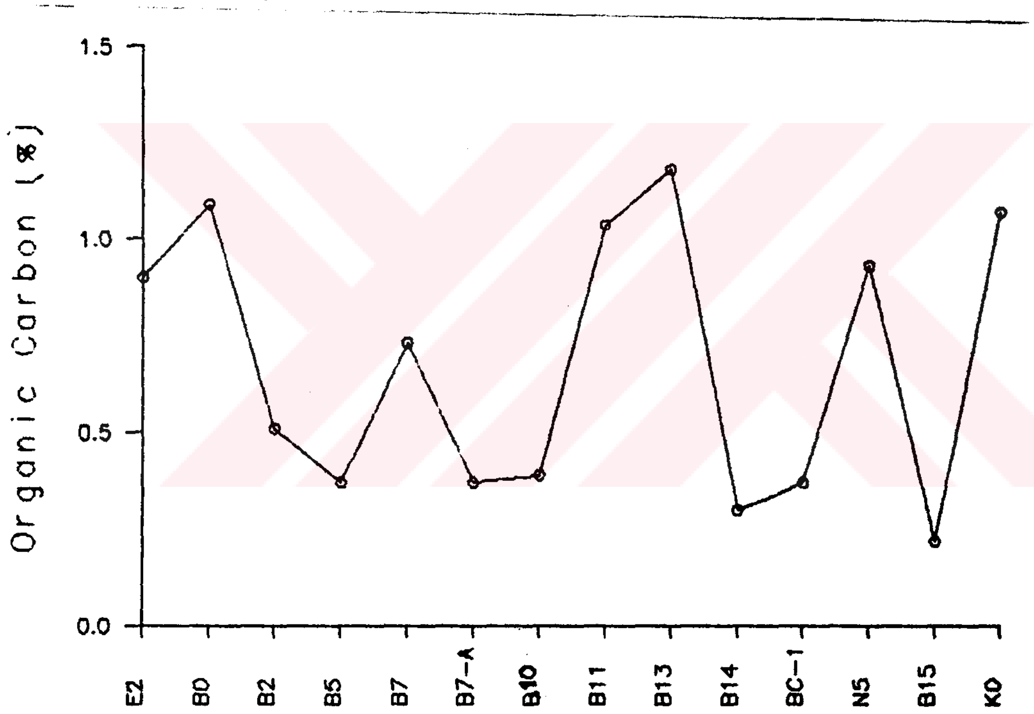

Figure 3.12 : Distribution of organic carbon concentrations in the surface sediments along the Strait of Bosphorus.

This probably suggests significant relationship between grain-size and organic carbon (Fig. 3.13), which in turn, indicates changes in the topography and current energy.

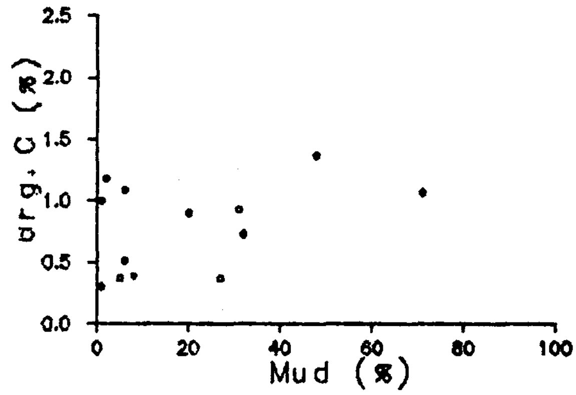

Figure 3.13 : **Plots of organic carbon and mud percentages in the surface sediments along the Strait of Bosphorus.**

These values are remarkably low when compared with organic carbon data from the Golden Horn estuary (Erdem, 1988 and Ergin *et al.*, 1988) but similar to those reported from İzmit Bay (0.35 to 1.62 %; Ergin and Yörük, 1990) (Table 3.9). Hirst (1974) gives an average value of 2 % for the organic carbon in sediments from the Bosphorus-Black Sea Junction. Other organic carbon values reported from the Black Sea-Bosphorus region fall between 0.13 and 2 %, depending on the nature of sediments (Shimkus and Trimonis, 1974; Yücesoy, 1991). The high org.C values are found in fine sediments (Yücesoy, 1991). The high organic carbon concentrations in the Black Sea sediments are normally taken to imply the high primary productivity rates in this region (Pedersen and Calvert, 1990).

JUNCTION OF THE BOSPHORUS STRAIT WITH THE SEA OF MARMARA (BMJ) :
The organic carbon concentrations at the Bosphorus-Marmara Junction, vary from 0.37 to 2.16 % with an average value of about 1.13 %, by dry weight (Table 3.2). These values are comparably higher than those found within the Bosphorus channel (avg. 0.70 %), where the deposition of the produced organic matter is lesser than the transportation of it. High organic carbon values are concentrated in nearshore areas off Bakırköy and Yenikapı at the European side and off Fenerbahçe, Pendik and Burgaz Island at the Asian side of the BMJ (Fig. 3.14). It has been shown that not only the fine materials but also the coarse sediments display high organic carbon percentages (Fig. 3.15). However, fine sediments in the studied area are, by far, the main association of organic matter.

In study area, the coarse fractions (gravel and sand) of the sediments are mostly comprised of skeletal remains of benthic organisms dominated by branched calcareous algae (encrusted with calcite). The high organic carbon contents associated with such coarse sediments (2.16, 1.87, 1.73, 1.70, 1.66, 1.60 and 1.55 % org.C) are found at sts.; (M1(2), M2, A18, M1(1), A26, E4 and V1 respectively). This is consistent with the high org.C levels of sediments associated with the benthic communities (Romankevich, 1984). According to Lyle (1983), highly productive waters are marked by the high fluxes of organic carbon to the sediments. As has been pointed out by numerous studies, the Bosphorus-Marmara Sea

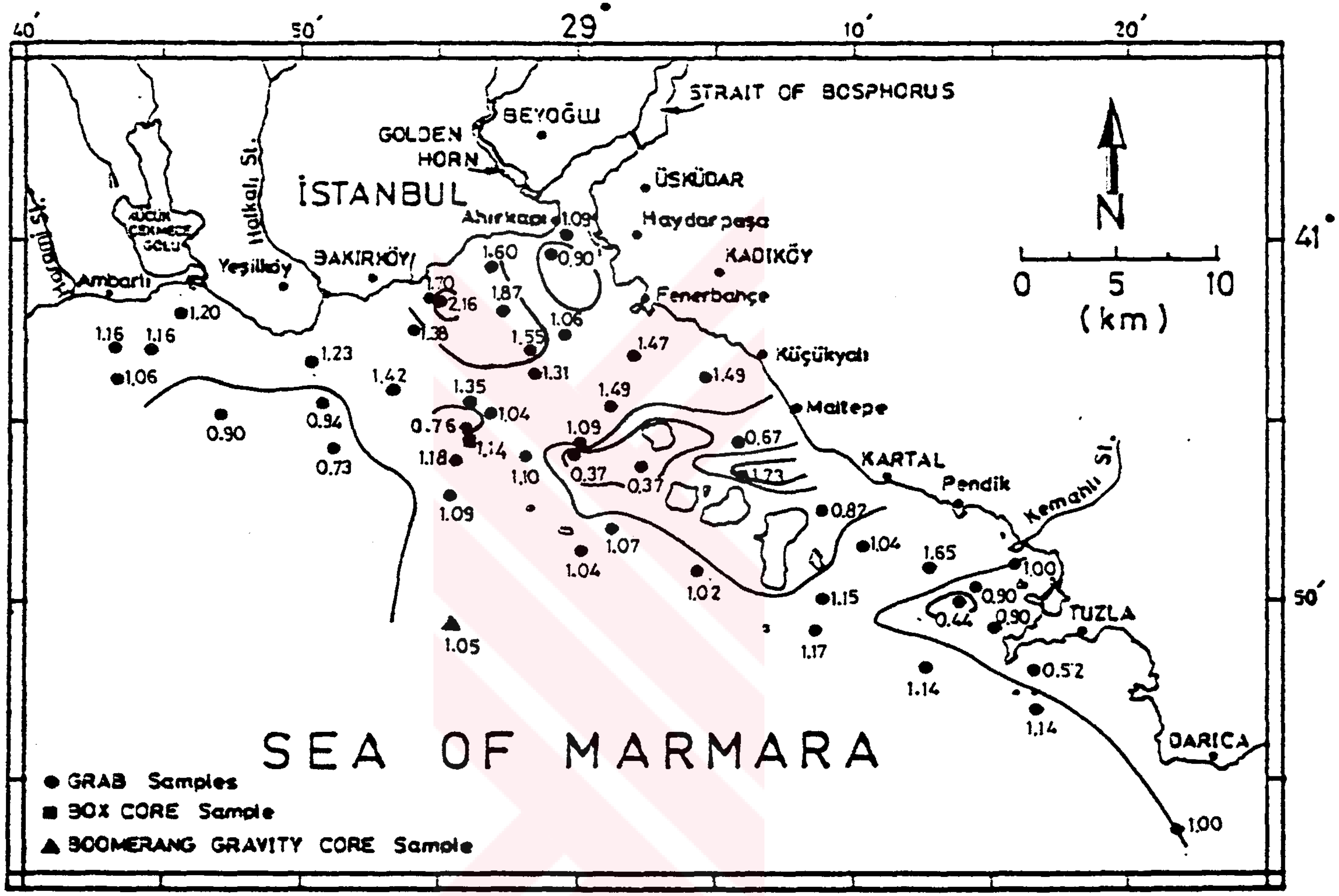

Figure 3.14 : Distribution of organic carbon concentrations in the surface sediments from the junction of the Bosphorus Strait with the Sea of Marmara.

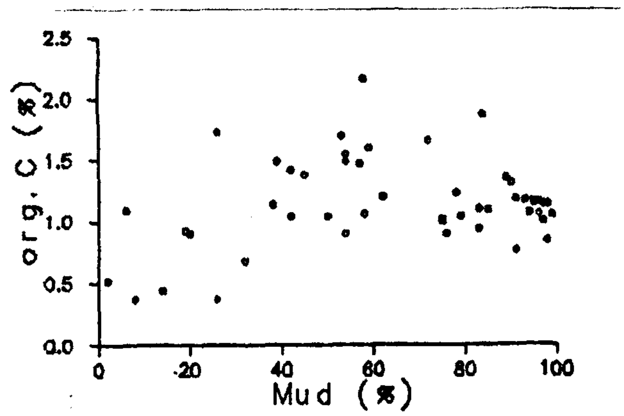

Figure 3.15 : Plots of organic carbon vs. mud percentages in the surface sediments from the junction of the Bosphorus Strait with the Sea of Marmara.

Junction is one of the most productive areas in the Marmara Sea (Ünlüata and Özsoy, 1986; Baştürk *et al.*, 1988; Göçmen, 1988; Polat, 1989). The region surrounding the Bosphorus-Marmara Junction produces organic matter not only by *in-situ* processes but also imparts significant amounts of organic matter produced within the Black Sea (Ünlüata and Özsoy, 1986). Therefore, the organic carbon concentrations of the sediments from this region may be related to the occurrences of high primary productivities, the influxes, the adjacent domestic land-sources and, partly to the Black Sea influx.

NORTHERN SHELF OF THE SEA OF MARMARA (NSM) : On the northern Marmara shelf, the organic carbon contents of the sediments vary between 0.57 and 1.64 % (mean; 1.06 % by dry weight) (Fig. 3.16 and Table 3.3). These values are associated with the generally high mud percentages of sediments (Fig. 3.17) (more than 50 %), except for the two

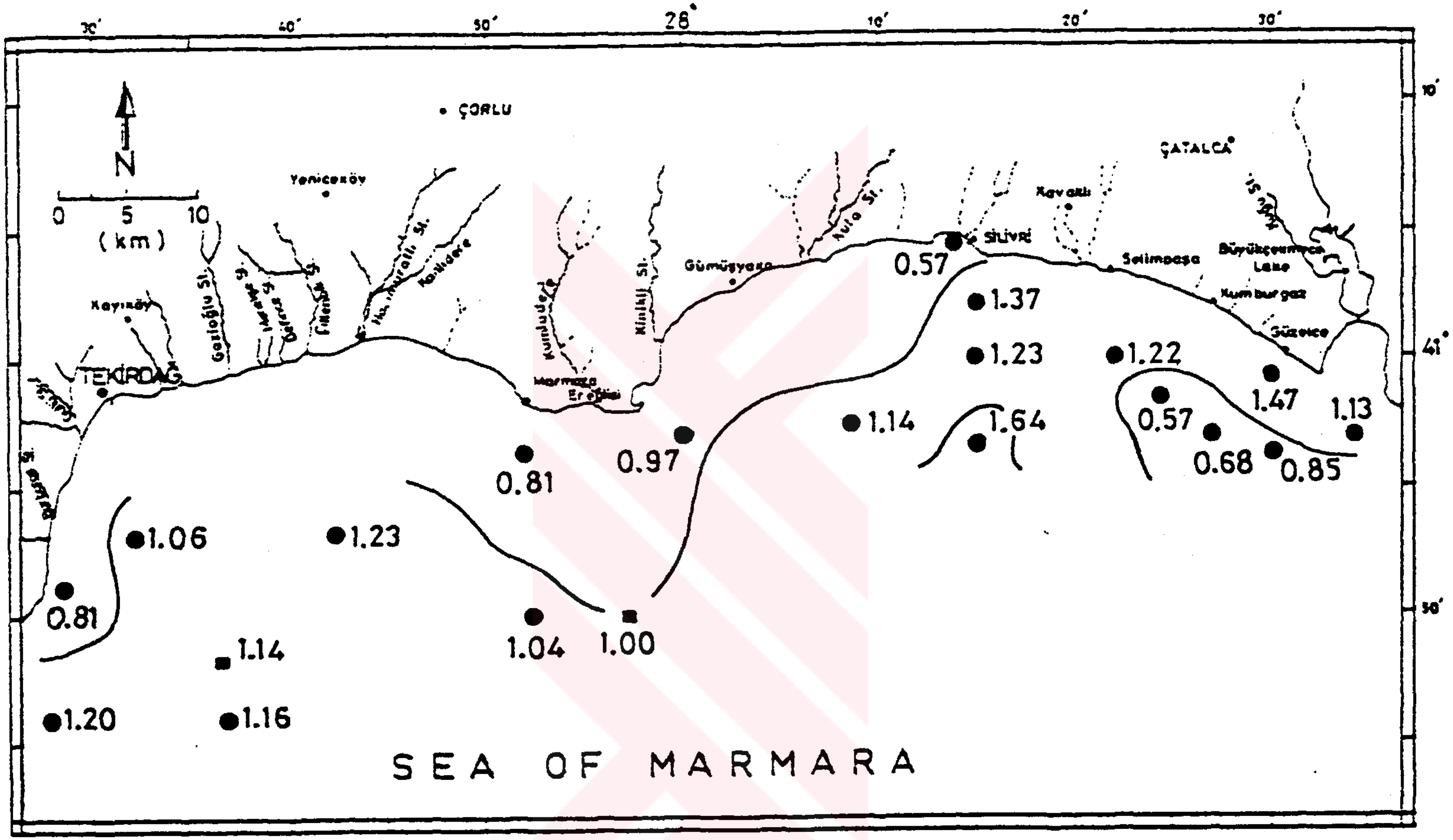

Figure 3.16 : Distribution of organic carbon concentrations in the surface sediments from the northern shelf of the Sea of Marmara.

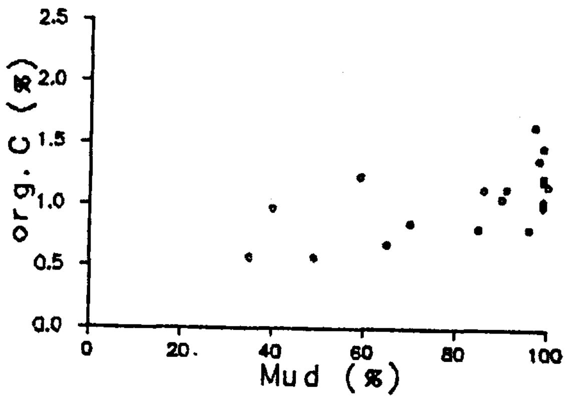

Figure 3.17 : Plots of organic carbon vs. mud percentages in the surface sediments from the northern shelf of the Sea of Marmara.

stations (N4 and N19; 0.57 % org.C). The influence of terrigenous supply is perceptible mainly in the variable content of organic matter, such as plant- and wood-tissues, slug, tarball and shiny coal-like materials present in the coarse fractions (>63 μ) of samples. The role of primary productivity should be considered as an important source of organic matter in these sediments.

SOUTHERN SHELF OF THE SEA OF MARMARA (SSM) : The organic carbon contents of the surface sediments from the southern Marmara shelf range between 0.44 and 1.90 % with an average value of about 1.01 %, except for the three stations N1 (0.35 %), N16 (0.26 %) and N12 (0.30 %) (Table 3.4). As it seen on Fig. 3.18, the maximum org.C concentration (1.90 %) was obtained in the deper-water sediments (station K40K52; 200 m), where apparently both land-based and marine sources must have delivered significant amounts of organic matter.

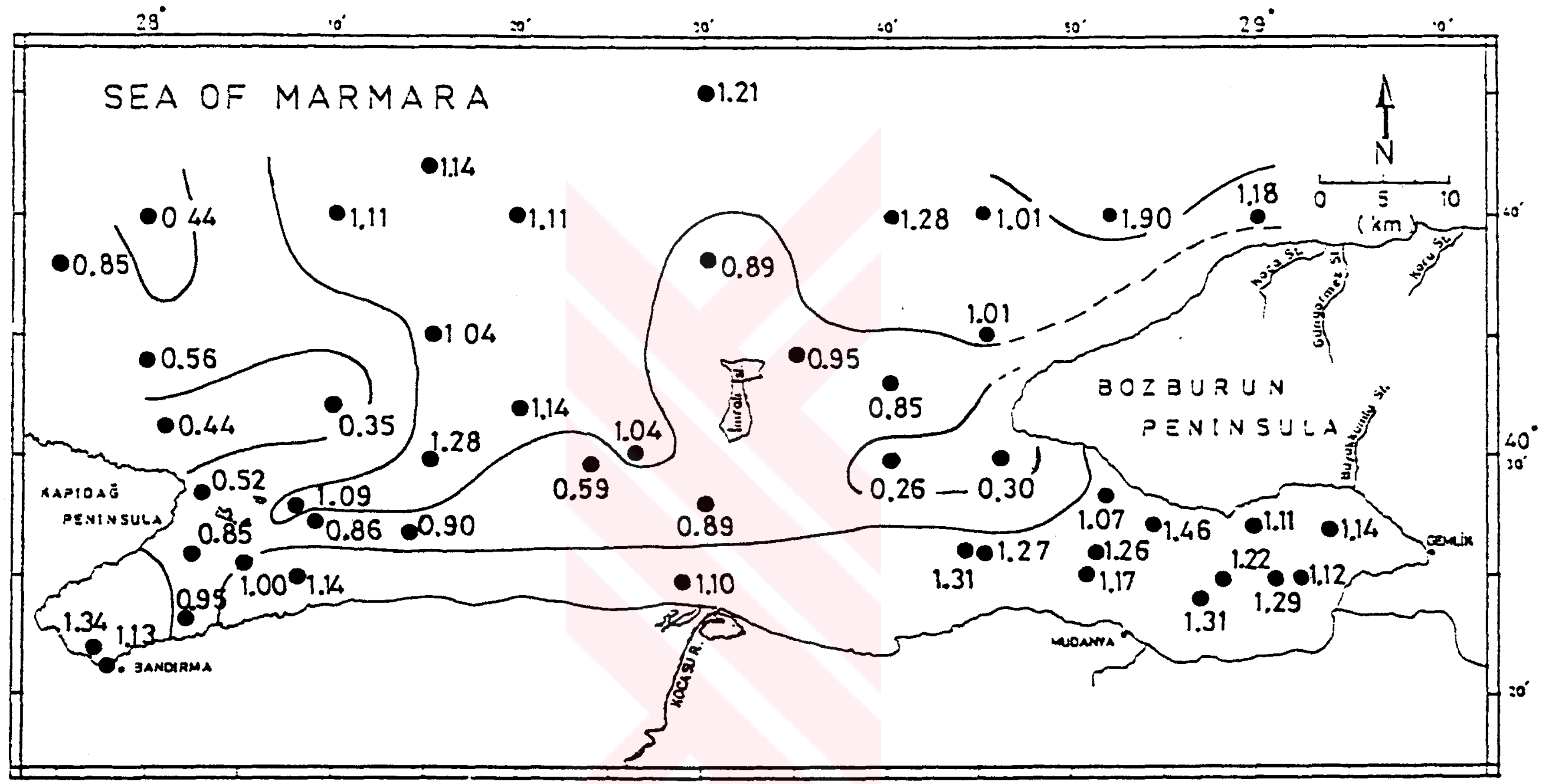

Figure 3.18 : Distribution of organic carbon concentrations in the surface sediments from the southern shelf of the Sea of Marmara.

In the Bays of Gemlik and Bandırma, organic carbon concentrations exceeded 1 %, because of the occurrences of large amount of mud portions (over 98 %). Although the microscopic studies revealed the presence of wood- and plant-tissues in the samples, it is believed that a great part of organic matter in the samples was bound to the fine-grained fractions because of the high occurrences of clay concentrations. This suggestion also confirms that there is a correlation, inferring from Fig. 3.19, between organic carbon and mud percentages.

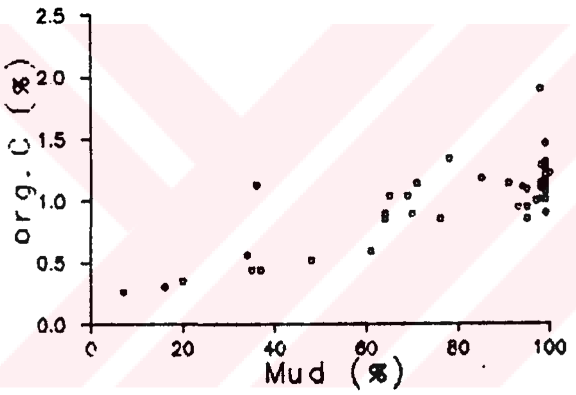

Figure 3.19 : Plots of organic carbon vs. mud percentages in the surface sediments from the southern shelf of the Sea of Marmara.

JUNCTION OF THE SEA OF MARMARA WITH THE DARDANELLES STRAIT (MDJ) : At the Marmara Sea-Dardanelles Junction, the organic carbon contents of the surface sediments vary from 0.37 to 1.51 % having an average value of 0.93 % (Table 3.5). In the bottom sediments, their distribution is illustrated in Fig. 3.20.

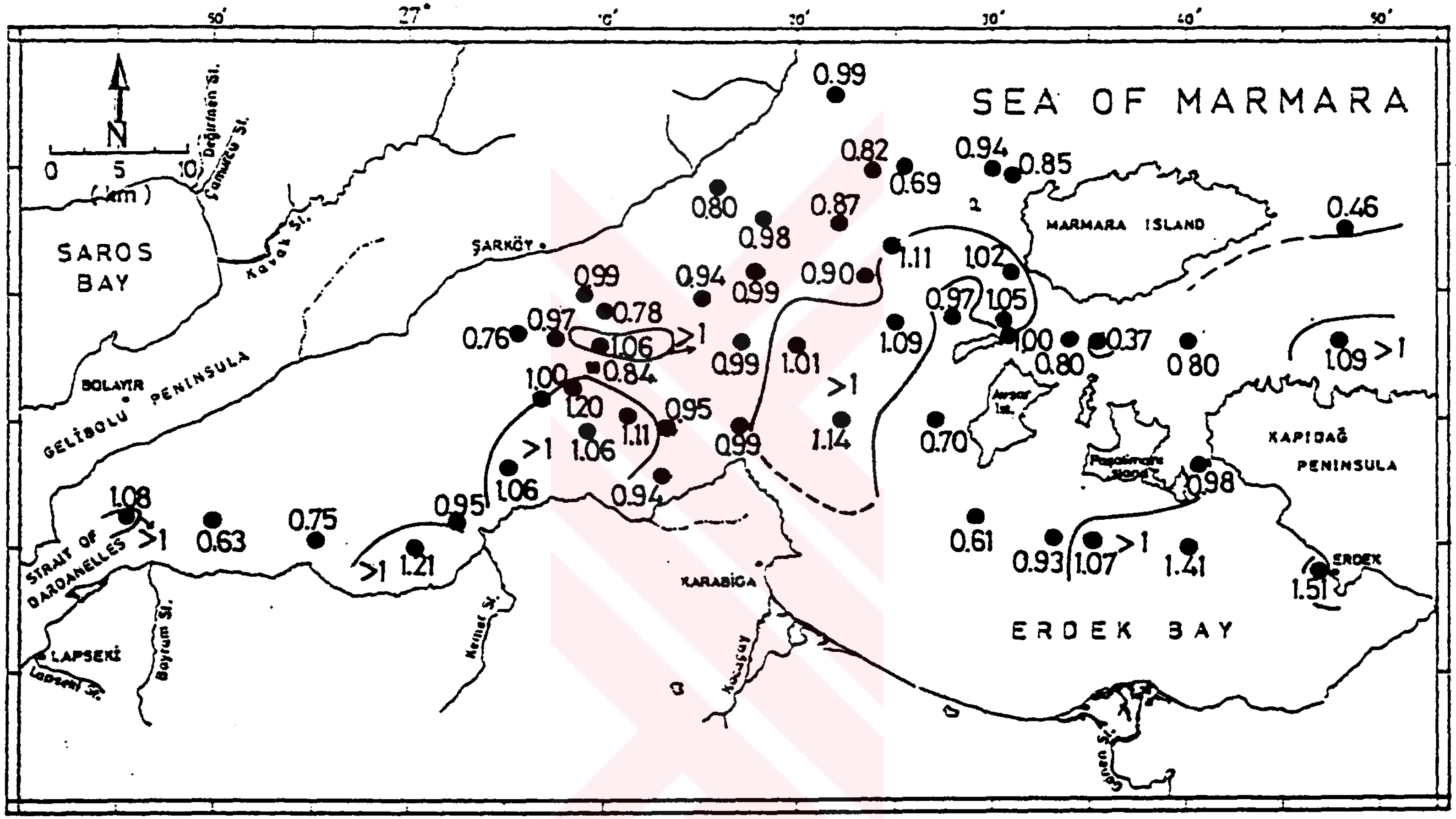

Figure 3.20 : Distribution of organic carbon concentrations in the surface sediments from the junction of the Sea of Marmara with the Dardanelles Strait.

The lowest org.C contents (0.37-0.46 %) are obtained at stations V51 and V17 where the sediments are made up of the gravelly-muddy sand. The org.C concentrations reached their maximum values in the nearshore areas of Erdek Bay, where relatively high portions of materials are observed due to presence of wood- and plant-tissues in coarse fractions of the samples, as shown by the microscopic examination, and it is also inferred from Fig. 3.21 that in general, there is a consistency between organic carbon and finer fractions of sediment samples. Compared with the Marmara Sea-Bosphorus Junction, the sedimentary organic carbon levels at the Marmara Sea-Dardanelles Junction are comparably low. This is probably due to lower primary productivity rates in the latter (Baştürk *et al.*, 1988).

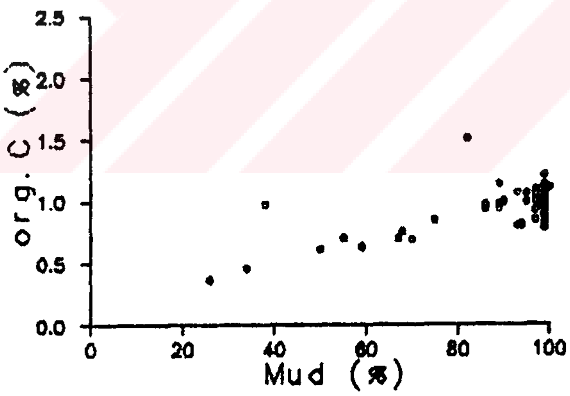

Figure 3.21 : Plots of organic carbon vs. mud percentages in the surface sediments from the junction of the Sea of Marmara with the Dardanelles Strait.

JUNCTION OF THE DARDANELLES STRAIT WITH THE AEGEAN SEA (DAJ) :

In the Dardanelles Strait and its junction with the Aegean Sea, the concentrations of organic carbon vary from 0.10 to 1.13 % with an average value of 0.57 % (Fig. 3.22). These

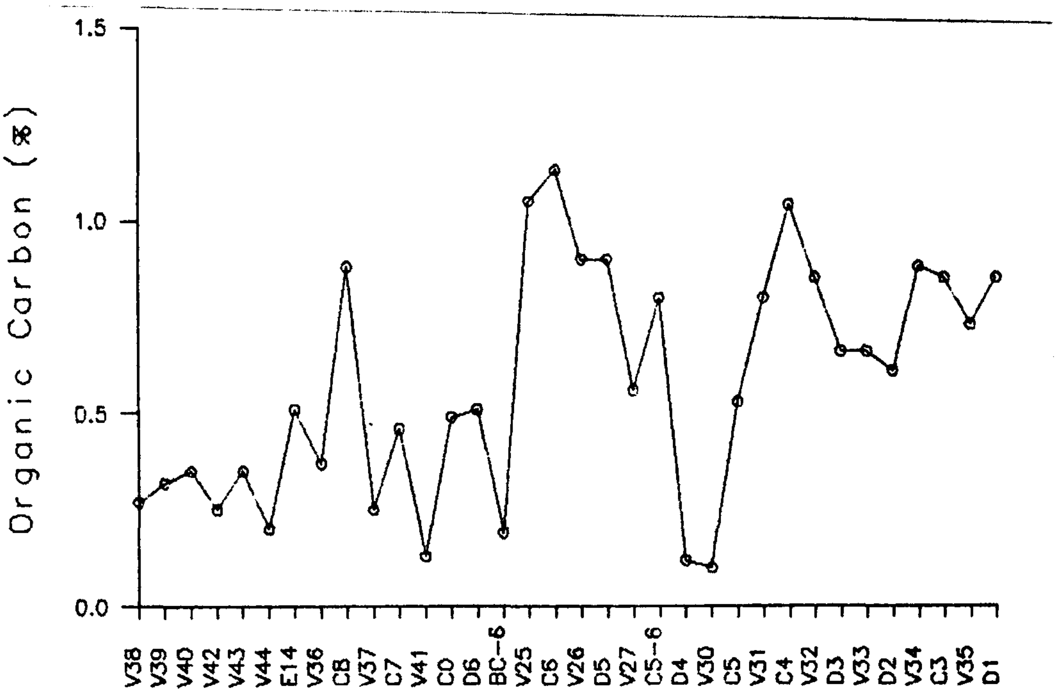

Figure 3.22 : Distribution of organic carbon concentrations in the surface sediments from the junction of the Dardanelles Strait with the Aegean Sea.

values seem to be comparable with those previously reported in this region (Ergin *et al.*, 1991a; 0.19 and 1.17 %). Slightly higher org.C values are found in the other regions of the Sea of Marmara (BS, 0.70; MBJ, 1.13; NSM, 1.06; SSM, 1.01 and MDJ, 0.93 %). According to Baştürk *et al.* (1986, 1988) and Polat (1989), the surface-flowing Black Sea waters, which are rich in organic matter because of the relatively high primary productivity and terrigenous influxes, are subject to exchange with the subsurface-flow of Mediterranean waters (poor in organic matter) in the Dardanelles Strait to increase the total organic carbon concentration of the bottom water layers. From this, it appears that such a water-mass exchange of between the Black and Mediterranean Sea waters in the Dardanelles would also contribute to the increased organic influxes to the sediments there. Because such an exchange is less significant at the Dardanelles Strait and its junction with the Aegean Sea, both the lower water layers and bottom sediments here are generally low in their organic carbon contents (avg. 0.62 mg C/l in lower water layers: Polat, 1989; 0.57 % in the sediments from the Dardanelles-Aegean Sea Junction). Consequently, sediments when approaching to the Bosphorus Strait or respectively Black Sea, should therefore show higher organic carbon contents which is the case in this study. The higher values of organic carbon concentration (over 0.50 %) usually correspond to the higher mud concentrations (over 70 %) in the samples (Fig. 3.23), especially those from the strait's channel. For example, stations: C8, V26, C6, V25, D5, C5-6, V31, V32, V34, C3, C4 and D1 (Fig. 2.2f) contained, more than 0.80 % organic carbon. In particular, samples from stations V26, V25, C6 and also D1 with great amounts of wood- and plant-tissues, displayed maximum values of organic carbon (over 1.00 %).

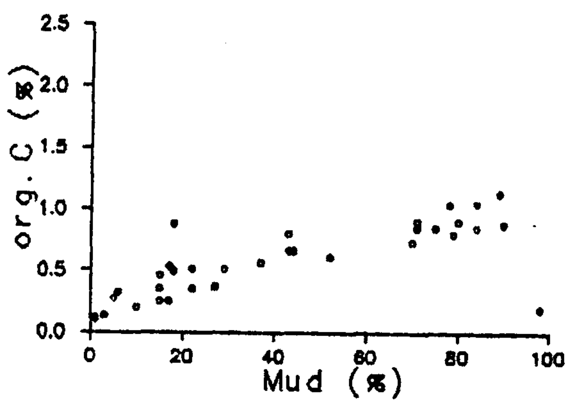

Figure 3.23 : Plots of organic carbon vs. mud percentages in the surface sediments from the junction of the Dardanelles Strait with the Aegean Sea.

3.1.2.1.2. CONCLUSION

The organic carbon concentrations of the surface sediments in the Sea of Marmara and its straits reflected marked lateral variations, being low towards the Aegean Sea but high towards the Black Sea (0.70 % at BS; 1.13 % at BMJ; 1.06 % at NSM; 1.01 % at SSM; 0.93 % at MDJ and 0.57 % at ADJ). Compared with data from the Eastern Aegean (0.35 % org.C; Voutsinou-Taliadouri and Satsmadjis, 1982; and 0.6-0.8 %, Emelyanov, 1972; and 0.30-0.70 %, Ergin *et al.*, 1990a) and North-eastern Mediterranean sediments (0.22 % org.C; Yılmaz, 1986, and 0.4-0.8 %, Emelyanov, 1972), the Marmara sediments contain somewhat higher organic carbon contents, mainly, as a result of differences in the marine production rates. This is common in many marginal seas where the sea is much more productive (Pedersen and Calvert, 1990).

However, the distribution of organic carbon within the sediments (Fig. 3.24) seems to be affected by the grain-size in different ways. In particularly, at the Marmara Sea-Bosphorus Strait Junction, where benthogenic -shelly gravel and sand were predominant deposits- sediments may bear large amounts of organic matter. Here, the org.C contents of the sediments were marked by the presence of corals, bryozoan and *Lithothamnium calcareum* and *Lithothamnium corallinoides*. Otherwise, the organic carbon contents of the sediments were related to their fine texture; finer-grained sediments invariably contained more organic carbon (Fig. 3.25),

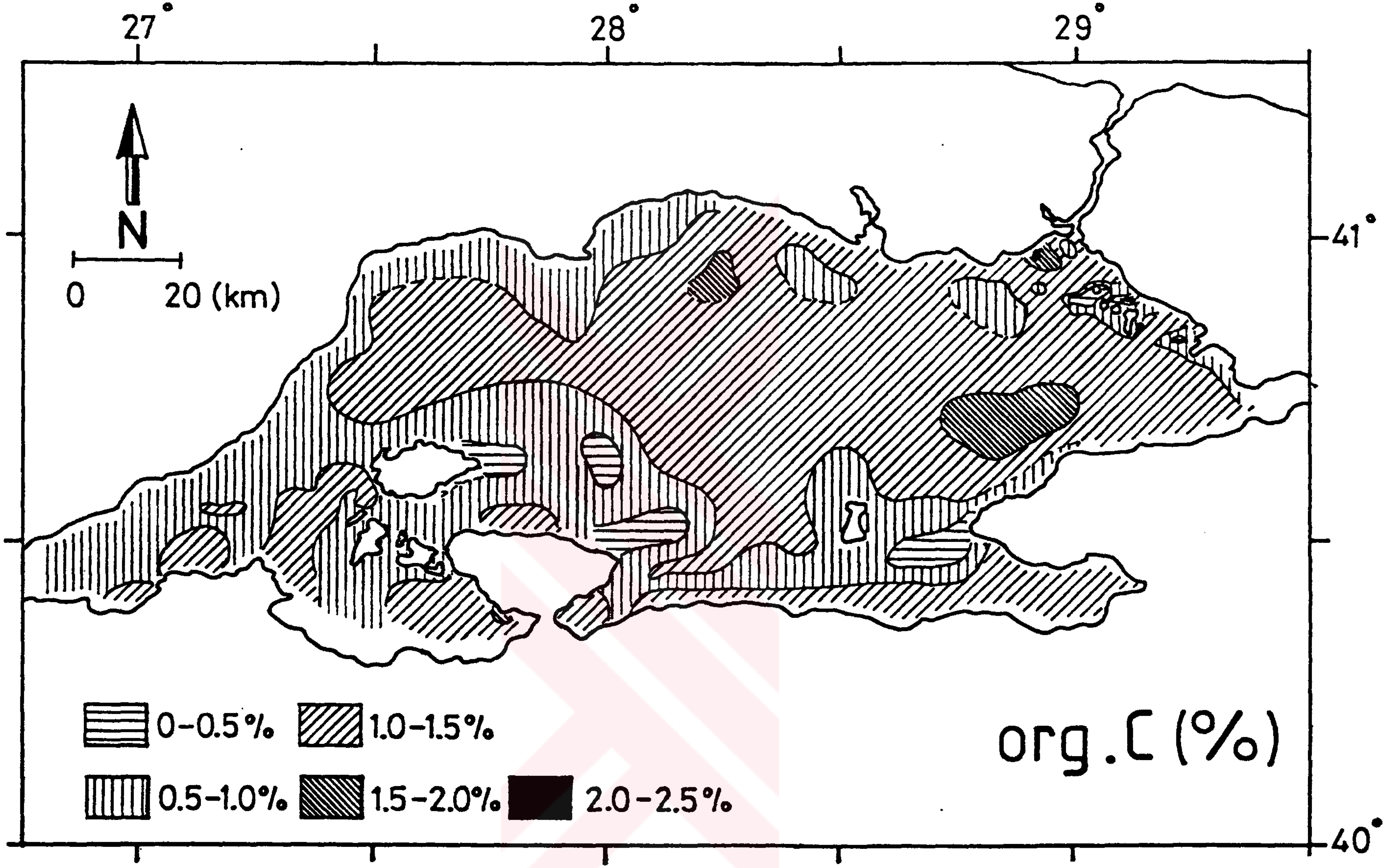

Figure 3.24 : Organic carbon distribution in the surface sediments from the Sea of Marmara.

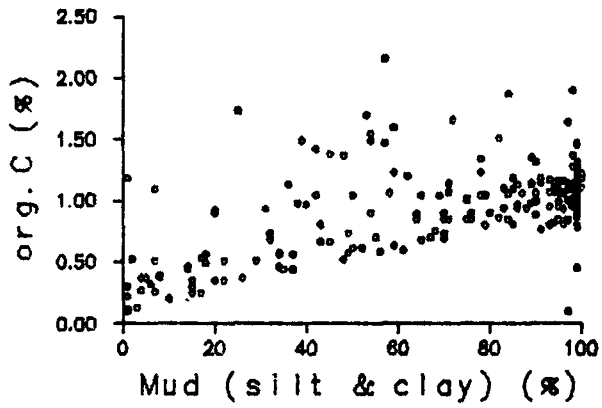

Figure 3.25 : Plots of organic carbon vs. mud percentages for all surface sediment samples from the Sea of Marmara.

presumably because particulate organic matter acts as the hydraulic equivalent of fine sediment particles, as shown by Calvert (1987).

3.1.2.2. TOTAL CARBONATES

3.1.2.2.1. REGIONAL DISTRIBUTION

THE STRAIT OF BOSPHORUS (BS) : The total carbonate contents (as % $CaCO_3$) of the surface sediments from the Bosphorus Strait range between 2 and 88 % with an average value of 37 %, by dry weight (Table 3.1 and Fig. 3.26).

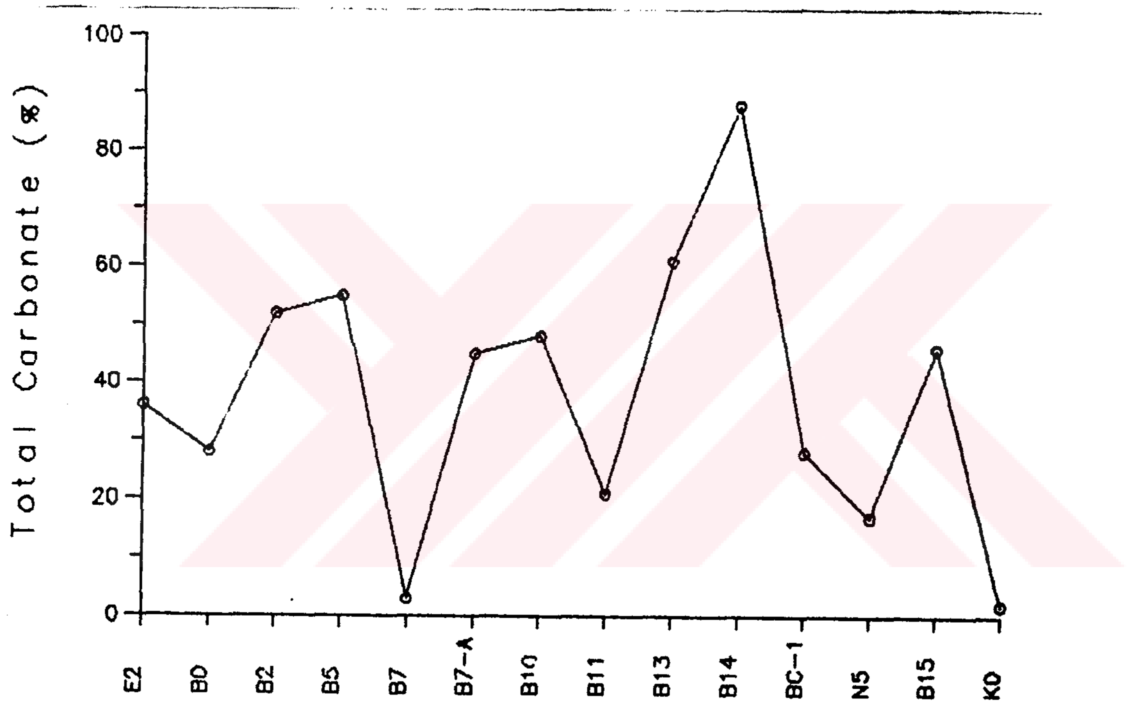

Figure 3.26 : Distribution of total carbonate percentages in the surface sediments along the Strait of Bosphorus.

Microscopic studies revealed that the measured carbonate values are consistent with the varying abundances of biogenic materials (mainly macrobenthos) in the samples, represented by the skeletal remains of calcareous organisms such as pelecypods (especially *Ostrea edulis*, *Mytilus* *galloprovincialis*; Güre, 1990; Mutlu, 1990 pers.com) and other molluscan species. As expected, high carbonate values are inversely correlated with the mud contents in the samples (Fig. 3.27).

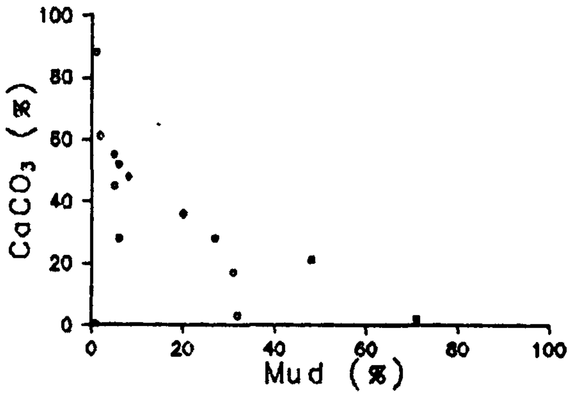

Figure 3.27 : Plots of carbonate vs. mud percentages in the surface sediments from the Strait of Bosphorus.

JUNCTION OF THE BOSPHORUS STRAIT WITH THE SEA OF MARMARA (BMJ) :
At the Junction of Bosphorus Strait and the Sea of Marmara, the total carbonate concentrations vary from 9 to 90 % with an average value of 29 % (Table 3.2).

High values are concentrated in the nearshore areas in both European and Asian sides (Fig. 3.28), where increased occurrences of coralline algae and other molluscan shells are observed in the samples. Exceptions are stations (M9, V4, M11, A28 and V7) located in the eastern part of BMJ. In general, the carbonate contents of the sediments decrease with the increasing depth of water and mud contents (Fig. 3.29), in particular, from the nearshore areas towards the inner Bosphorus canyon-offshore (Fig. 3.28).

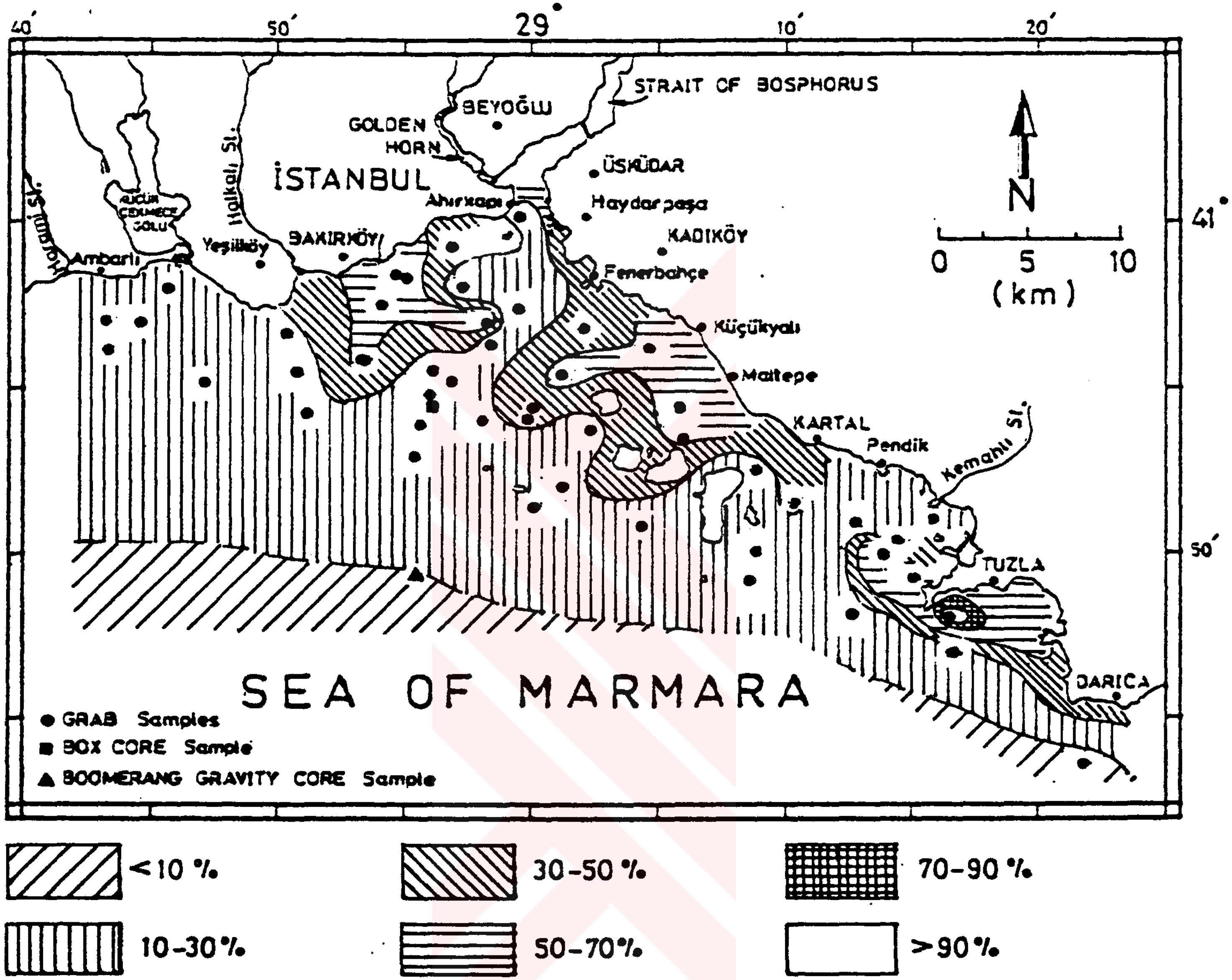

Figure 3.28 : Distribution of total carbonate percentages in the surface sediments from the junction of the Bosphorus Strait with the Sea of Marmara.

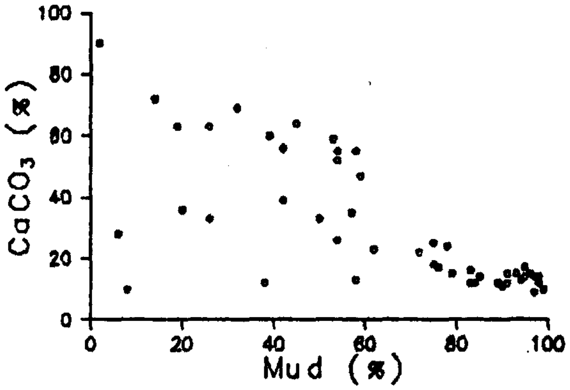

Figure 3.29 : Plots of carbonate vs. mud percentages in the surface sediments from the junction of the Bosphorus Strait with the Sea of Marmara.

NORTHERN SHELF OF THE SEA OF MARMARA (NSM) : Total carbonate contents of surface sediments from the northern Marmara shelf, ranged between 8 and 36 % with an average value of 14 % (Table 3.3 and Fig. 3.30). The majority of carbonate was contributed by the calcareous organisms such as pelecypod, gastropod and foraminifera with the minor amounts of echinoid spine and plates, which are mostly present in coarse fractions (>63 µ) of the sediment samples. The distribution pattern revealed the tendency of $CaCO_3$ contents to decrease towards deeper waters (Fig. 3.30) where shell materials from benthic organisms are rare and mud fraction is dominant here. Fig. 3.31 also confirms that the carbonate percentage seem to be inversely correlated to the mud fraction of the sediment samples.

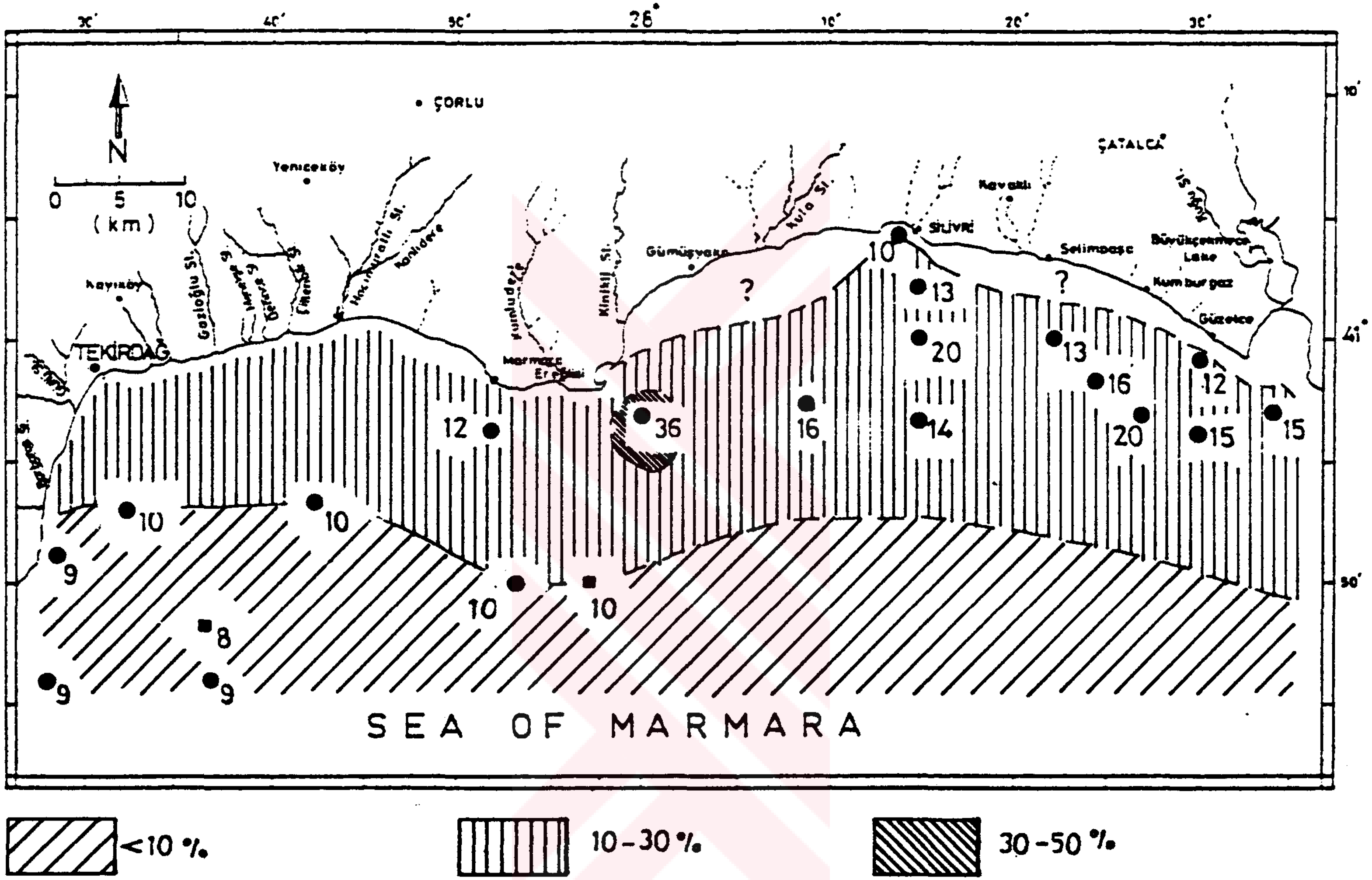

Figure 3.30 : Distribution of total carbonate percentages in the surface sediments from the northern shelf of the Sea of Marmara.

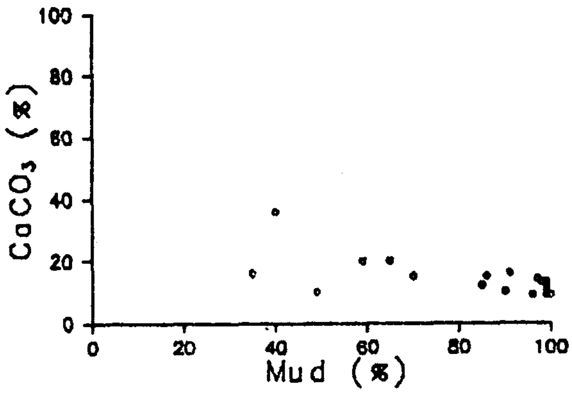

Figure 3.31 : Plots of carbonate vs. mud percentages in the surface sediments from the northern shelf of the Sea of Marmara.

SOUTHERN SHELF OF THE SEA OF MARMARA (SSM) : Total carbonate contents of surface sediments from the southern shelf of the Sea of Marmara are between 4 and 76 %, with an average value of 14 % (Table 3.4). In the nearshore including the Bays of Gemlik and Bandırma, the $CaCO_3$ concentration on the average, is 7 %. The highest carbonate contents are found at stations V12 (34 %), K34K00 (32 %) and, N16 (76 %) and N12 (36 %) (more than 30 % $CaCO_3$; of between the Bozburun and Kapıdağ Peninsulas Fig. 3.32).

The remains of biogenous materials (present in the gravel and sand fractions) are the important $CaCO_3$ contributors to the sediments. Although the highest carbonate concentrations are associated with the coarse fractions of sample, their values decrease with the increasing of mud fractions in the samples (Fig. 3.33).

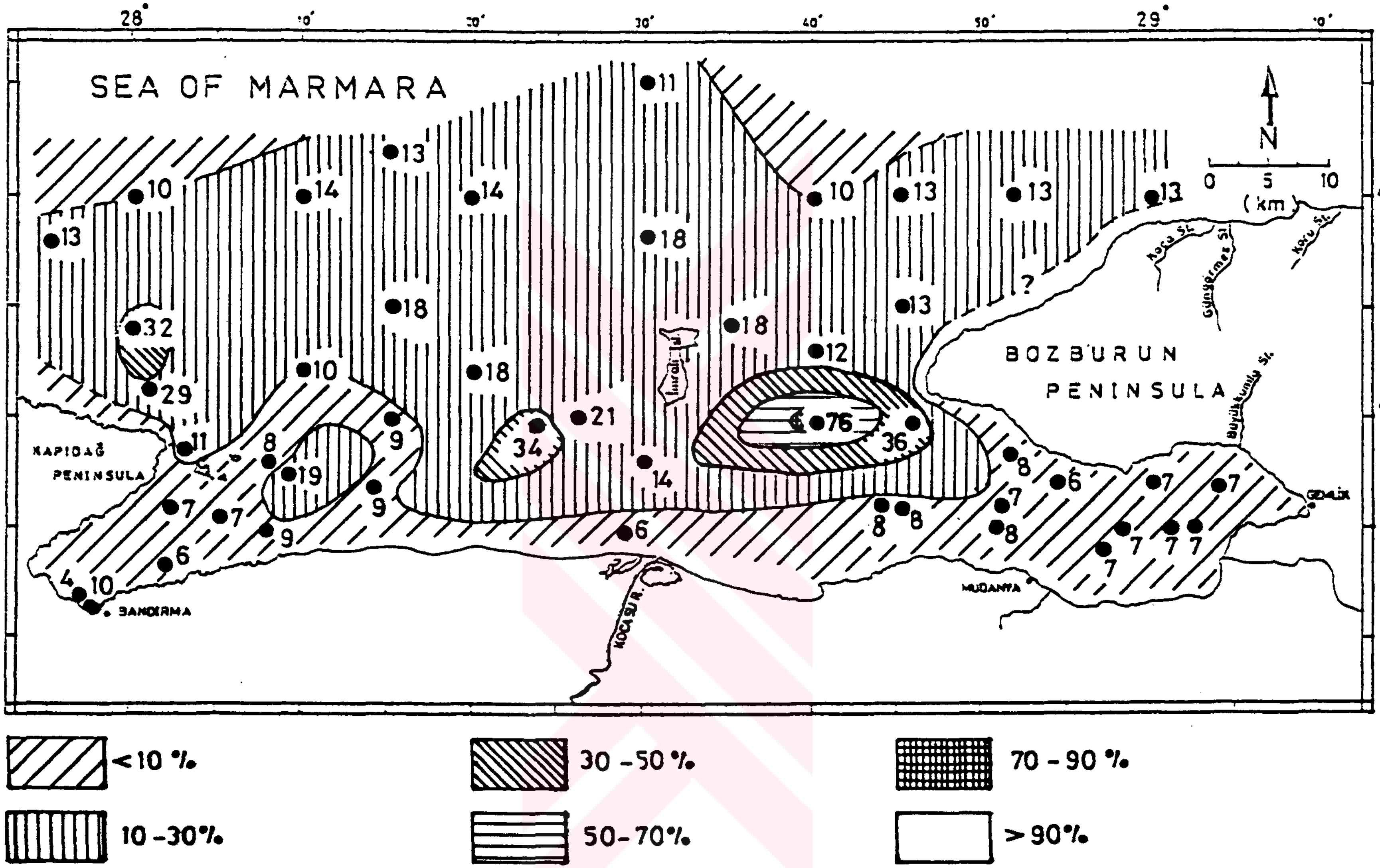

Figure 3.32 : Distribution of total carbonate percentages in the surface sediments from the southern shelf of the Sea of Marmara.

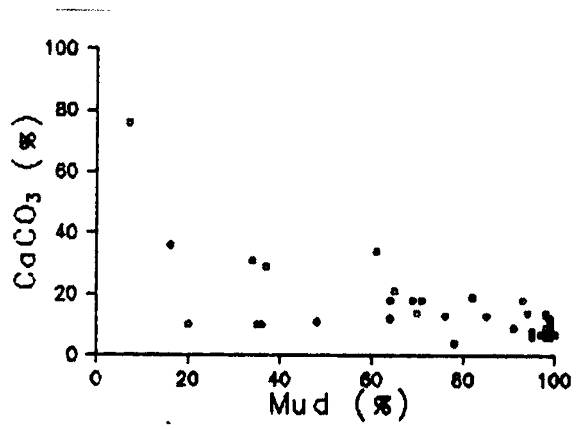

Figure 3.33 : Plots of carbonate vs. mud percentages in the surface sediments from the southern shelf of the Sea of Marmara.

JUNCTION OF THE SEA OF MARMARA WITH THE DARDANELLES STRAIT (MDJ) : Total carbonate concentrations of surface sediments from the Junction of the Marmara Sea and Dardanelles Strait, range between 6 and 50 % with an average value of 12 % (Table 3.5). The $CaCO_3$ contents were usually between 6 and 11 % in most of the samples, except for some stations in the west (37 %), southwest (16-22 %), and in the northeast (13-23 %) (Fig. 3.34). The microscopic studies showed the presence of high amounts of calcareous algae and molluscan shells in the samples. Therefore, a close relationship between the $CaCO_3$ contents and biogenic admixtures of the sediment samples (mostly in the coarse, gravel and sand fractions) is inferred. Because of low carbonate contents (<30 % $CaCO_3$), these sediments are considered as being mainly of terrigenic origin. Fig. 3.35 does not show any relation with the mud percentages and this suggests that carbonate comes from coarse fraction of sediments. This suggestion is also confirmed by the petrographical examination of samples under the microscope.

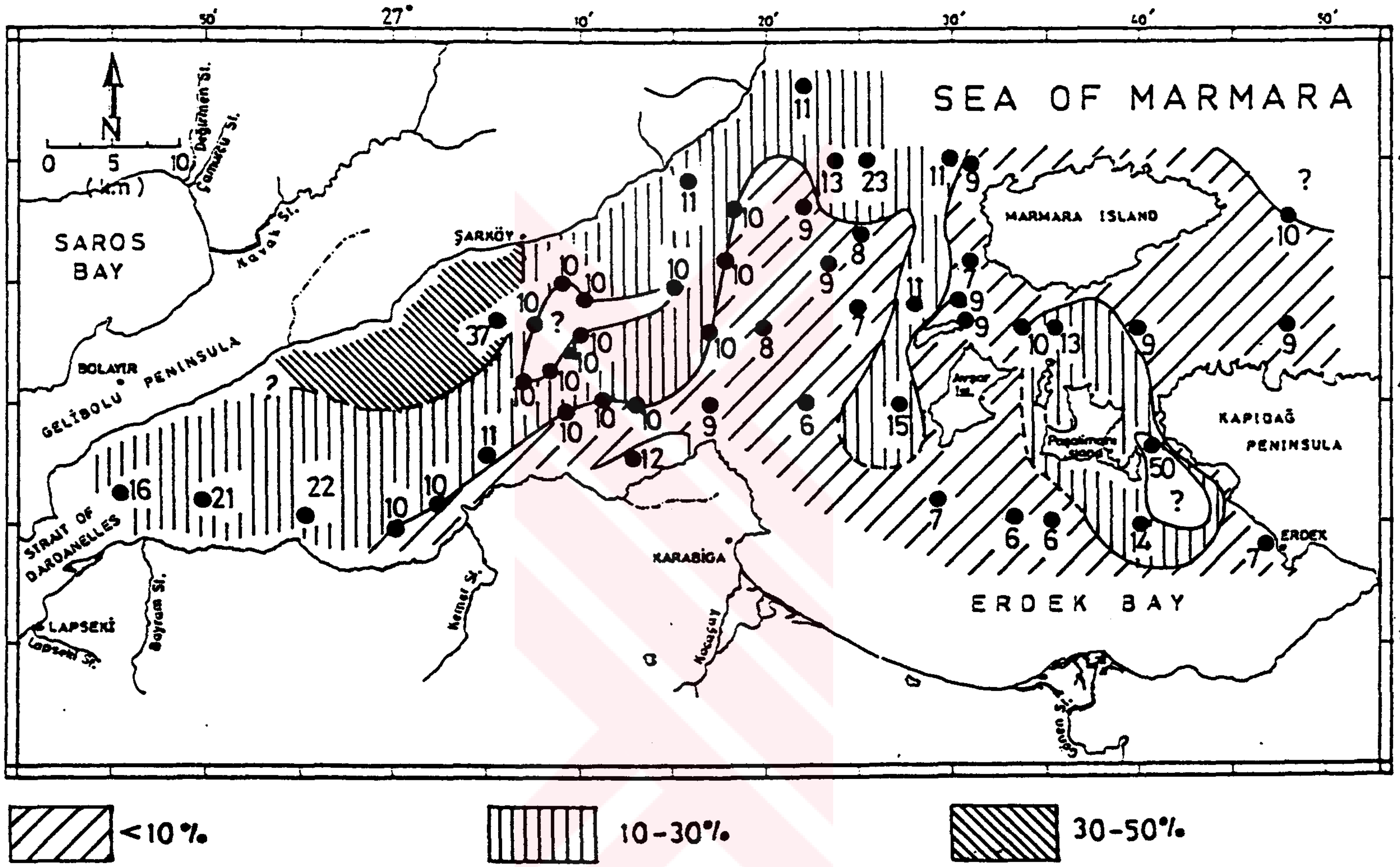

Figure 3.34 : Distribution of total carbonate percentages in the surface sediments from the junction of the Sea of Marmara with the Dardanelles Strait.

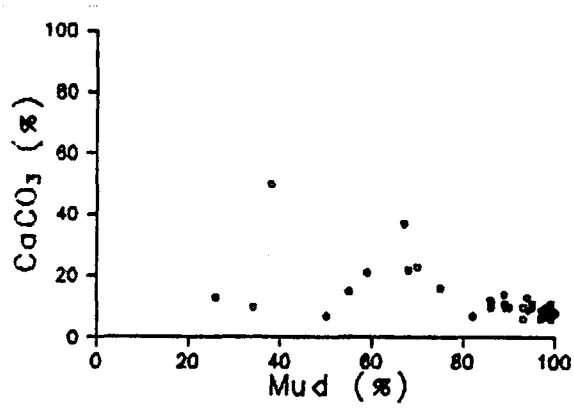

Figure 3.35 : Plots of carbonate vs. mud percentages in the surface sediments from the junction of the Sea of Marmara with the Dardanelles Strait.

JUNCTION OF THE DARDANELLES STRAIT WITH THE AEGEAN SEA (DAJ) :

At the Dardanelles Strait and Aegean Sea Junction, total carbonate contents vary from 5 to 83 % with an average value of 26 % (Table 3.6 and Fig. 3.36). Sediments with high $CaCO_3$ concentrations are found at the Aegean exit (sts.; V38, V39, V40, V42, V44, V36, C8, V37, C7 and V41; >30 %; Fig. 2.2f) and the northeastern part of the Dardanelles Strait (stations; D3 and D4; 37, 50 % respectively). In general, the carbonate-rich samples were poor in fine-material (Fig. 3.37). While sediments from st. D3 contained bryozoans and other molluscan shell remains (partly encrusted with calcite) as the main carbonate sources, carbonate rock fragments from terrigenous sources are dominant at st. D4. On the other hand, calcareous algae and associated molluscan shell remains presented the majority of the carbonate materials in the samples especially from the Aegean exit of strait. The carbonate contents within the strait (from 5 to

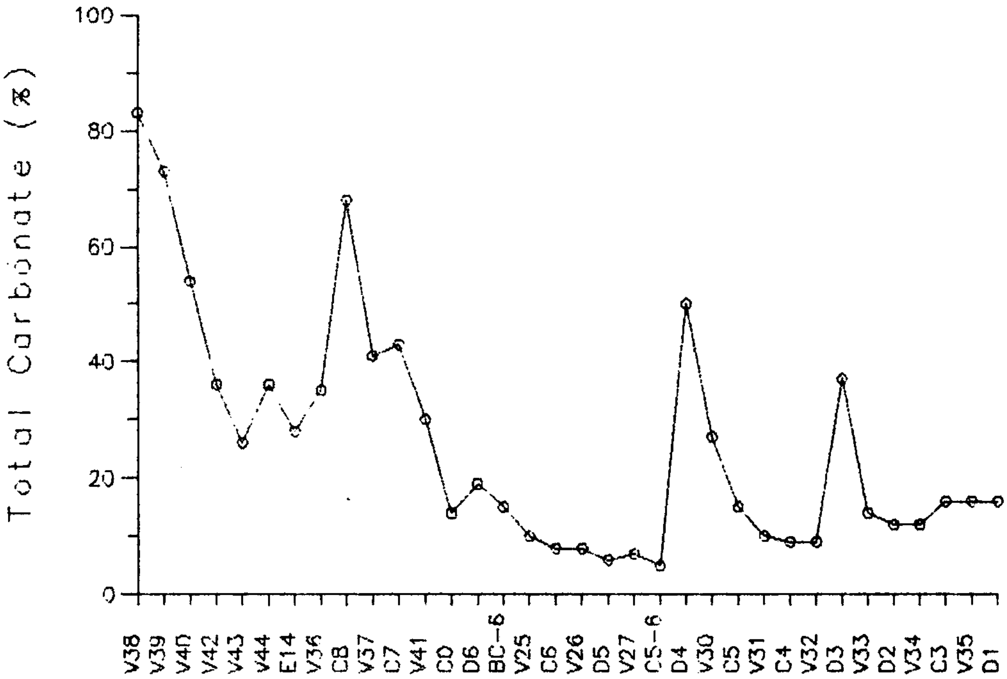

Figure 3.36 : Distribution of total carbonate percentages in the surface sediments from the junction of the Dardanelles Strait with the Aegean Sea.

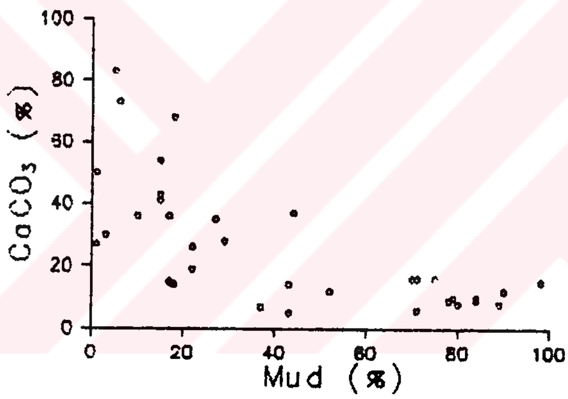

Figure 3.37 : Plots of carbonate vs. mud percentages in the surface sediments from the junction of the Dardanelles Strait with the Aegean Sea.

50 % $CaCO_3$) are represented mainly by the abundance of shell fragments from various calcareous organisms. On the basis of their biogenic carbonate contents, sediments from the Dardanelles Strait can be regarded as terrigenous (<30 % $CaCO_3$). In contrast, the samples from stations D3 and D4, are classified as biogenous (>30 %, $CaCO_3$). The sediment samples from the Aegean exit of this strait are of biogenous

type originated mainly from the calcareous algae, with the exception of two stations (V43 and E14) where, the sediments show more terrigenic character due to the presence of carbonaceous rock particles, in addition to the shell fragments. The carbonate-rich biogenic sediments have also been reported by Perissoratis *et al.* (1987) in this part of the Aegean Sea.

3.1.2.2.2. CONCLUSION

The overall results, obtained from a total of 216 sediment samples, have shown a wide range of $CaCO_3$ (2 to 90 %; avg. 20 %) distribution in the sediments from the Sea of Marmara and its straits. Their average values decrease from the Bosphorus Strait towards the Dardanelles Strait (37 %, at BS; 29 %, at MBJ; 14 %, at NSM; 14 %, at SSM; 12 %, at MDJ and 26 %, at DAJ) but suddenly increases at the Dardanelles Strait and its Aegean Sea exit. Of the carbonates, the branched and rounded forms of calcareous algae (encrusted with *melobesid* and other calcareous shell fragments) are most characteristic in the Sea of Marmara. The carbonate distribution map (Fig. 3.38) shows that their concentrations are mostly less than 30 % of $CaCO_3$, but some patchy areas (>30 % $CaCO_3$) are concentrated at around BMJ and stations K57K00, N12, N16, V12, K34K00 and C2X(1). The sediment samples from those stations most commonly derived from biogenous origin. Microscopic studies combined with carbonate analysis revealed that most of the carbonates occur in the

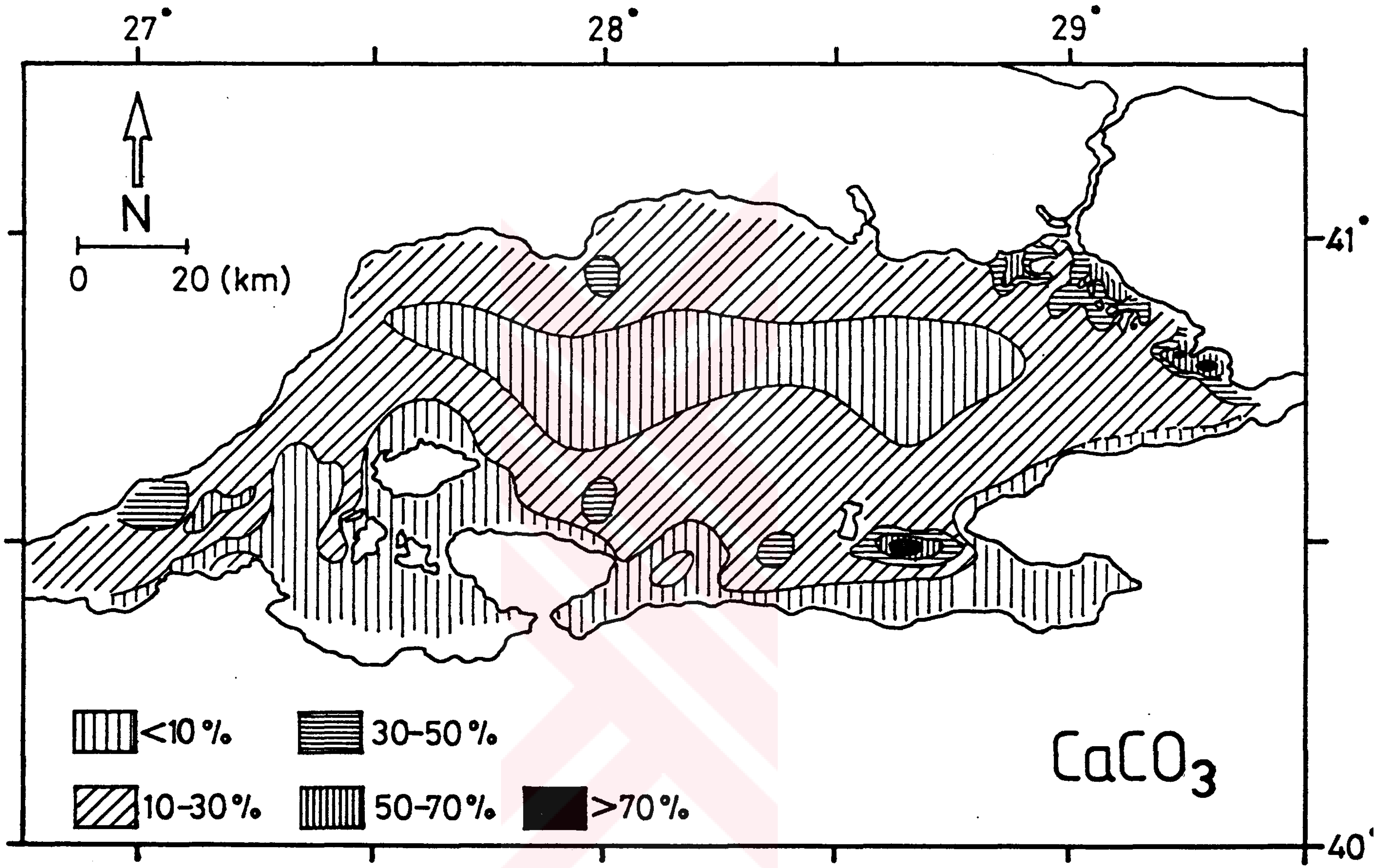

Figure 3.38 : Carbonate distribution in the surface sediments from the Sea of Marmara.

coarse grained fraction of sediments. The $CaCO_3$ distribution in the sediments reflects marked local fluctuations.
For example, in the Bosphorus approach of the Sea of Marmara, carbonate contents of sediments decrease towards the open sea, due to changes in the carbonate sources, namely from benthic in nearshore to planktonic in offshore.
The carbonates in the investigated surface sediments from the whole Marmara Sea basin occur mainly in the coarse-sized fraction, which is mostly represented by carbonaceous shell materials. The carbonate content of sediment samples from the same locality may show a wide range of values.
In coarse-grained samples, their contents are higher compared to that of the fine-grained. It is also confirmed by the Fig. 3.39. The total carbonate content of the sediments decrease towards the offshore and basinal areas.
The source of the carbonate materials in the surface sediments are commonly of terrigenous type (<30 % $CaCO_3$) based on the genetic classification of all sediment samples.

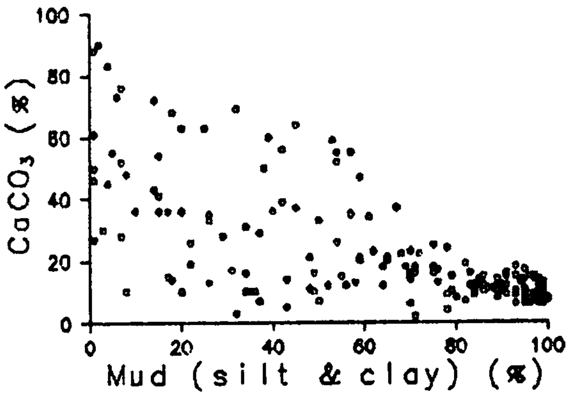

Figure 3.39 : Plots of carbonate vs. mud percentages for all surface sediment samples of the Marmara Sea.

3.1.2.3. HEAVY METALS

Numerous studies have shown that heavy metals in recent marine sediments may have their origin not only from geological but also from anthropogenic sources (Förstner and Wittmann, 1979; GESAMP, 1985; Krauskopf, 1985). Of the geological sources, the diagenesis (Chester and Aston, 1976), hydrothermal deposits (Krauskopf, 1985; German *et al.*, 1990) and volcanic-ultramafic series (Rankama and Sahama, 1968; Kukal, 1971; Krauskopf, 1985) are important contributors of heavy metals to the sediments. Anthropogenic sources include various types of metal compounds from the industrial, municipal and domestic waste discharges, entering the sea either directly or indirectly (Förstner and Wittmann, 1979; GESAMP, 1985). On the other hand, in the sediment, metals mostly occur as associated with and/or incorporated into oxides/hydroxides of iron and manganese silicates, sulfides, carbonates, and organic matter (Förstner and Wittamnn, 1979; Krauskopf, 1985). Because these above metal association in most cases, occur in the finer sizes, the clay- and mud-sized sediments are known to be the best traps for heavy metals (Mayer and Fink, 1980; Tessier and Campbell, 1987). Thus, grain-size plays an important role which controls heavy metal distribution in the sediments. In particular, Cauwet (1987) cited that the clay minerals due to their larger specific surface area are able to accumulate high amounts of metals. Loring (1990) recently mentioned that in most areas, hydraulic and mineralogical (chemical) particulate fractionation usually results in increasing heavy metal concentrations with decreasing sedimentary grain sizes. Thus, grain-size seems to play an important role which controls heavy metal distribution in the sediments.

3.1.2.3.1. ELEMENTAL DISTRIBUTION

The concentrations of Fe, Mn, Ni, Zn, Cr, Co, Cu, and Pb measured in the 23 grab and 7 core sediment samples (upper 10 cm of the cores) from the Sea of Marmara and its two straits are shown in Figs. 3.40 to 3.47 and their values are listed in Table 3.8. The heavy metal data from other sources are also given for comparison (Table 3.9).

3.1.2.3.1.1 IRON

The total iron concentrations ranged from 1.09 to 4.79 % with an average of 3.30 % in the thirty surface samples (Fig. 3.40). Comparison with average sedimentary rocks and relatively older sedimentary units in and around the study areas suggest that the iron concentrations of surface sediments from the Sea of Marmara are largely at natural levels. The variations in the Fe contents of sediments were interpreted as being due to variations in the lithologic and biogenic admixtures. This is best shown at stations E2 (10 % clay; 0.90 % org.C) and M2 (44 % clay; 1.87 % org.C).

Table 3.8 : Chemical compositions of the surface sediments from the Sea of Marmara and its Straits.

	Depth	Clay	org.C	$CaCO_3$	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb	Sediment
	(m)	%	%	%	%	(.......		µg/g			.......)		Texture
BC-1*	54	13	0.37	28	1.45	274	28	42	52	11	16	17	(g)mS
E2	55	10	0.90	36	1.09	197	30	69	58	9	48	34	gmS
M2	66	44	1.87	12	3.54	422	59	149	141	20	92	94	(g)sM
N7	60	39	1.31	11	2.89	338	55	109	104	20	47	73	(g)sM
M8	66	33	1.04	15	2.29	394	50	91	100	19	32	60	(g)sM
BC-2*	64	38	1.14	12	2.91	388	59	88	119	12	39	46	(g)sM
M16	250	45	1.09	14	3.29	451	57	91	95	19	33	39	(g)sM
MBC-3*	1200	73	1.05	10	4.10	3719	86	111	102	16	44	49	C
L02K15	56	61	1.37	13	3.80	451	102	88	137	25	27	39	(g)M
K56K15	320	64	1.64	14	3.74	563	125	89	145	27	34	39	gM
K45K30	496	82	1.21	11	3.60	760	114	107	112	29	43	51	C
K27L04	70	67	1.14	7	4.09	817	134	101	129	30	37	51	(g)M
N14	104	78	1.22	7	3.92	1915	161	107	137	30	35	56	C
N15	74	77	1.26	7	3.97	929	150	112	141	30	37	60	C
K26K44	67	70	1.31	8	4.09	732	129	109	129	29	33	60	C
K57K00	75	25	0.97	36	1.51	253	50	46	58	12	15	34	gmS
BC-3*	1226	76	1.00	10	3.74	5538	125	109	112	13	45	40	C
K40K00	101	25	0.44	10	1.83	394	68	52	91	14	15	26	(g)mS
N23	67	44	0.81	12	2.40	310	82	63	124	16	19	30	(g)sM
K50J53	855	83	1.04	10	3.80	1070	123	110	129	30	40	64	C
K53J42	480	76	1.23	10	3.66	563	116	98	133	26	33	43	C
N24	180	47	0.81	9	3.72	479	118	85	149	19	29	34	M
BC-4*	1106	67	1.14	8	4.68	3854	119	100	123	20	38	48	C
K46J37	700	73	1.16	9	3.86	845	123	107	133	30	40	68	(g)M
K43J22	70	50	0.99	11	3.66	507	125	89	166	29	29	34	M
V54	126	45	0.69	23	2.69	591	82	83	124	23	25	39	(g)sM
K35J15	84	62	0.94	10	3.92	591	129	100	137	27	35	47	(g)M
BC-5*	65	56	0.84	10	4.79	854	114	89	134	24	32	59	M
N27	68	39	1.00	10	4.03	591	118	103	133	22	34	47	(g)sM
BC-6*	74	47	0.19	15	1.98	467	39	44	78	11	13	33	(g)M
Avg.	276	54	1.04	13	3.30	952	96	88	118	21	35	47	
Std.	366	20	0.34	8	0.97	1240	38	29	28	7	14	16	

Note : (*) mean values for the upper 10 cm of cores

g: gravelly S: sand M: Mud C: Clay
(g): slightly gravelly s: sandy m: muddy

Table 3.9 : Chemical compositions of the studied surface sediment samples (results are given in $\mu g/g$, except for iron, org.C and $CaCO_3$ in %) and others are given for comparison.

	org.C	$CaCO_3$	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
1. BC-1 (top 10 cm)	0.75	36	1.08	229	20	34	32	11	14	15
1. BC-2 (")	0.89	15	2.53	384	53	76	86	10	29	34
1. MBC-3(")	1.06	10	4.10	2381	89	102	106	15	40	49
1. BC-3 (")	0.91	11	4.64	4903	129	92	113	20	39	38
1. BC-4 (")	1.03	9	4.02	3010	120	95	141	18	37	40
1. BC-5 (")	0.76	11	4.30	636	112	84	145	20	33	45
1. BC-6 (")	0.41	24	1.44	408	40	44	73	13	16	27
1. Grab sediments	0.94	20	3.30	952	96	88	118	21	35	47
2. M1 and M4	1.38	17	4.13	2500	91	90	115	25	41	38
3. Golden Horn	4.80	-	3.20	398	125	1259	334	23	972	293
4. Golden Horn	4.68	12	-	-	-	-	-	-	-	-
5. Izmit Bay	1.15	11	2.62	245	66	73	30	72	25	36
6. E.Aegean Sea	0.35	59	2.42	925	143	39	92	16	18	17
7. Black Sea			-	722	51	-	93	22	36	7
8. Black Sea	2.00	15	3.88	799	82	98	143	26	38	12
9. Black Sea	1.03	11	3.28	570	77	87	110	11	49	35
10. Cilician Basin			5.30	1103	326	107	551	-	42	-
11. Mersin Bay	0.42	41	2.74	449	362	125	37	27	20	11
12. Near-shore muds			6.99	850	55	95	100	13	48	20
12. Deep-sea carbonates			0.90	1000	30	35	11	7	30	9
13. Carbonates			0.38	1100	20	20	11	0.1	4	9
12. Deep-sea clays			6.50	6700	225	165	90	74	250	80
13. Shales			4.70	850	80	90	100	20	50	20
13. Sandstones			-	X0	2	16	35	0.3	X	7
13. Basalt			8.60	1700	150	100	200	48	100	4
13. Granite			2.70	500	0.8	50	20	3	12	20
13. Crustal rocks			5.40	1000	75	70	100	22	50	13
14. Soil			2.10	320	17	36	43	10	15	17
13. Sea-water (10^{-4} ppm)			20.00	2	17	49	3	0.5	5	0.3

Note : X means between 1 and 10 ppm
X0 means between 10 and 100 ppm

1. This study
2. Evans *et al.*, 1989
3. Erdem, 1988
4. Ergin *et al.*, 1990a
5. Yörük, 1988
6. Voutsinou-Taliadouri and Satsmadjis, 1982
7. Çağatay *et al.*, 1987
8. Hirst, 1974
9. Yücesoy, 1991
10. Shaw and Bush, 1978
11. Bodur and Ergin, 1988
12. Chester and Aston, 1976
13. Krauskopf, 1985
14. Rose *et al.*, 1979

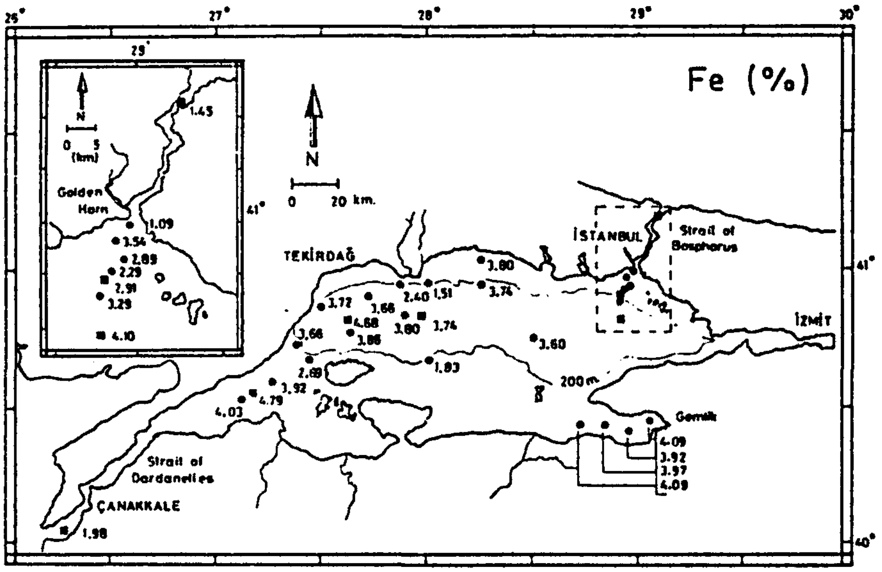

Figure 3.40 : Distribution of iron concentrations in the surface sediments from the Sea of Marmara.

3.1.2.3.1.2. MANGANESE

The manganese concentrations in the studied sediments ranged from 197 to 5538 μg/g; being highest in the three deep basins along the Marmara Trough (3719-5538 μg/g Mn) (Table 3.8 see also Fig. 3.41). Lower Mn levels are usually confined to sediments from the shallower waters of the study areas (197-1915 μg/g; Fig.3.41).

As shown in Table 3.9, sedimentary rocks usually exhibit Mn levels up to 1100 μg/m and remarkably high values are reported from deep-sea clays associated with the formation of ferro-manganese concentrations (Chester and Aston, 1976). However, such materials also contain high concentrations of

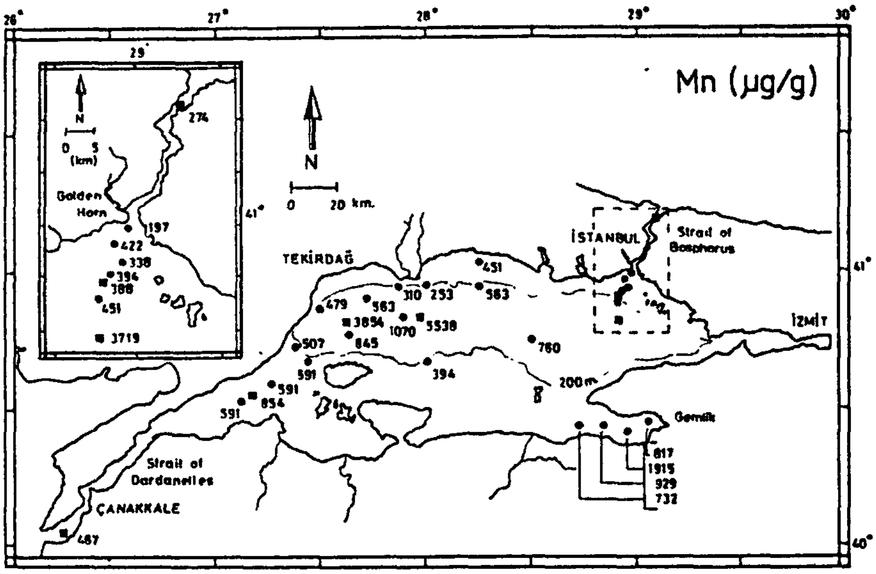

Figure 3.41 : Distribution of manganese concentrations in the surface sediments from the Sea of Marmara

other elements (*i.e.*, Fe) which seems to be not the case in this study. Also, comparison with data from adjacent region suggests that the high Mn values in the deep-sea sediments of this study must have been resulted largely from other processes (*i.e.*, diagenesis) than the lithogenic input. Such diagenetic Mn-enrichments are known from the Black Sea (Arthur *et al.*, 1988) but they also show high Fe values which can not be considered in the study area.

3.1.2.3.1.3. NICKEL

The nickel concentrations ranged from 28 to 161 µg/g with an average value of 96 µg/g (Fig. 3.42 and see also Table 3.8). These values are mostly comparable with the average concentrations of sedimentary rocks, and again, the variations are regarded as a result of the lithogenic and biogenic variations in the samples. Emelyanov (1972) found that the nickel concentrations in the surface samples range from 10 to 300 μg/g for the whole Mediterranean Sea.

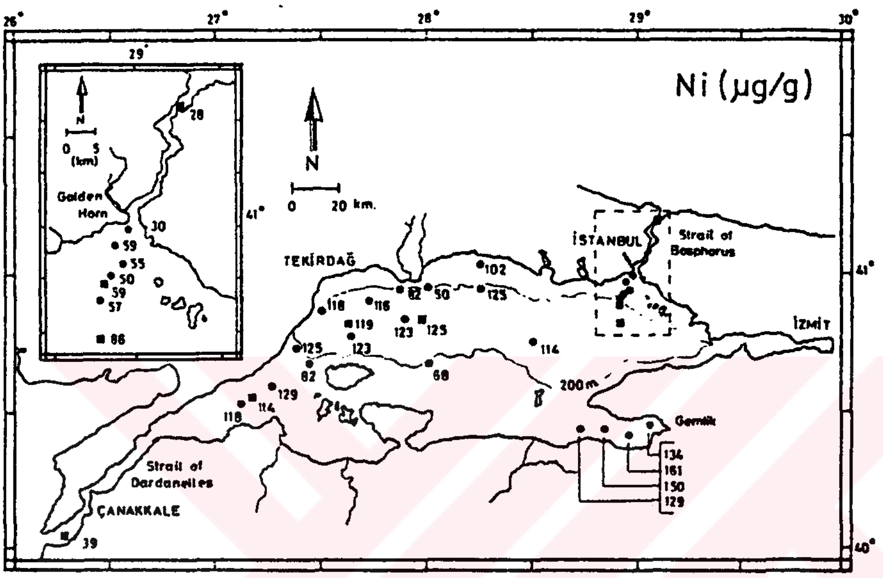

Figure 3.42 : **Distribution of nickel concentrations in the surface sediments from the Sea of Marmara.**

The sediments from the Gemlik Bay contain slightly higher Ni levels (Fig. 3.42), maybe due to presence of relatively higher clay portions in the samples. However, the source of Ni could primarly be particular terrigenous materials on land, as observed under the microscope. This approach has been taken from the petrographical examination of the samples from stations K27L04, N14, N15 and K26K44. As known, on the coastal hinterland, weathered serpentine rocks are characteristic (Ternek *et al.*, 1987) and these materials normally carry significant Ni. Therefore, the nickel concentrations in the surface sediments from the Bay of Gemlik may thought to be originated, at least in part, from the hinterland by the weathering of serpentine rocks with the exposed lithology on the land.

3.1.2.3.1.4. ZINC

The concentrations of zinc ranged from 42 to 149 µg/g with an average value of 88 µg/g (Table 3.8 and Fig.3.43). These values are comparable with the average sedimentary rocks (Table 3.9). At station M2, high Zn contents may come partly from the man-made activities in the surroundings. For example, the Golden Horn sediments contain anomalously high Zn (Erdem, 1988).

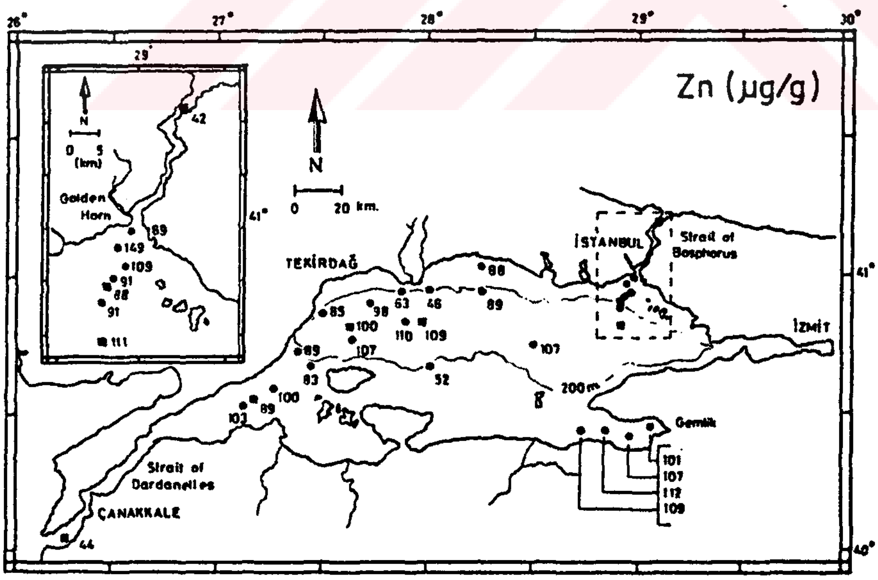

Figure 3.43 : Distribution of zinc concentrations in the surface sediments from the Sea of Marmara.

3.1.2.3.1.5. CHROMIUM

The chromium concentration in the studied samples ranged from 52 to 166 µg/g with an average value of 118 µg/g (Table 3.8 and see also Fig. 3.44). These values are usually in agreement with the values found in average sedimentary rocks (Table 3.9), and thus, are believed to have originated largely from terrigenic sources. The slightly elevated occurrences of chromium in the study area probably reflects the presence of particular geological sources adjacent to the stuided areas. Volcanic materials on the surrounding land-masses have already been reported by Ternek *et al.* (1987).

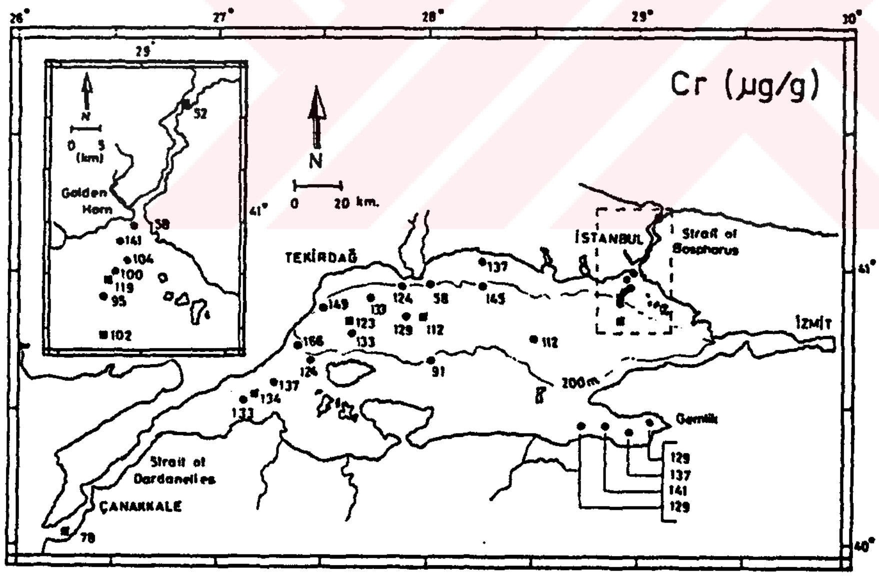

Figure 3.44 : Distribution of chromium concentrations in the surface sediments from the Sea of Marmara.

3.1.2.3.1.6. COBALT

The cobalt concentrations ranged from 9 to 30 µg/g (mean: 21 µg/g) (Table 3.8 and Fig. 3.45), being mostly comparable with the average compositions of sedimentary rocks (Table 3.9). In the Gemlik Bay, the surficial sediments contained relatively high Co levels probably due to occurrences of the increased clay fractions in the samples. Therefore this suggests that input from the natural sources is predominant.

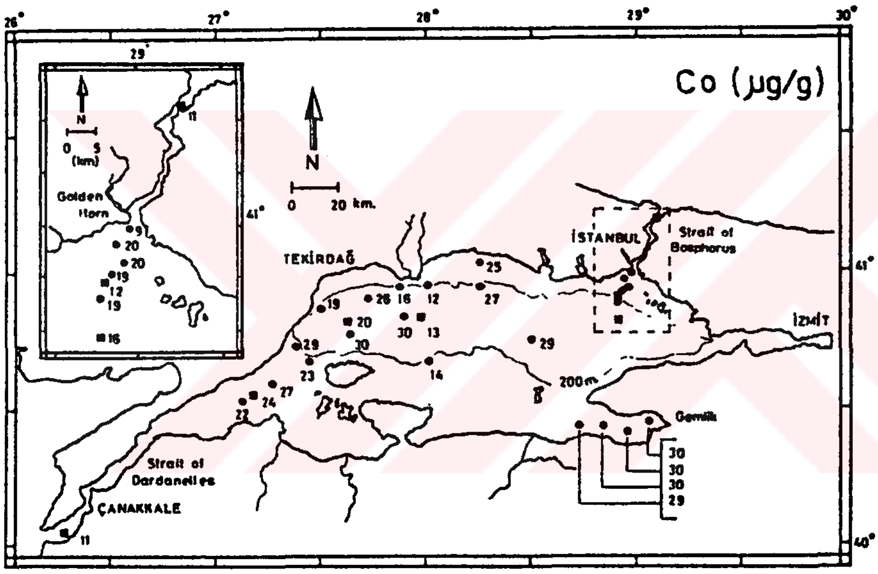

Figure 3.45 : Distribution of cobalt concentrations in the surface sediments from the Sea of Marmara.

3.1.2.3.1.7. COPPER

The copper concentrations ranged from 13 to 92 $\mu g/g$ with a mean value of 35 $\mu g/g$ (Table 3.8 and Fig. 3.46). These values are nearly comparable with the average values found in sedimentary rocks (Table 3.9).

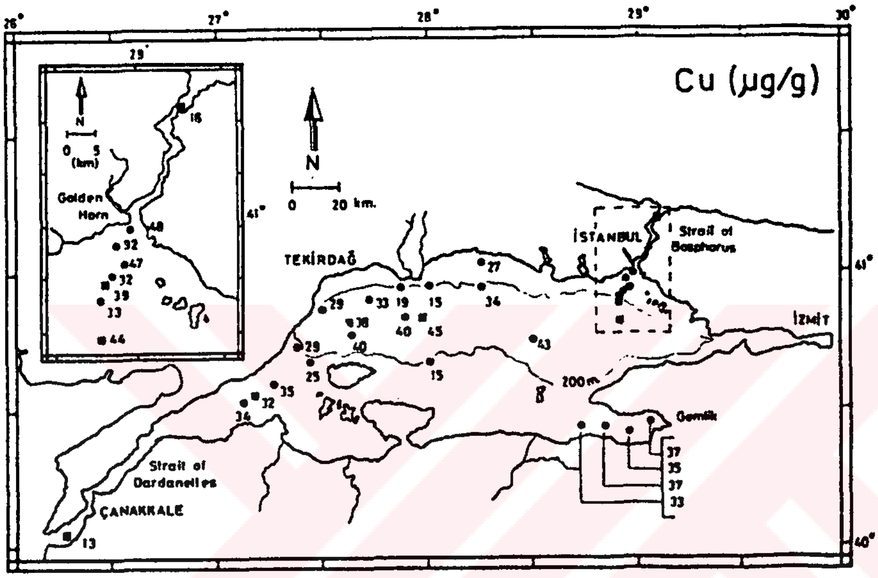

Figure 3.46 : Distribution of copper concentrations in the surface sediments from the Sea of Marmara.

3.1.2.3.1.8. LEAD

Lead concentrations vary between 17 and 94 µg/g with an average value of 47 µg/g (Table 3.8). In most cases, these values are consistent with the compositions of average sedimentary rocks (Table 3.9). Maximum Pb content measured at st. M2 which is located in around the junction of Bosphorus Strait with the Sea of Marmara (Fig. 3.47 and see also Table 3.8) would possibly indicate anthropogenic effluents from the adjacent regions.

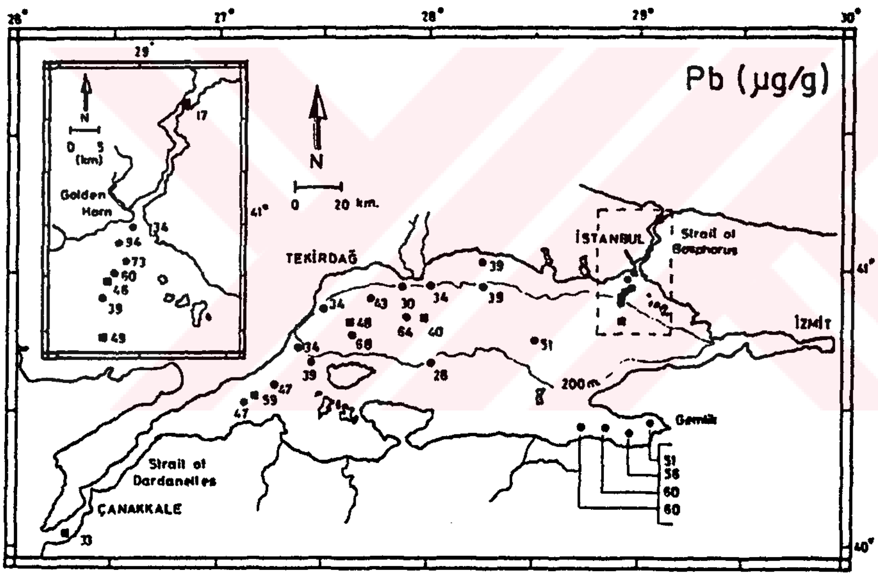

Figure 3.47 : Distribution of lead concentrations in the surface sediments from the Sea of Marmara.

3.1.2.3.2. INTER-ELEMENTS RELATIONSHIPS

Fig.3.48 shows that there exists a significant relationship between the contents of Fe and clay, Ni, Zn, Cr, Co, and Mn. It seems that these elements are remarkably concentrated in the iron phases, whereby Co, Mn and Fe, on the other hand, would be affected by post-depositional processes (*i.e.*, diagenesis).

In general, iron appears to have originated from the lithogenic materials. Fe considerably correlates with the organic carbon and Pb, even at significance level (N=30, p=0.05, r=0.36; Table 3.10). This may suggest, also, association of Fe with the organic fraction and Pb.

Table 3.10 : Correlation coefficient matrix of textural and chemical parameters of surface sediments from the Sea of Marmara and its Straits (N=30, p=0.05, r=0.36).

	Depth	Clay	org.C	$CaCO_3$	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00	.55	.11	-.23	.39	.84	.27	.33	.04	.02	.22	.09
Clay	.55	1.00	.43	-.70	.80	.48	.82	.62	.61	.73	.23	.40
org.C	.11	.43	1.00	-.34	.52	.06	.37	.64	.51	.50	.72	.67
$CaCO_3$	-.23	-.70	-.34	1.00	-.78	-.26	-.67	-.50	-.75	-.59	-.19	-.39
Fe	.39	.80	.52	-.78	1.00	.43	.82	.71	.79	.71	.35	.48
Mn	.84	.48	.06	-.26	.41	1.00	.34	.34	.06	-.08	.21	.05
Ni	.27	.82	.37	-.67	.82	.34	1.00	.56	.78	.81	.08	.24
Zn	.33	.62	.64	-.50	.71	.34	.56	1.00	.58	.52	.69	.59
Cr	.04	.61	.51	-.75	.79	.06	.78	.58	1.00	.75	.29	.40
Co	.02	.73	.50	-.59	.71	-.08	.81	.52	.75	1.00	.17	.46
Cu	.22	.23	.72	-.19	.35	.21	.08	.69	.29	.17	1.00	.77
Pb	.09	.40	.67	-.39	.48	.05	.24	.59	.40	.46	.77	1.00

With the exception of four samples from the deep-basins in the Sea of Marmara, Mn concentrations in most cases, significantly correlated with the clay and organic fraction but also with the contents of other metals (N=30, p=0.05, r=0.36; Table 3.10, see also Fig. 3.49). It appears that the Mn concentrations in the samples, as a result of diagenesis, control the distribution of other metals, mainly in the clay-sized fractions.

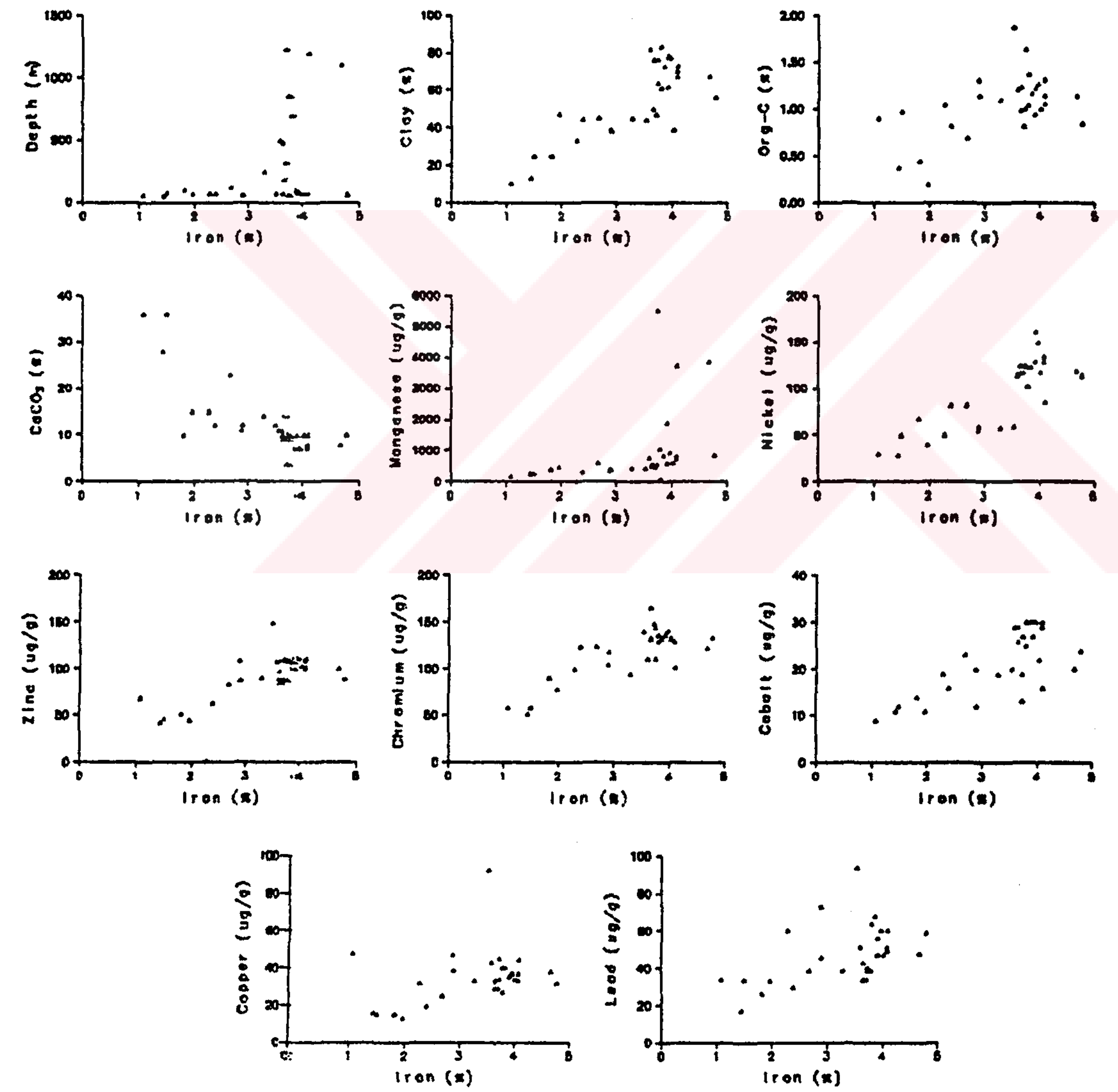

Figure 3.48 : The relationships between the Fe contents and other parameters such as water depth, clay, organic carbon, carbonate etc.

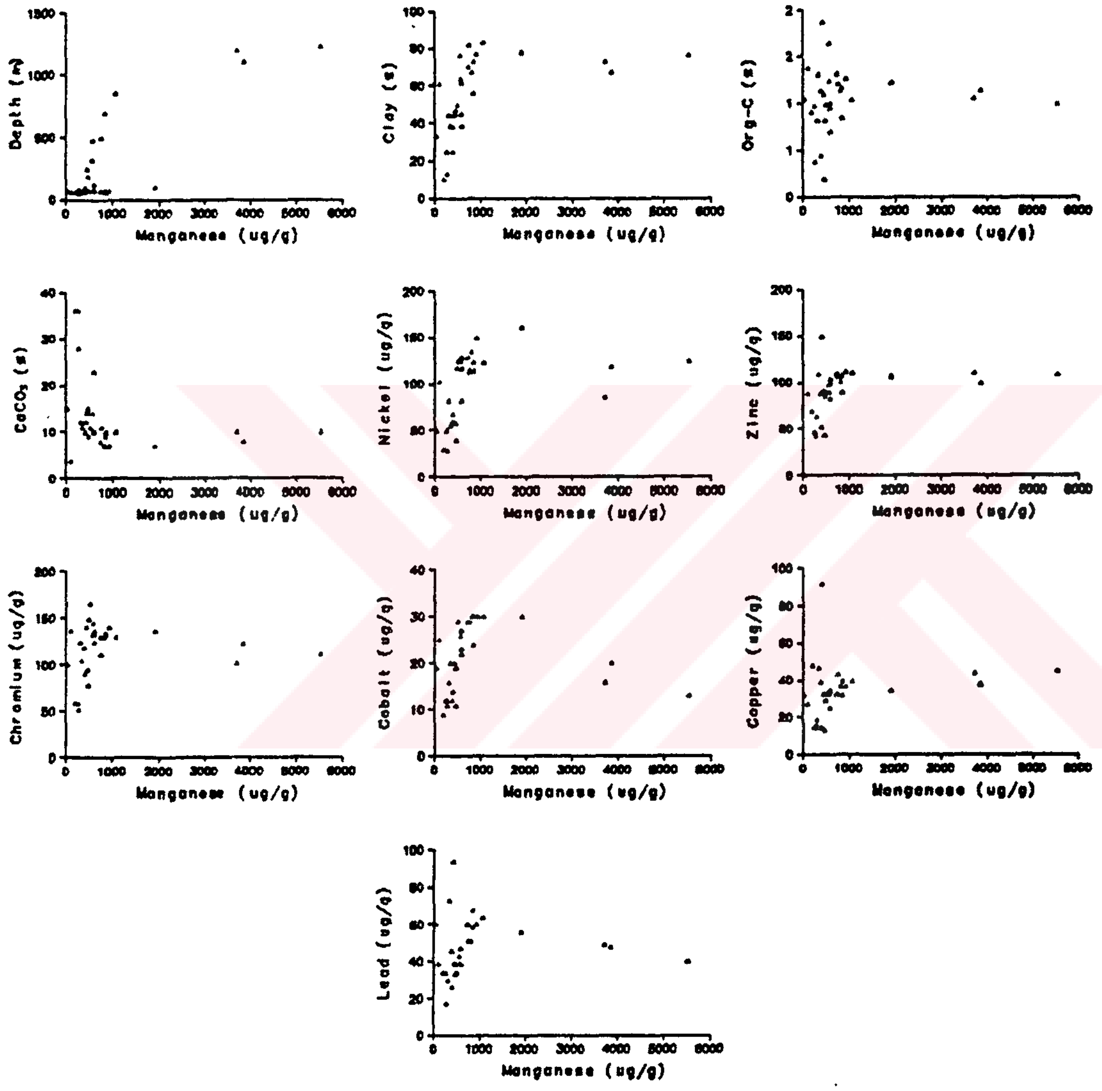

Figure 3.49 : The relationships between the Mn contents and other parameters such as water depth, clay, organic carbon, carbonate *etc.*

Nickel values strongly correlate with the clay, Fe, Cr and Co values (Fig. 3.50), but Ni contents inversely related with the $CaCO_3$ values. Although there is a considerable relation between Ni and Zn values, nickel concentrations does not significantly related with the org.C, Mn, Cu and Pb values at a significance level (N=30, p=0.05, r=0.36; Table 3.10). This would suggest that Ni together with Cr, Co and also Zn occur dominantly in organic, Fe, and clay fractions of the samples, whereby Cr and Ni possibly from the common source is enriched in clays. It is known that Ni may occur in organic matter in appreciable amounts (Kukal, 1971).

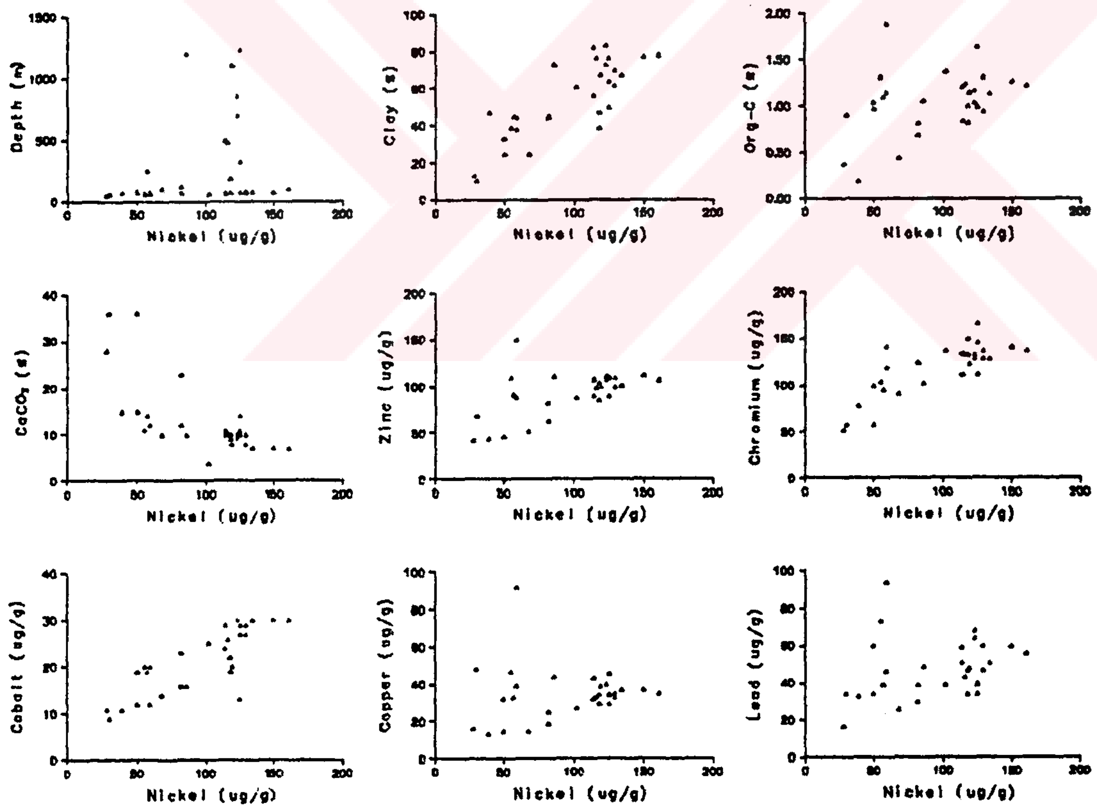

Figure 3.50 : The relationships between the Ni contents and other parameters such as water depth, clay, organic carbon, carbonate *etc*.

Zinc concentrations are significantly correlated with the Cu, Pb, Cr, and Co usually in the organic and clay fractions (Fig. 3.51). The Zn values are also positively correlated with the Fe and Ni values. The inverse correlation between Zn and the $CaCO_3$ indicates the dillution effect of carbonates on the metals at a level of significance (N=30, p=0.05, r=0.36; Table 3.10).

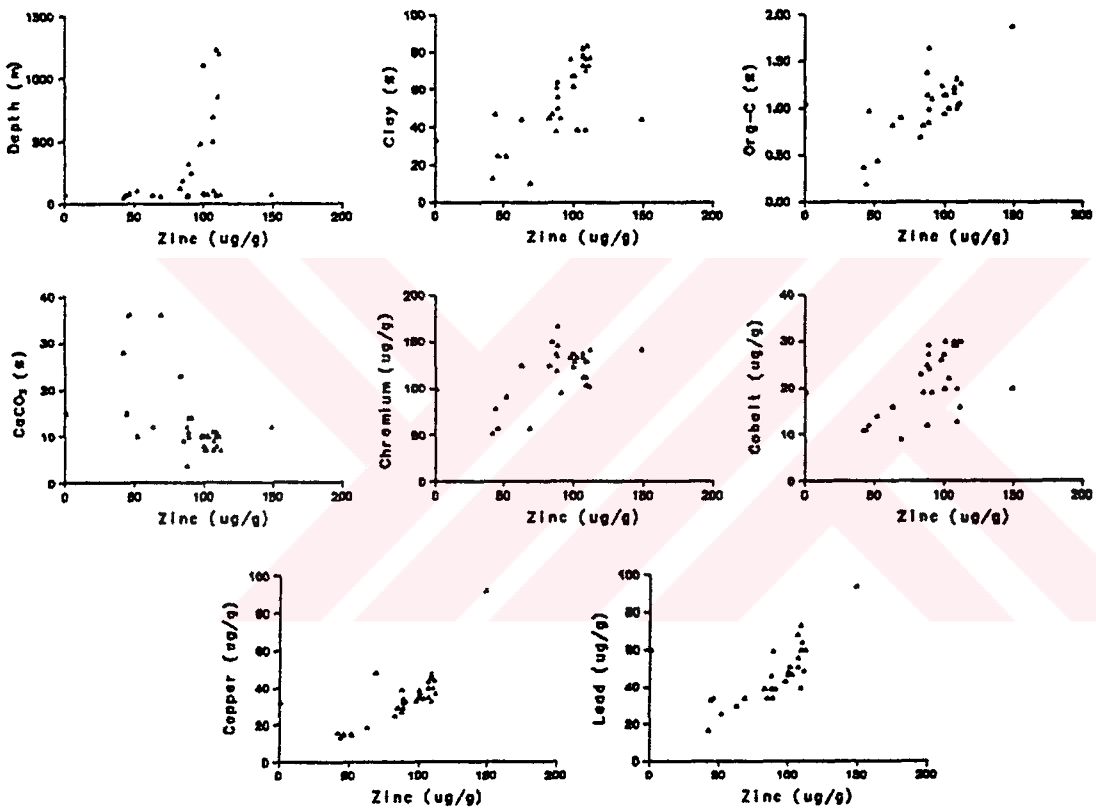

Figure 3.51 : The relationships between the Zn contents and other parameters such as water depth, clay, organic carbon, carbonate *etc.*

As shown in Fig. 3.52, chromium concentrations are correlated with most of the metals at significant levels (N=30, p=0.05, r=0.36; Table 3.10). Of these, the concentrations of Co and Pb follow the same trend of Cr. Such relationships are commonly taken to imply that these metals are associated with each other. Again, the inversely correlation with carbonates indicates dilution of Cr. The clay and organic fractions appear to be important associations of Cr in the sediment.

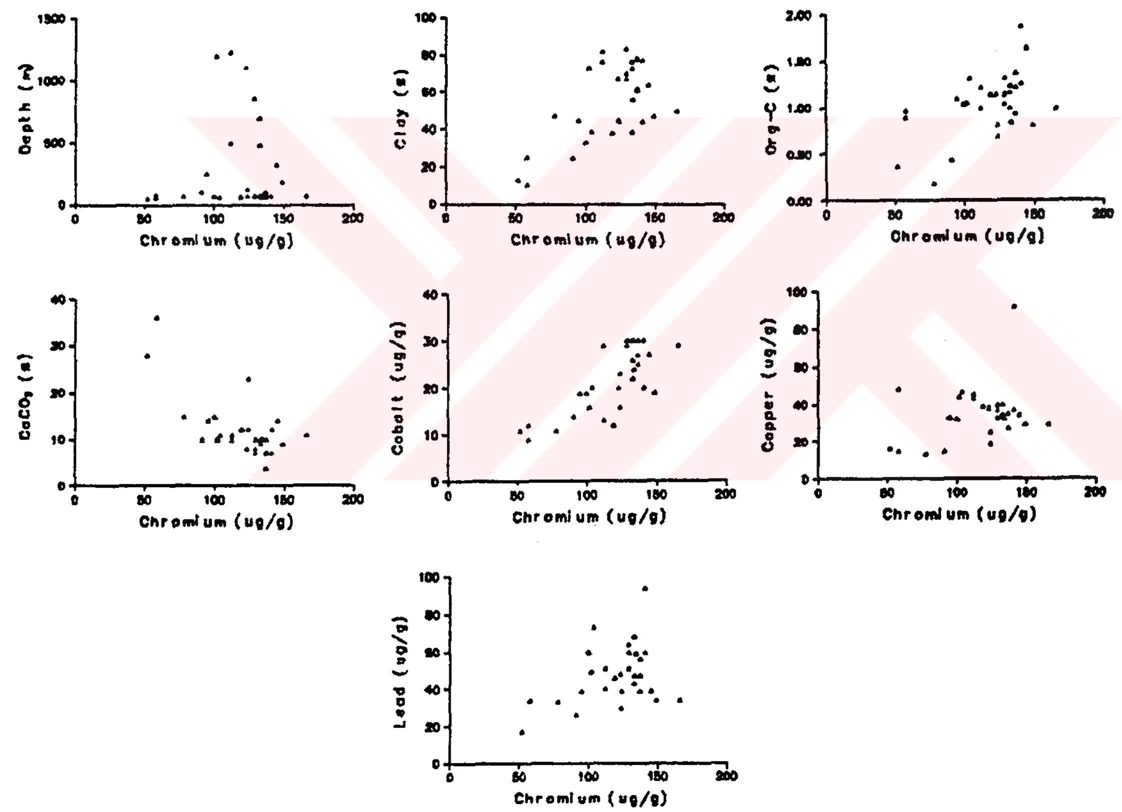

Figure 3.52 : The relationships between the Cr contents and other parameters such as water depth, clay, organic carbon, carbonate *etc*.

As it seen in Fig. 3.53, cobalt correlates with lead, clay and organic fractions. This suggests significant association of Co with the clay-sized and organic substances. The cobalt values are also well correlated with Fe, Ni and Cr values at significant level (N=30, p=0.05, r=0.36; Table 3.10). Again here, carbonates have a dilution effect on Co, like on chromium.

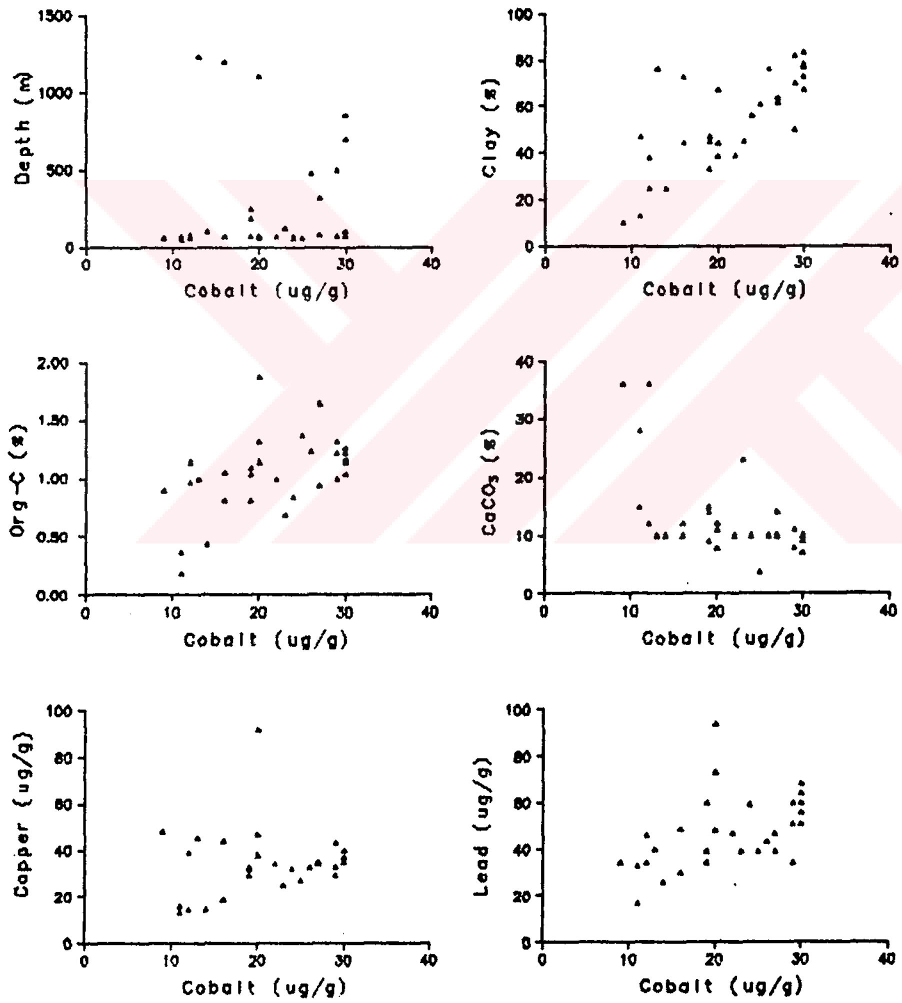

Figure 3.53 : The relationships between the Co contents and other parameters such as water depth, clay, organic carbon, carbonate *etc.*

Fig. 3.54 shows the correlation of Cu with other variables. Of these, Pb resembles the trend of Cu together with the clay fractions. The copper values are strongly correlated with the organic carbon in the sediments. Thus, this would suggests that there is a good association between them, and the association of Cu with the organic matter in marine sediment has been already pointed out by Chester *et al.* (1988).

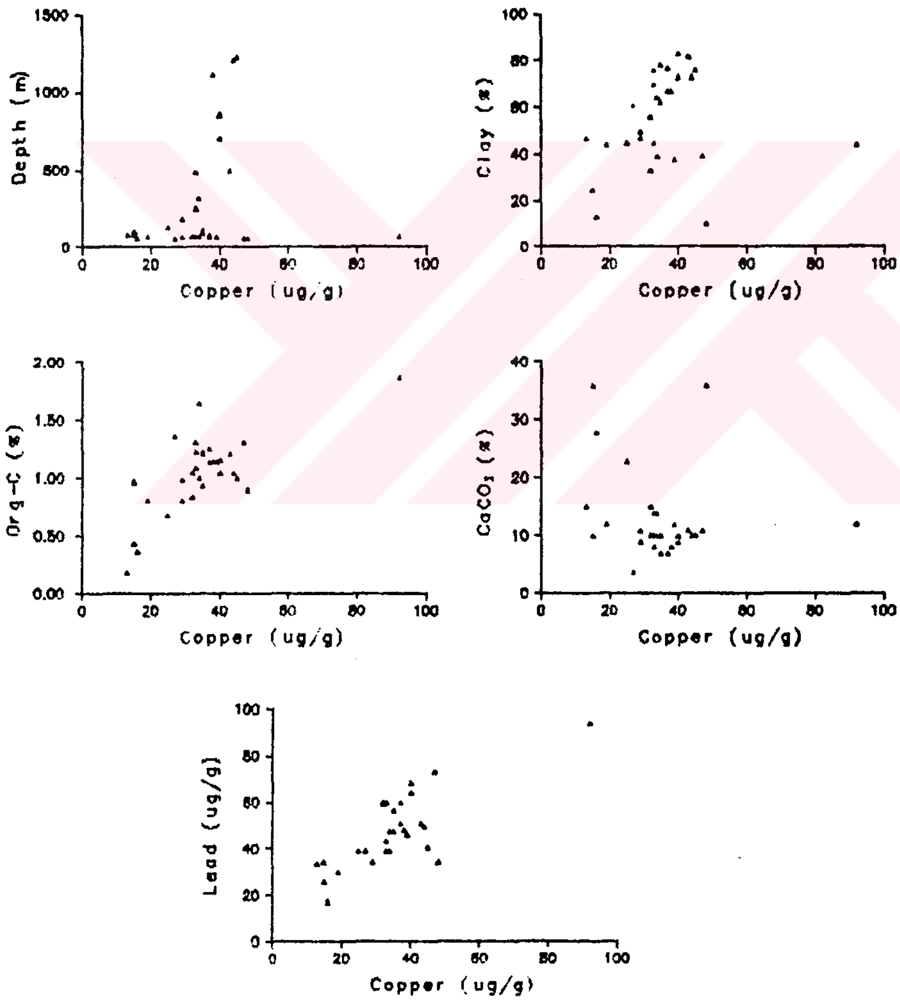

Figure 3.54 : The relationships between the Cu contents and other parameters such as water depth, clay, organic carbon, carbonate *etc.*

Lead concentrations correlate well with the organic and clay fractions in the samples (Fig. 3.55). Although, the lead values are also strongly correlated with the copper values and it is significantly related with the zinc values at asignificant level (N=30, p=0.05, r=0.36; Table 3.10). This would suggests that there is a close association between those parameters in the marine sediments.

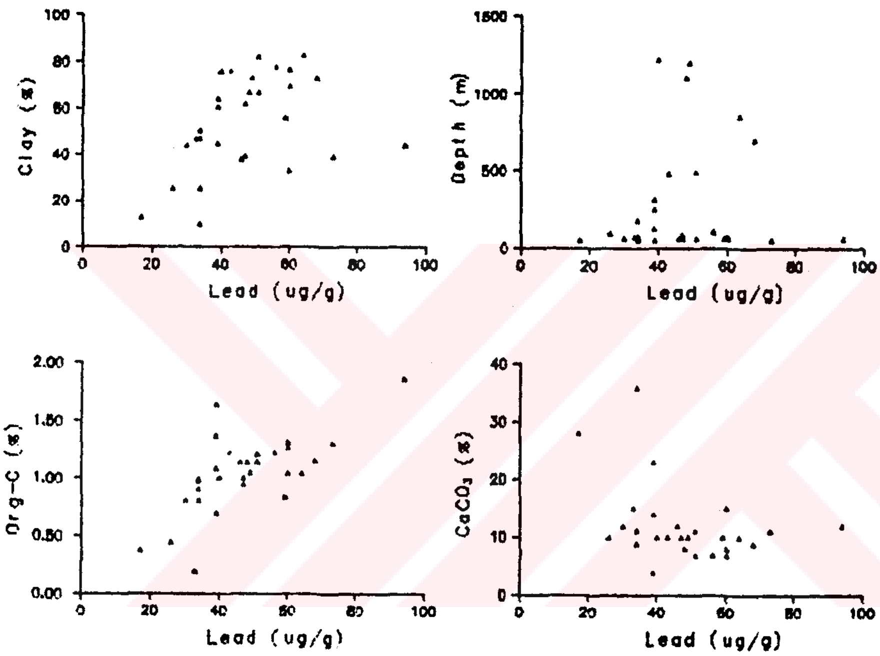

Figure 3.55 : The relationships between the Pb contents and other parameters such as water depth, clay, organic carbon, and carbonate.

3.1.2.3.3. CONCLUSION

In general, the studied heavy metals in the surficial Marmara sediments reflect marked variations in the sediment texture and mineralogy, in response to various environmental and depositional conditions.

The heavy metal data showed that the concentrations of Fe, Ni, Zn, Cr, Co, Cu and Pb in the samples are largely at natural levels when compared with their baseline in the deeper core sediments and their probable source rocks in the region. Also, they are similar in their values to the composition of average sedimentary rocks worldwide. From this it appears that the terrigenous materials from land-based sources (directly or indirectly) are the main supplier of these metals to the sediments. Consequently, there is no satisfactory evidence for an anthropogenic input of the metals studied, although this can not be ruled out.

Furthermore, the role of diagenesis seems to be effective in the distribution of these metals, particularly in the case of Mn which shows anomalously high concentration values. Comparison with the deeper core sediments reveals high Mn baseline and thus suggests additional mechanisms of the Mn-enrichment.

3.2. COMPOSITION AND DISTRIBUTION OF THE CORE SEDIMENTS

In this part of the Chapter Three, the textural and petrological compositions of the core sediment samples will be discussed.

The grain-size parameters are given in Tables 3.11 to 3.17, and their profiles through the cores are shown in Figures 3.56 to 3.62.

3.2.1. TEXTURE AND PETROLOGY OF THE CORE SEDIMENTS

Core BC-1 : Site of Core BC-1 is situated in the northern part of the Bosphorus Strait (water depth 54 m, Fig. 3.56). In this core, gravel percentages ranged from less than 1 % to 15 % (avg. 7 %; Table 3.11), with a tendency to increase towards the base of core, especially between 2 and 18 cm depths (Fig. 3.56).

Table 3.11 : Grain-size and chemical composition of sediments in Core BC-1.

#	CD (cm)	G %	S %	Z %	C %	org.C %	(C) %	Fe %	Mn (.......	Ni	Zn	Cr	Co	Cu	Pb	W/D
											μg/g	......)				
* 1	0-2	0	45	29	26	0.57	12	2.28	415	53	72	111	11	25	26	1.71
2	2-4	<1	43	31	25	0.62	14	2.49	388	48	62	106	13	26	28	1.50
3	4-6	3	75	11	11	0.21	30	0.83	235	21	33	26	13	14	16	1.34
4	6-8	9	87	2	2	0.04	40	0.83	166	6	24	5	10	6	8	1.31
* 5	8-10	6	93	1	<1	0.43	45	0.83	166	10	21	11	9	9	8	1.42
6	10-12	5	93	2	<1	0.74	44	0.42	180	13	22	11	7	11	12	1.49
7	12-14	12	86	1	<1	0.74	42	0.42	194	13	26	5	13	11	12	1.41
8	14-16	10	87	3	<1	1.03	46	0.83	166	10	22	5	16	14	16	1.41
* 9	16-18	15	83	2	<1	0.74	48	0.83	152	8	20	5	10	10	8	1.33
Avg.		7	77	9	7	0.57	36	1.08	229	20	34	32	11	14	15	1.44
Std.		5	18	12	10	0.29	13	0.72	95	17	18	42	3	7	7	0.12

* indicates dublicated samples with average values
\# " Subsample number
CD " Core-Depth
G " Gravel
S " Sand
Z " Silt
C " Clay
org.C " Organic carbon
(C) " Carbonate (expressed as $CaCO_3$)
W/D " Wet-Dry ratio

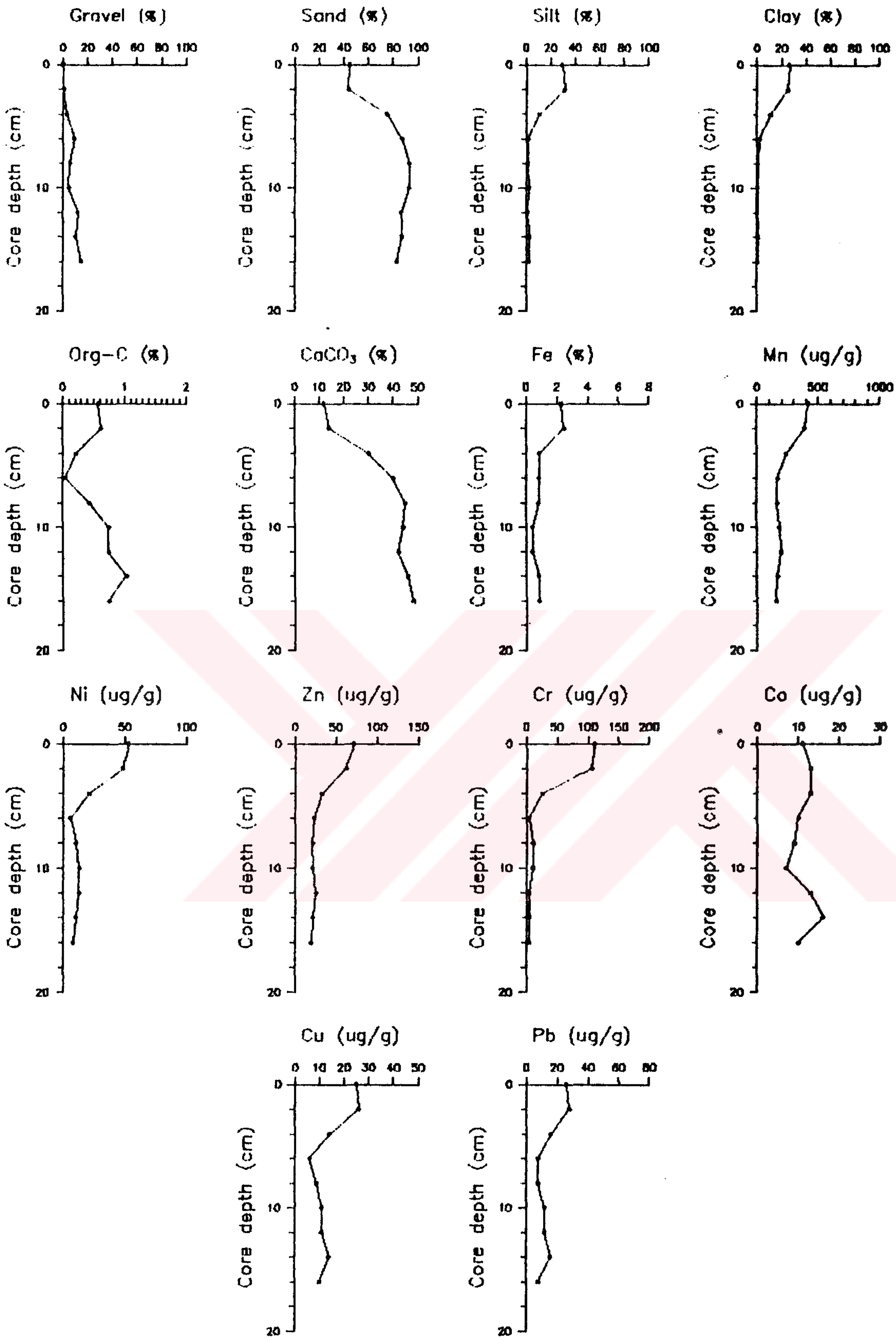

Figure 3.56 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core BC-1.

Like gravel, sand percentages (43-93 %; Table 3.11) below 2 cm depth, generally increased down the core (Fig. 3.56). The maximum sand contents are found at 10-12 cm depth (93 %). Consequently, the clay (<1-26 %) and silt (1-31 %) portions of the sediment decreased down the core (Fig. 3.56). Below about 6 cm depth, clay and silt reached their minimum concentrations. Visual examination of the core by naked eye showed no major changes in the sediment structure. Exceptions are the occurrences of two thin and dark-brownish laminae at the base of core (14-18 cm depth)

Sand was mainly composed of the biogenous materials dominated by pelecypodal shell debris, appeared partly as encrusted, altered, perforated and subrounded. Terrigenous constituents of sand are mainly represented by quartz (mostly subrounded to rounded) and metamorphic rock fragments throughout the core. A possible epidote-garnet-amphibole-pyroxene assemblages, as described from the north off Bosphorus (Müller and Stoffers, 1974) can not be recognized in the samples. Minor amounts of mica flakes, pyrite and pyritized material are also observed, especially in the upper part of the core. From about 6-8 cm depth downward, coarse sediments commonly contained coal particles (about 5 %). Biogenous components as associated with the coarse to fine sand included the occurrences of foraminifers (mostly *Ammonia beccarii*, *Quenqueloculina sp.*), pelecypods, gastropods (*Turritella sp.*) with minor amounts of ostracods, bryozoans, calcareous algae and echinoid spine. The vertical changes in the sediment texture above 6 cm depth of Core BC-1 can be explained rather by the changes in the depositional and environmental conditions during the much younger periods of time. However, at this stage, it is difficult to find a reliable explanation for this.

Core BC-2 : Site of Core BC-2 is located in the south off Bosphorus Strait (water depth 64 m, Fig. 3.57). The gravel fractions of sediments are relatively low (<1-2 %) being, on the average, 0.71 % (Table 3.12).

Table 3.12 : Grain-size and chemical composition of sediments in Core BC-2.

#	CD (cm)	G %	S %	Z %	C %	org.C %	(C) %	Fe %	Mn (....... µg/g ....)	Ni	Zn	Cr	Co	Cu	Pb	W/D
*1	0-2	<1	13	49	38	1.06	11	2.49	360	53	85	124	10	38	34	1.87
2	2-4	1	11	52	36	1.13	13	2.91	388	60	97	121	8	40	47	1.79
3	4-6	1	12	49	38	1.11	12	2.91	388	58	88	111	16	39	51	1.83
4	6-8	1	12	48	40	1.18	12	2.91	401	62	83	121	13	37	51	1.84
5	8-10	<1	12	48	39	1.20	12	3.32	401	60	85	116	13	39	47	1.85
6	10-12	<1	13	50	37	1.08	13	3.32	415	58	82	106	16	37	47	1.79
7	12-14	<1	12	50	38	0.94	14	2.91	415	58	91	100	16	35	43	1.74
8	14-16	<1	13	44	42	0.94	14	3.32	415	52	77	95	16	32	43	1.74
9	16-18	<1	12	47	40	0.86	14	2.51	326	55	79	81	9	28	41	1.75
10	18-20	1	13	47	40	0.84	15	2.15	425	53	73	76	7	26	30	1.68
11	20-22	<1	14	46	40	0.94	15	2.51	297	59	65	76	12	24	24	1.61
*12	22-24	1	15	42	42	0.77	15	2.15	425	54	70	76	9	24	32	1.62
13	24-26	<1	16	45	38	0.77	17	2.15	439	49	67	76	9	23	20	1.57
14	26-28	1	15	43	41	0.68	16	2.51	241	51	68	71	7	23	24	1.59
15	28-30	<1	17	42	41	0.86	16	2.15	354	51	73	71	7	24	27	1.63
16	30-32	1	17	48	34	0.81	16	2.15	340	49	70	71	9	24	30	1.61
17	32-34	1	17	48	34	0.78	16	2.15	382	45	64	67	7	23	27	1.57
18	34-36	1	17	45	37	0.86	17	2.15	425	51	75	71	7	24	30	1.58
19	36-38	1	19	42	37	0.81	18	2.15	382	49	75	71	7	26	34	1.58
20	38-40	2	22	43	34	0.71	19	2.51	439	51	67	67	9	24	27	1.53
21	40-42	1	21	44	34	0.71	20	2.15	453	51	101	71	7	24	24	1.50
22	42-44	1	19	43	36	0.80	20	2.51	411	47	59	71	12	24	30	1.50
*23	44-46	2	22	40	36	0.73	21	2.33	319	45	59	64	7	22	25	1.46
Avg.		1	15	46	38	0.89	15	2.53	384	53	76	86	10	29	34	1.66
Std.		0.5	3	3	3	0.16	3	0.41	51	5	11	20	3	6	10	0.12

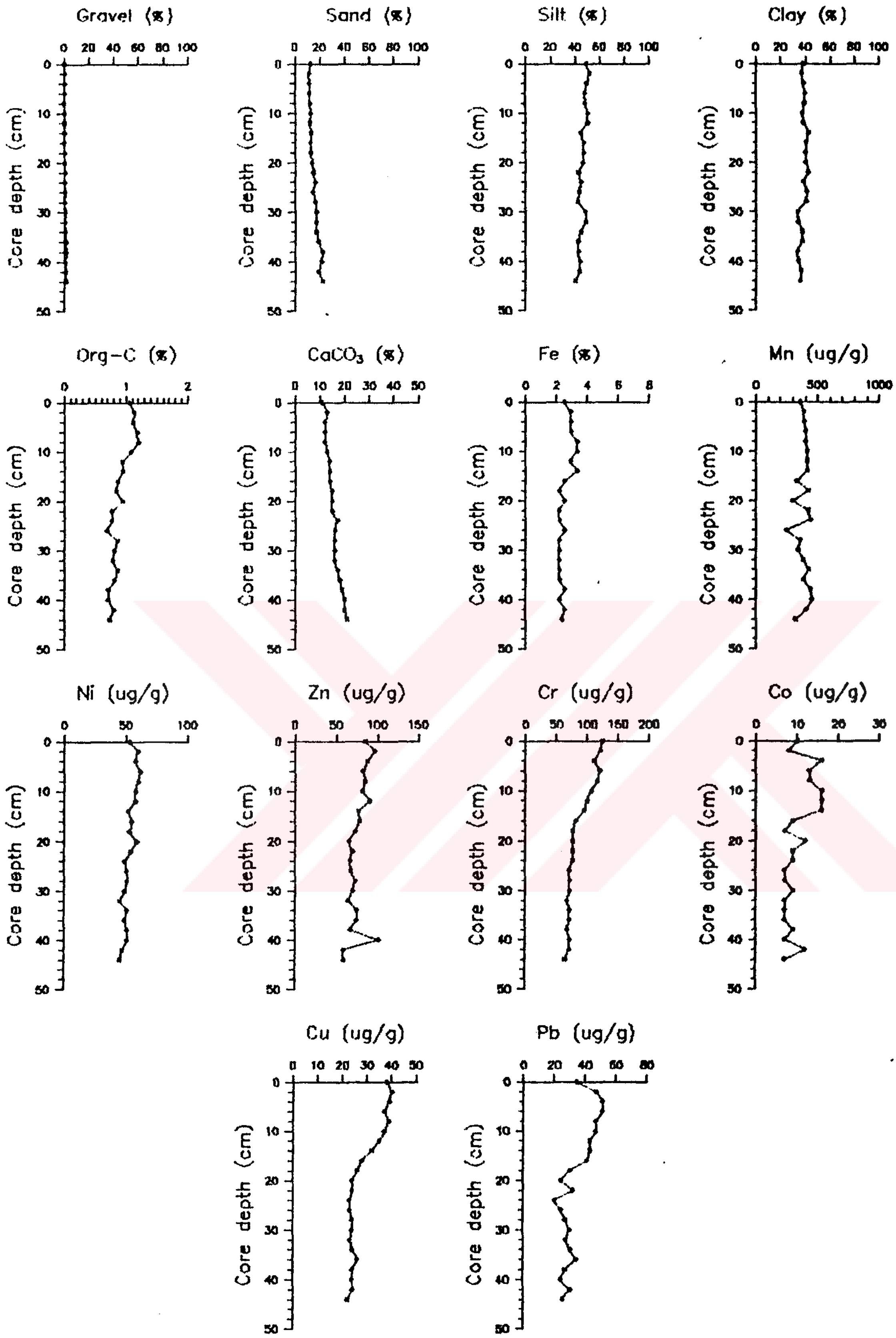

Figure 3.57 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core BC-2.

The sand fractions make up about 11 to 22 % of the bulk sample (avg. 15 %), with a slight tendency to increase with depth (Fig. 57). This must have resulted in slight increase of the clay contents (33-42 %) towards the surface, whilst silt percentages remained nearly uniform throughout the core (40-51 %; Fig. 3.57). Mud is the dominant sediment type in the core, with percentages from 76 to 88 % (avg. 84 %). Visual examination of core BC-2 by naked eye reveals some slight changes in the colors of sediments along the core. Its color changes from dark grayish-green to greenish-gray, but it was observed that there were some thin laminae in brown color at around 34-46 cm core depth. The sediments from top to about 12 cm depth appear greenish-gray in color showing traces of bioturbation by large amounts of polychaetes. Between about 12 and 24 cm depth, the color changes to grayish-green with no significant polychaetes occurrences. Below this depth, till down to about 36 cm polychaetes reappeared. The sediments below about 32 cm depth were dark grayish-green in color and two distinct, laminated layers occurred in brown color.

Microscopic studies of sand-sized fractions of the sediments indicate the dominance of terrigenous materials, (70 %). Quartz is the most common terrigenous minerals that shows subrounded and partially-rounded shape. Metamorphic rock fragments are commonly found in dark gray and green in color Other components of sand include organic debris, mica flakes and coalified wood particles which are less common. Biogenous constituents are mainly represented by the foraminiferal tests of hyaline types (*Triloculina*, *Bulimina*, *Bolivina*, *Ammonia beccarii* and *Uvigerina sp.* etc.) and agglutinated and milioline type. *Elphidium* and *Globorotalia sp.* are also observed. The other important biogenous materials are derived from the pelecypodal shell fragments (mostly abundant in >500 μ size), ostracods, gastropods, annelida, siliceous sponge spicules, echinoid-spines and -partially plates, bryozoa, worm tubes, and calcareous algae. Many of the foraminiferal (*Triloculina*, *Bolivina*, and *Valvulineria sp.*) and ostracodal shell tests show pyrite/pyritization. The nearly uniform clay distribution in Core BC-2 would suggest no major changes in the depositional conditions, although slight decreases in the sand contents towards the surface may be indicative of an environmental response.

Core MBC-3 : Site of coring of MBC-3 is situated in the eastern deep basin of the Sea of Marmara (water depth 1200 m). Sediments of Core MBC-3 are practically gravel-free (<1 %) but contains some sand (<1-8 %) (Table 3.13). Other studies from the same region (Ergin and Evans, 1988; Evans *et al.*, 1989) show comparable trend with their values (1-5 %, sand). Mud comprising of up to over 92 % of bulk samples, is the predominant sediment type in Core MBC-3 (Fig. 3.58). In Core MBC-3, the color of sediments shows variations. It is yellowish-brown to grayish-green in the upper parts of core and changes to green-greenish gray in mid-parts to dark-greenish gray in the lower parts.

Table 3.13 : Grain-size and chemical composition of sediments in Core MBC-3.

#	(D) (cm)	G %	S %	Z %	C %	org.C %	(C) %	Fe %	Mn (.......	Ni	Zn µg/g	Cr	Co	Cu	Pb)	W/D
* 1	0-2	0	1	29	70	1.15	10	4.09	5166	85	120	106	14	46	52	1.89
2	2-4	0	1	26	72	1.05	10	4.23	3882	87	113	106	15	46	49	1.83
3	4-6	0	1	27	72	1.05	10	4.20	3099	87	107	96	15	43	44	1.83
4	6-8	0	1	17	82	1.08	10	4.04	3725	85	104	101	21	43	49	1.80
5	8-10	0	1	27	71	0.93	11	3.94	2724	84	113	101	15	42	49	1.79
6	10-12	0	1	27	72	1.03	10	4.10	1284	84	103	101	21	43	44	1.83
7	12-14	0	1	37	62	1.03	10	4.05	619	91	100	99	21	44	50	1.78
8	14-16	0	1	26	73	1.13	10	3.73	2053	91	100	104	21	44	61	1.79
9	16-18	0	<1	34	66	1.10	10	3.51	2020	89	100	109	21	42	56	1.77
10	18-20	0	<1	33	67	1.05	10	3.49	1336	91	105	104	21	41	52	1.76
11	20-22	0	2	35	63	1.00	10	4.34	1727	87	95	99	21	39	48	1.72
12	22-24	0	2	29	70	0.96	11	4.44	3940	91	103	104	18	41	52	1.75
13	24-26	0	1	28	71	1.08	10	3.94	2491	85	84	113	15	41	63	1.72
14	26-28	0	1	27	72	1.00	10	4.44	2041	89	103	108	15	39	52	1.73
15	28-30	0	1	24	75	1.03	10	4.09	2082	89	92	108	15	41	58	1.72
16	30-32	0	1	34	65	1.05	10	4.34	1837	91	113	108	18	41	46	1.72
17	32-34	0	1	27	72	1.13	11	4.24	2368	89	94	108	15	39	69	1.73
18	34-36	0	1	27	72	0.98	11	4.19	2123	89	98	108	12	38	63	1.72
19	36-38	0	1	29	70	0.98	11	4.24	1143	89	103	93	15	38	63	1.70
20	38-40	0	2	32	66	1.03	10	4.39	1143	83	91	93	15	38	46	1.68
*21	40-42	0	1	33	65	0.91	12	4.18	3164	89	95	96	15	38	49	1.68
22	42-44	0	1	25	74	1.08	11	4.24	735	91	99	88	15	38	40	1.68
23	44-46	0	1	23	77	1.11	10	4.24	572	89	98	98	15	39	35	1.67
24	46-48	0	1	27	72	1.06	10	4.46	857	91	98	93	15	39	46	1.68
25	48-50	0	1	32	67	1.11	10	4.34	1797	93	98	98	15	36	63	1.71
26	50-52	0	1	29	69	1.01	11	4.04	4001	83	92	93	15	38	46	1.68
27	52-54	0	1	28	71	1.15	12	4.19	4667	95	102	126	15	39	46	1.68
28	54-56	0	1	19	80	1.13	11	4.34	1867	89	99	121	18	39	39	1.66
29	56-58	0	1	21	78	1.08	11	4.14	2921	89	103	126	15	39	31	1.68
30	58-60	0	1	30	69	1.13	10	4.29	2258	93	96	126	12	40	46	1.67
31	60-62	0	1	38	61	1.15	9	4.26	1235	95	99	126	15	40	54	1.63
32	62-64	0	4	29	66	1.03	9	4.03	1596	89	101	131	12	37	39	1.61
33	64-66	0	3	32	65	1.03	12	3.60	4336	84	102	101	9	36	39	1.67
34	66-68	0	1	27	72	1.13	11	4.17	2319	93	116	116	12	40	39	1.64
35	68-70	0	1	27	72	1.08	11	3.93	3975	91	79	101	12	39	39	1.66
36	70-72	0	1	28	70	1.08	11	3.69	3945	89	108	106	12	37	62	1.67
37	72-74	0	8	25	67	1.06	11	4.05	2921	93	110	106	12	39	54	1.66
38	74-76	0	1	27	72	1.03	10	4.00	1747	91	96	111	9	40	46	1.79
39	76-78	0	1	30	68	1.13	10	4.07	1385	89	110	106	15	39	39	1.59
*40	78-80	0	3	35	62	1.08	11	3.86	2123	85	117	101	13	39	46	1.57
Avg.		0	1	29	70	1.06	10	4.10	2381	89	102	106	15	40	49	1.71
Std.		0	1	4	5	0.06	1	0.24	1170	3	8	10	3	2	9	0.07

The grain-size profiles show that there are fluctuations in the silt and clay percentages along the cores (Fig. 3.58), which may be a consequence of variations in the depositional conditions.

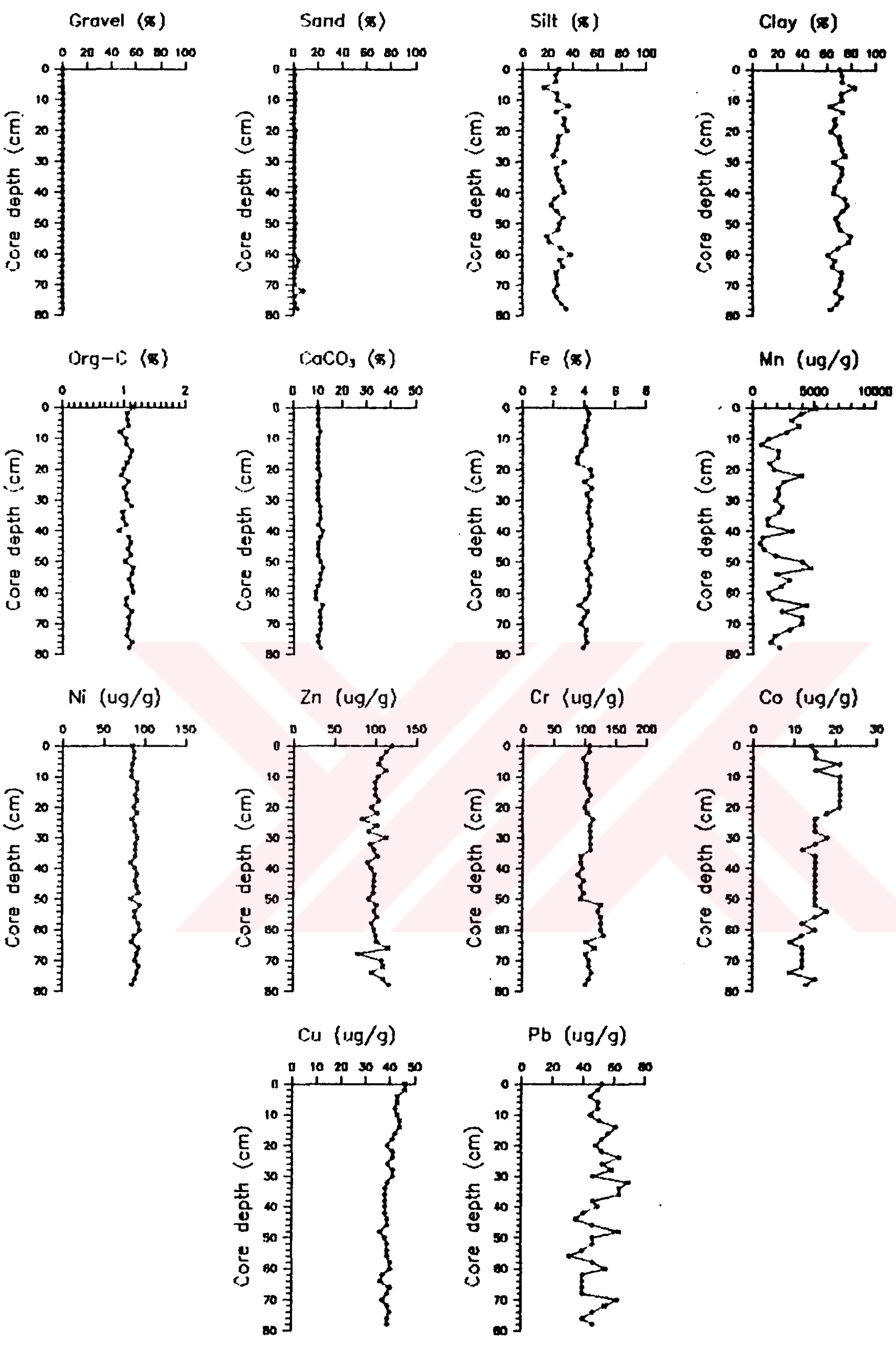

Figure 3.58 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core MBC-3.

The sand fractions of sediments contain large amounts of biogenous materials which include pelecypods, pteropods and foraminifers (commonly *Bulimina*, *Globulimina*, *Bolivina*, *Uvigerina*, *Textularia*, *Globigerina*, and *Globorotalia sp.'s*), as well as, echinoid-spine, and -plates, siliceous sponge spicules, calcareous algae, ostracods. Of these, foraminifers, small benthic molluscs, echinoids and some siliceous sponge spicules are enriched in the coarser-sand fractions (>125 μ). Such observations were also made by Alavi (1988) and Evans *et al.* (1989). Fecal pellets are also common especially in the upper parts of core but their abundances gradually decrease down the core. The terrigenous components are mainly composed of quartz grains (rounded and partially subrounded), but other lithic particles such as chert, quartzite, serpentine, mica flakes, and some unidentified dark- and light-colored mineral grains. Traces of pyrites are also identified, particularly as infill with the foraminiferal tests of *Triloculina* and *Bolivina sp.* Organic debris (coal, wood and plant remains) and slug particles are additional components in the sediment which play a minor role. Pyritization within organism remains (*i.e.*, foraminiferal tests) as was observed previously in the sediments of eastern Marmara basin (Stanley and Blanpied, 1980), is related to the post-depositional changes of in redox conditions within the sediment. Organic debris is very common at the core depth between 14 and 50 cm interval.

Core BC-3 : Site of Core BC-3 is located in the central basin of the Sea of Marmara (water depth 1226 m). The sediments throughout the core are fully composed of mud (over 98 %), whereby clay is dominant. The gravel and sand fraction are usually less than 1 % of the bulk sample (Table 3.14 and Fig. 3.59).

Table 3.14 : Grain-size and chemical composition of sediments in Core BC-3.

#	CD (cm)	G %	S %	Z %	C %	org.C %	(C) %	Fe %	Mn (.......	Ni	Zn µg/g	Cr	Co	Cu	Pb ....)	W/D
* 1	0-2	0	1	24	75	0.93	10	2.87	4050	108	106	98	12	46	25	2.15
2	2-4	0	1	26	73	0.93	10	3.23	7165	122	110	114	14	46	34	2.09
3	4-6	0	1	21	78	1.05	10	3.23	5947	122	107	114	14	47	37	2.13
4	6-8	<1	1	21	78	1.02	11	4.37	5569	137	105	116	11	44	55	2.08
5	8-10	0	1	22	78	1.07	11	4.98	4957	137	111	116	14	42	48	2.05
6	10-12	0	1	23	76	1.05	11	4.98	5628	133	102	116	14	40	41	2.01
7	12-14	<1	1	21	78	0.88	12	4.61	5832	131	95	112	16	40	45	2.00
8	14-16	<1	<1	21	78	0.93	11	4.86	4753	131	102	112	14	40	45	1.98
9	16-18	0	<1	17	83	0.98	11	4.86	3586	133	94	112	14	40	31	2.00
10	18-20	0	1	18	82	0.95	11	4.61	3324	133	88	116	14	40	48	1.99
11	20-22	0	1	21	78	0.85	12	4.25	6473	133	95	112	16	40	28	2.00
12	22-24	0	1	19	80	0.78	13	4.37	8981	130	75	112	11	39	38	1.97
13	24-26	0	1	18	81	0.80	10	4.37	2683	142	85	120	14	42	38	1.94
*14	26-28	0	1	22	77	0.98	10	4.43	2071	138	88	107	11	39	47	1.68
15	28-30	0	1	22	77	0.93	11	6.31	3032	142	91	112	11	39	48	1.93
16	30-32	0	1	21	78	0.93	11	5.71	3645	133	97	107	11	37	31	1.92
17	32-34	0	1	17	82	0.88	11	5.58	3120	131	97	107	14	37	35	1.88
18	34-36	<1	1	20	79	0.78	16	5.34	8427	124	89	90	14	32	21	1.89
19	36-38	0	1	19	80	0.88	14	5.10	9127	124	91	99	16	32	35	1.89
20	38-40	0	1	19	80	0.80	12	5.10	4461	131	111	107	11	37	35	1.87
21	40-42	0	1	21	79	0.88	11	5.22	3412	129	89	107	14	32	28	1.87
22	42-44	0	1	21	78	0.93	12	5.22	4957	129	102	107	14	32	35	1.91
23	44-46	0	1	19	80	0.88	11	4.73	3382	124	85	99	14	37	41	1.88
24	46-48	0	1	25	75	0.83	11	4.26	4006	118	85	123	20	37	45	1.86
25	48-50	0	1	21	78	0.78	11	4.50	3105	118	90	139	16	37	40	1.85
26	50-52	0	1	24	76	0.88	11	4.26	6459	124	90	139	10	37	40	1.81
*27	52-54	0	<1	21	78	0.85	11	4.17	4229	122	93	127	16	38	38	1.84
Avg.		0	1	21	78	0.91	11	4.64	4903	129	92	113	20	39	38	1.94
Std.		0	0	2	2	0.08	1	0.74	1878	8	9	11	2	4	8	0.11

The rather uniform profiles of clay and silt along the core are interpreted as a result of stable depositional conditions for most of the time. Below the surface, down to about 8 cm depth of core, sediments are reddish to dark brown in color and further downward, grayish-green color occurs.

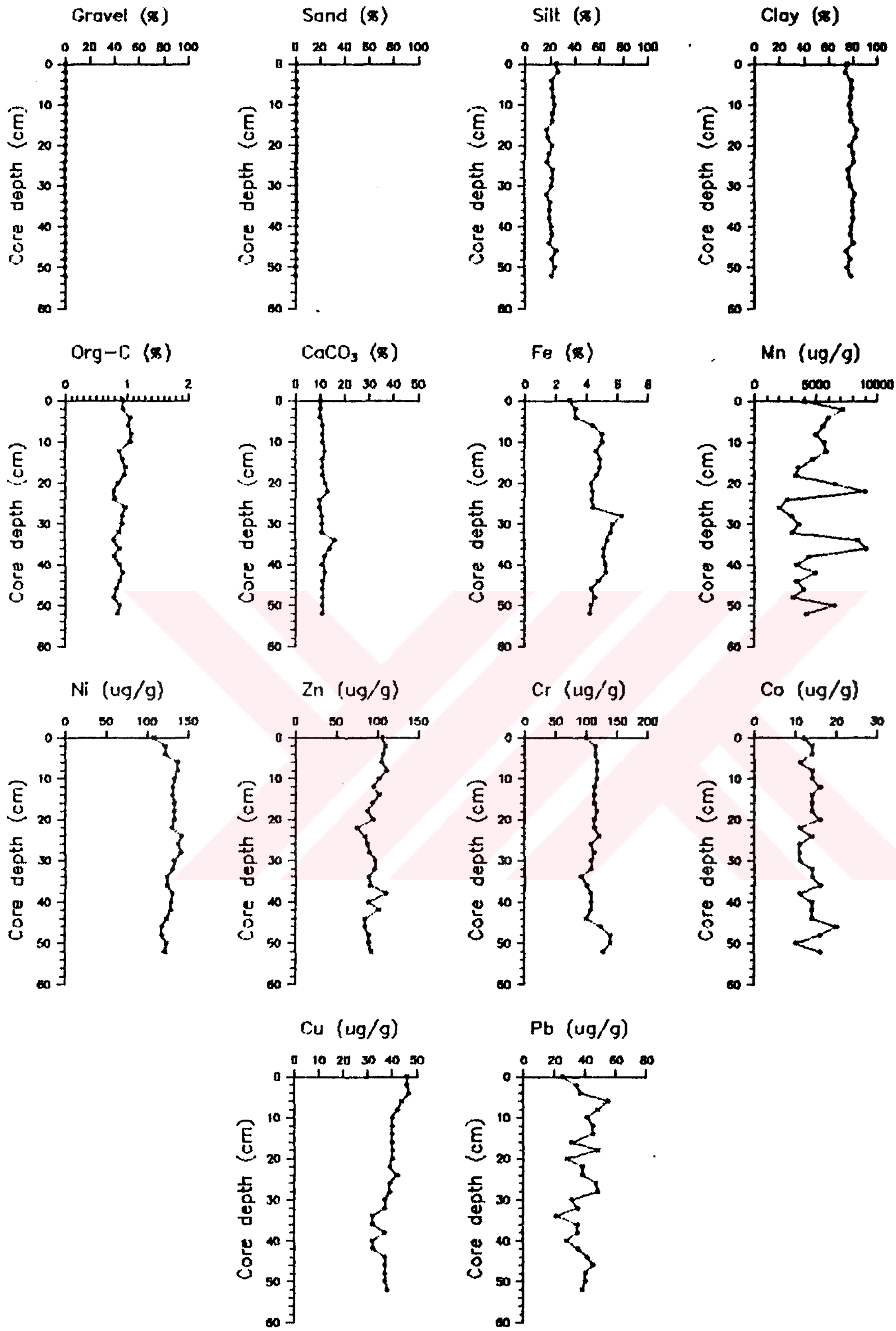

Figure 3.59 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core BC-3.

This suggests that the sediments in the upper 8 cm of core are oxidizing, when compared with those below this depth where reducing conditions are dominant.

Quartz and mica minerals seem to be important terrigenous components in the sediments. Mica flakes in greenish color is commonly found at 24-26 cm depth. Pyrite, as a minor constitute of the sediments, occasionally infills *Bulimina sp.* Biogenous components include hyaline types of pelecypods, gastropods, pteropods, echinoids, siliceous sponge spicules, polychaete tubes and rotalina types of foraminifera. *Globigerina* is a common species of planktonic foraminifers at depths below 28 cm.

Core BC-4 : Site of Core BC-4 is situated in the western basin of the Marmara Sea (water depth 1106 m). The sediments of this core can practically be regarded as sand- and gravel-free (Fig. 3.60). The gravel fraction ranges between <1 % and 1.6 % and the sand fraction constituted <1 % to 6 % of the bulk sample (Table 3.15). Mud contents exceeded over 94 % and dominated by clay. Downcore distribution of clay and silt reveal, in general, no relevant changes and the fluctuations in clay contents are largely compensated by silt (Fig. 3.60). Therefore, grain-size profiles show a strong fluctuations throughout the core. This leads to the consumption that the depositional and environmental conditions have remained nearly constant in most of the time. Koreneva (1971) concluded that the core taken from northwestern depression of the Marmara Sea

Table 3.15 : Grain-size and chemical composition of sediments in Core BC-4.

#	CD	G	S	Z	C	org.C	(C)	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb	W/D
	(cm)	%	%	%	%	%	%	%	(....... µg/g ....)							
* 1	0-2	<1	<1	31	68	1.19	8	4.26	6133	122	99	118	20	39	55	2.76
2	2-4	0	<1	35	64	1.19	8	4.87	4658	118	109	123	20	40	55	2.70
3	4-6	<1	<1	35	65	1.12	8	4.99	2453	120	100	124	20	37	40	2.41
4	6-8	0	<1	34	65	1.10	8	4.63	4347	118	93	123	20	37	35	2.60
5	8-10	0	<1	28	72	1.10	8	4.63	1677	118	100	129	20	38	55	2.67
6	10-12	0	<1	31	68	1.07	8	4.87	1925	116	97	134	16	37	45	2.17
7	12-14	0	1	39	60	1.14	8	4.63	1894	116	97	134	16	37	60	2.20
8	14-16	0	1	38	61	1.12	8	3.86	1805	114	99	137	12	36	40	2.31
9	16-18	0	1	45	53	0.98	8	3.46	1869	122	152	158	12	38	24	2.11
10	18-20	0	2	45	53	1.02	8	3.46	1267	114	94	137	18	36	40	2.16
11	20-22	0	1	39	59	1.02	8	3.01	1520	118	87	142	9	35	16	1.99
12	22-24	0	2	37	61	1.14	8	3.40	1425	126	180	142	18	35	48	2.19
13	24-26	0	3	45	52	1.05	8	3.01	2059	124	76	142	12	36	40	2.06
14	26-28	0	<1	41	59	0.95	8	3.27	1394	128	105	142	12	36	32	2.02
*15	28-30	0	<1	44	56	1.00	8	3.63	1869	128	94	145	18	35	28	1.95
16	30-32	0	1	43	56	1.00	8	3.73	1932	123	88	142	21	35	32	2.00
17	32-34	0	6	46	48	0.90	9	3.27	1584	123	78	142	18	33	24	1.88
18	34-36	0	5	38	57	1.00	10	3.66	3801	114	81	142	18	33	56	2.00
19	36-38	2	1	26	71	1.00	11	3.86	8235	122	81	132	18	38	56	2.15
20	38-40	1	<1	29	69	1.12	10	3.99	6683	125	81	137	21	39	56	2.22
21	40-42	0	<1	26	74	1.10	9	3.92	2470	123	114	137	21	39	48	2.16
22	42-44	0	<1	30	70	1.02	9	3.92	2851	123	64	132	24	38	32	2.23
23	44-46	<1	<1	29	71	1.05	9	3.79	3389	123	73	132	21	36	32	2.09
24	46-48	0	<1	31	69	1.00	9	3.66	1267	125	88	142	18	36	32	2.02
25	48-50	0	1	39	60	0.93	8	3.59	950	127	85	152	21	36	32	1.79
26	50-52	0	3	35	62	0.98	10	4.48	2426	115	89	174	21	38	34	1.78
27	52-54	0	4	32	64	0.90	11	4.99	4487	111	85	169	15	36	39	1.77
28	54-56	0	<1	24	75	0.83	13	5.06	7428	113	90	158	21	41	34	1.80
*29	56-58	0	<1	24	76	0.95	8	4.77	3457	122	95	171	21	42	44	1.82
Avg.		0	1	35	63	1.03	9	4.02	3010	120	95	141	18	37	40	2.14
Std.		0	1	7	7	0.09	1	0.63	1935	5	22	14	4	2	11	0.28

(water depth 1160 m) was not older than Holocene on the basis of vertical distribution of spore and pollen concentrations and he belived that the sedimentation rate was greatest in this part of the Sea of Marmara.

The limited amounts of sand and gravel fractions showed the presence of terrigenous and biogenous materials. Feldspar, quartz, micas minerals were important terrigenous detritus. In addition, pyrite occurrences are observed in the presence of biogenous and organic substances (especially with *Bulimina sp.*).

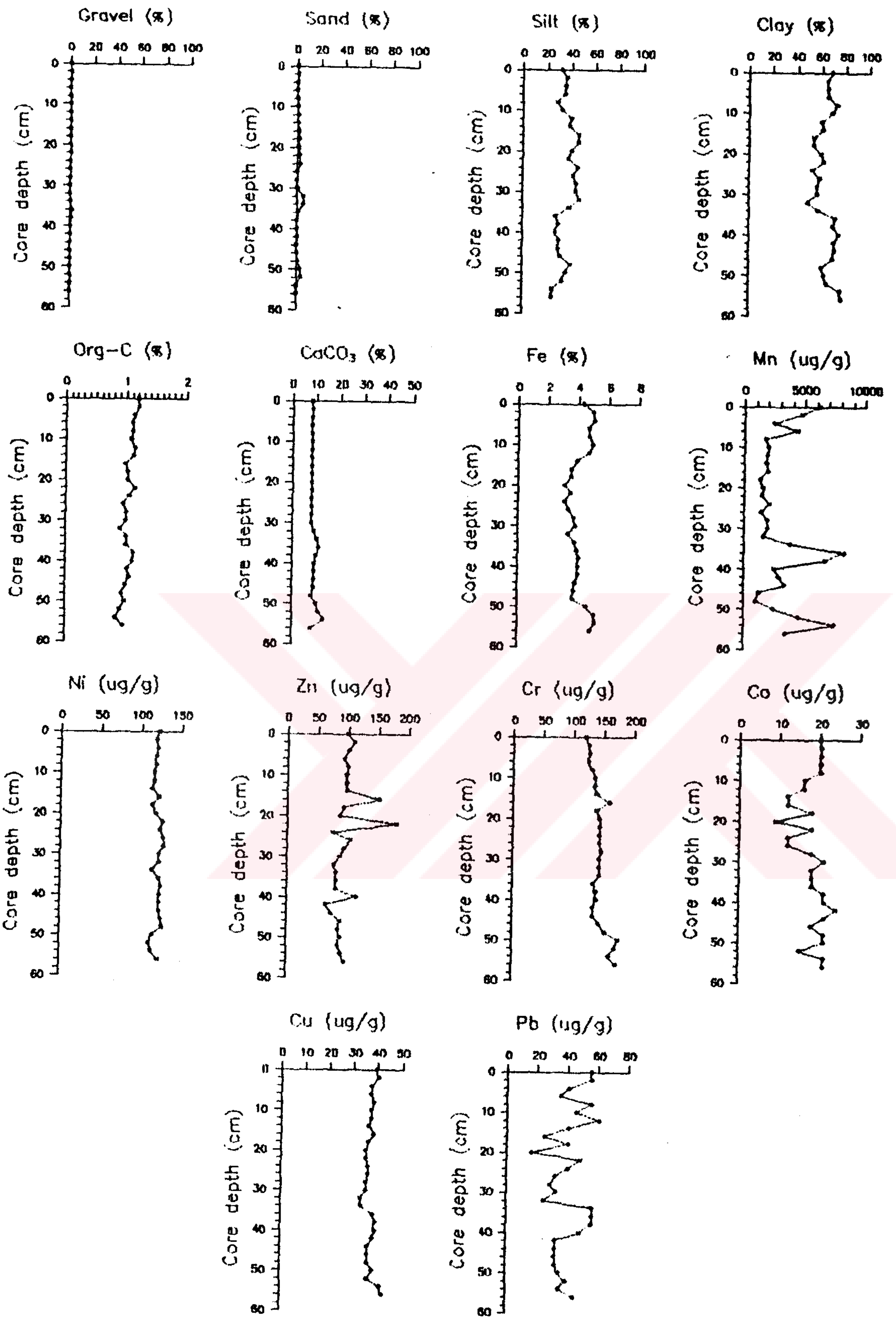

Figure 3.60 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core BC-4.

Biogenic constituents are dominated by hyaline types of foraminifers (some of them were oxidized, especially the agglutinated types), of pelecypods, ostracods and pteropods with minor amounts of echinoid-spine, and -plates and also siliceous sponge spicules. *Globigerina* and *Globorotalia sp.* are highly abundant at 40-42 cm and 54-56 cm intervals.

It is observed that in the uppermost parts of this core, the color of sediments ranges from reddish dark-brown to greenish-brown (at about 10 cm depth), after this interval with slight gray color turns to grayish green in color represented by clayey materials.

Core BC-5 : The coring site of BC-5 is located at the northeastern approach of Dardanelles Strait to the Marmara Sea (water depth 65 m), just near the head of Dardanelles Canyon. As shown in Fig. 3.61, sediments of Core BC-5 are almost sand- and gravel-free. The percentages of gravel and sand did not exceed 1 % throughout the core (Table 3.16). Consequently, the mud concentrations made up of over 99 % of the bulk sample, whereby clay overwhelmed the silt. Again here, nearly stable depositional conditions are inferred from the uniform trend in clay and silt percentages (Fig. 3.61). The color of sediments in the uppermost part of core (0-4 cm) is reddish-brown which changes to greenish-gray, from this depth down to 10 cm. Thereafter it constantly shows green color. This is a typical sediment profile with oxidizing layers at or near the surface, underlain with

Table 3.16 : Grain-size and chemical composition of sediments in Core BC-5.

#	(D) (cm)	G %	S %	Z %	C %	org.C %	(C) %	Fe %	Mn (.......	Ni	Zn	Cr µg/g	Co	Cu	Pb ....)	W/D
* 1	0-2	0	1	45	55	0.87	11	4.38	1320	108	84	131	23	31	63	1.77
2	2-4	0	<1	43	56	0.84	11	4.50	776	116	78	134	26	32	60	1.76
3	4-6	0	1	42	57	0.84	10	4.75	683	116	85	134	26	32	55	1.76
4	6-8	0	1	43	56	0.87	10	5.11	761	112	99	134	23	32	65	1.79
5	8-10	<1	1	42	57	0.79	10	5.23	730	120	97	139	23	34	50	1.76
6	10-12	<1	1	44	55	0.74	10	4.38	776	118	96	129	23	34	50	1.73
7	12-14	0	1	45	54	0.74	10	4.75	714	120	87	134	23	35	65	1.68
8	14-16	<1	1	40	59	0.74	10	4.53	728	109	80	158	15	36	39	1.64
9	16-18	<1	1	43	56	0.64	11	4.60	652	109	79	164	15	35	24	1.62
10	18-20	0	1	41	58	0.69	10	4.46	652	107	76	164	15	35	24	1.63
11	20-22	<1	1	43	56	0.69	11	4.33	667	115	92	169	18	35	15	1.61
12	22-24	<1	1	35	64	0.74	11	4.19	713	107	88	153	18	35	32	1.63
13	24-26	<1	1	39	60	0.67	11	4.02	603	113	90	149	24	33	48	1.72
14	26-28	<1	1	39	61	0.72	11	4.19	586	115	85	154	24	33	43	1.72
*15	28-30	0	<1	41	59	0.72	11	4.00	570	117	64	154	15	33	48	1.73
16	30-32	<1	<1	42	57	0.72	11	3.97	538	109	95	149	21	33	43	1.71
17	32-34	<1	<1	44	56	0.79	11	3.97	505	107	78	149	15	33	39	1.70
18	34-36	<1	1	43	57	0.72	11	4.10	521	109	81	149	18	33	39	1.68
19	36-38	<1	1	41	58	0.74	11	4.00	521	111	85	144	18	31	48	1.70
20	38-40	<1	1	41	59	0.79	11	3.97	538	107	77	134	18	33	50	1.68
21	40-42	<1	1	42	57	0.74	11	4.02	489	111	80	139	18	33	39	1.66
22	42-44	<1	<1	44	56	0.82	11	4.00	489	107	77	139	15	33	48	1.66
23	44-46	<1	1	42	57	0.77	11	3.97	456	109	78	139	15	33	39	1.63
*24	46-48	<1	<1	41	58	0.77	11	3.92	481	111	88	131	18	33	43	1.65
Avg.		<1	1	42	57	0.76	11	4.30	636	112	84	145	20	33	45	1.69
Std.		0	0	2	2	0.06	0	0.36	184	4	8	12	4	1	12	0.05

reducing layers, as observed in many areas elsewhere (Arthur *et al.*, 1988).

Minor amounts of hyaline (*Bulimina*, *Bolivina*, and *Uvigerina sp.*) and agglutinated tubular types (usually in the top sections of core: *Valvulineria*, *Globorotalia*, *Ammonia beccarii* and *Textularia sp.*) of foraminifers with scattered occurrences of pelecypods, ostracods, sponge spicules, echinoid-spine and- plates, pteropods, bryozoa, gastropods (*Turritella sp.*) and calcareous worm tubes represented the biogenic fraction in the sediments. The visible terrigenous constituents under microscope were quartz, feldspar, mica

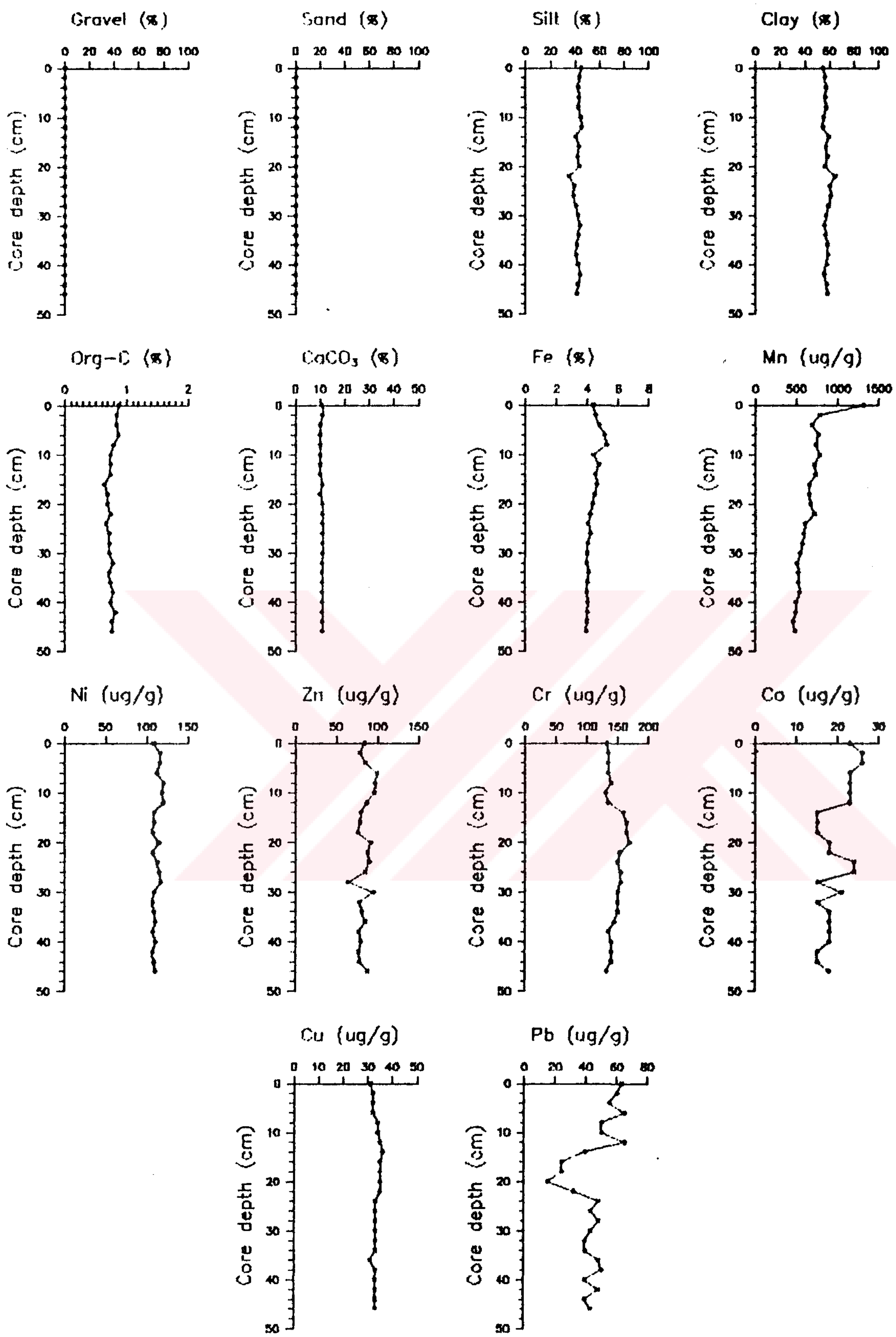

Figure 3.61 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core BC-5.

flakes, and organic debris (wood and plant remains). Pyrite and/or pyritization within the foraminiferal tests occured in very low concentrations throughout the core.

Core BC-6 : Coring site of BC-6 is located in the southwest (water depth 74 m), just before the Aegean exit of Dardanelles Strait (Fig. 2.3). As shown in Fig. 3.62, gravel is nearly absent in Core BC-6 and sand reaches no more than 3 % throughout the core (see also Table 3.17). Thus, mud is prominent (more than 96 % of the bulk sample) In general, the clay, silt and sand profiles (Fig. 3.62) show constant trend throughout the core, suggesting stable depositional conditions, probably at lower energy levels to favor fine-sedimentation. The color in the upper 2 cm of core is reddish-brown and changes to grayish-green down to 10 cm depth. Below this depth, it becomes brownish-gray to green. From this, an upper oxidizing unit and a reducing unit below can be suggested in the core.

Table 3.17 : Grain-size and chemical composition of sediments in Core BC-6.

#	(D) (cm)	G %	S %	Z %	C %	org.C %	(C) %	Fe %	Mn (.......	Ni	Zn	Cr μg/g	Co	Cu	Pb ....)	W/D
* 1	0-2	0	3	52	45	0.10	15	1.84	423	30	31	68	9	10	27	1.38
2	2-4	0	1	51	48	0.15	17	1.89	376	37	44	81	12	12	22	1.42
3	4-6	0	1	51	47	0.17	13	2.15	454	42	54	81	12	15	38	1.38
4	6-8	0	2	51	47	0.17	13	2.02	470	42	52	81	12	15	33	1.35
5	8-10	<1	2	50	48	0.37	19	2.02	610	44	37	81	12	15	44	1.36
6	10-12	<1	1	50	48	0.42	23	1.95	470	42	52	71	12	15	38	1.37
* 7	12-14	0	1	54	45	0.37	21	1.94	446	39	49	68	11	16	30	1.38
8	14-16	<1	1	50	49	0.45	26	1.14	379	40	40	74	18	17	20	1.38
9	16-18	<1	2	48	50	0.59	28	1.12	349	42	46	69	18	19	24	1.40
10	18-20	0	1	50	49	0.52	32	0.88	364	40	40	69	15	17	15	1.38
11	20-22	<1	1	49	50	0.49	31	0.93	364	40	40	74	15	17	29	1.39
12	22-24	<1	1	50	49	0.66	34	0.78	349	42	40	63	12	17	29	1.38
13	24-26	<1	1	50	49	0.66	30	0.80	349	42	40	69	12	17	15	1.39
*14	26-28	<1	1	51	48	0.66	34	0.73	303	44	46	79	13	17	20	1.38
Avg.		<1	1	51	48	0.41	24	1.44	408	40	44	73	13	16	27	1.38
Std.		0.1	1	1	1	0.19	7	0.54	75	3	6	6	3	2	9	0.02

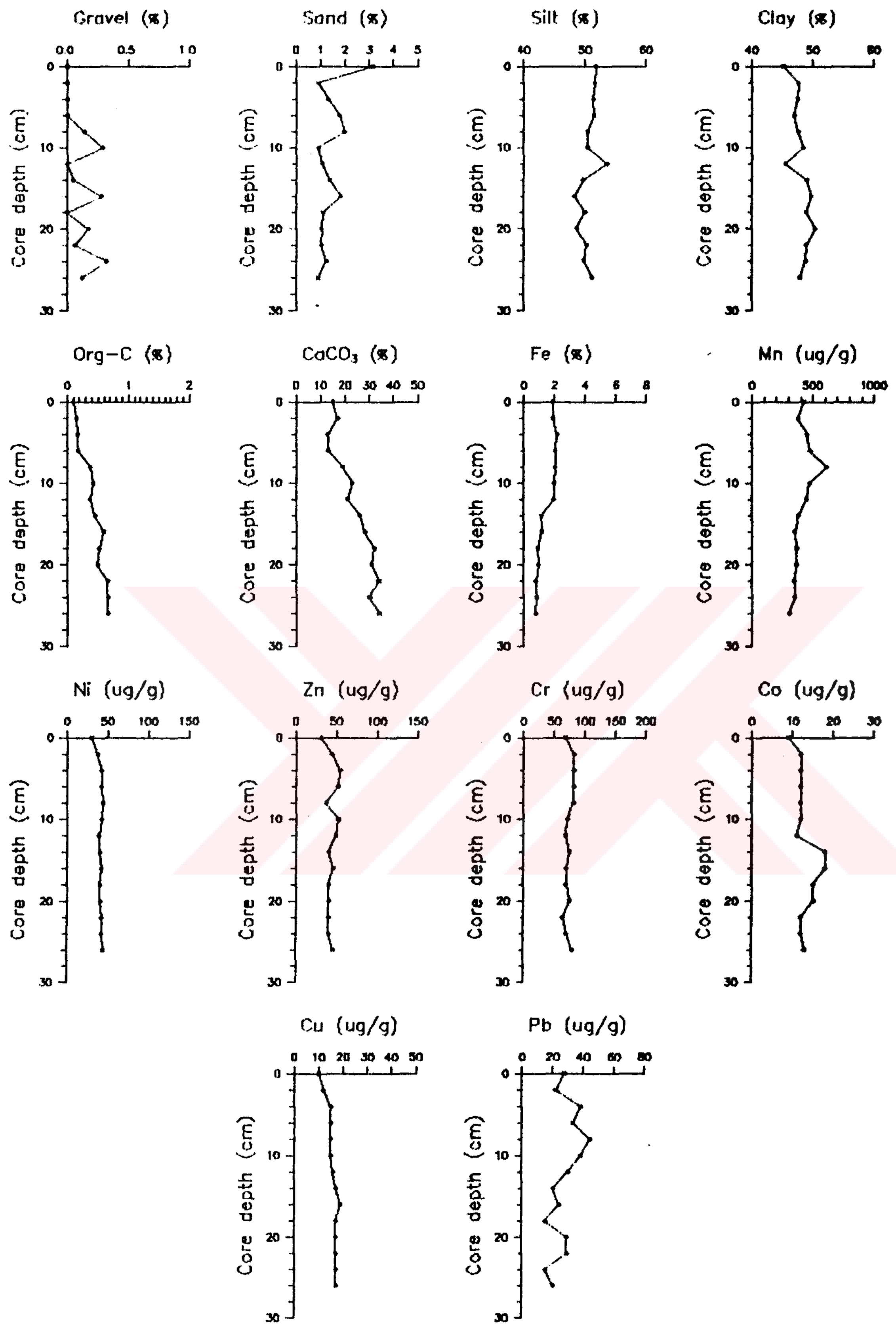

Figure 3.62 : Distribution profiles of grain-size, organic carbon, carbonate and heavy metals in Core BC-6.

The only visible terrigenous materials under microscope are siliceous detritus such as quartz, feldspar, mica and metamorphic rock fragments. Biogenic constituents even in minor amounts, are the remains of foraminifers (*Globigerina*, *Textularia*, *Milioline*, *Elphidium* and *Ammonia beccarii sp.*) bryozoa, echinoid-spine and -plates, calcareous worm tubes, siliceous sponge spicules, gastropods, pelecypods, ostracods and calcareous algae. Some of pelecypods and gastropods shell are pinkish in color. The barnacles were found only at 16-18 cm depth.

3.2.1.1. CONCLUSION

With the exception of the two cores from the northern part and south off the Bosphorus Strait (Cores BC-1 and BC-2 respectively), the cores from the eastern, central, and western basins of the Sea of Marmara (Cores MBC-3, BC-3, and BC-4 respectively), as well as, the Dardanelles Strait-the Sea of Marmara Junction (Core BC-5), and the southwestern part of Dardanelles Strait (Core BC-6), are mainly composed of terrigenous mud. This is interpreted that relatively low-energy conditions have prevailed in these areas at most of the time of deposition. On the other hand, the slight fluctuations in the clay and silt contents of sediments along the cores are attributed to the generally uniform, and stable depositional conditions may be interrupted by some temporal and spatial changes in the natural sedimentary processes. Occurrences of high sand and gravel percentages below 2 cm depth of Core BC-1, as well as, the generally downward increasing sand contents in the Core BC-2 are consistent with the increased benthogenic activities within the Bosphorus channel system. It seems that some environmental changes must have occurred in the most recent times during which the benthic-biogenic activities are interrupted by the deposition of fine-grained sediments. Terrigenous components of the cores include quartz, feldspar, mica minerals and metamorphic rock fragments etc, which reflects their sources to be mainly from the surrounding land-masses.

Although sediments from all cores contained both biogenic and terrigenic components, the latter was dominant. The biogenic fractions constituted various species of pteropods, foraminifers, pelecypods, echinoids, even in minor concentrations in most of the cores. Bioturbation by the polychaetes was characteristic in the upper sections of cores.

The presence of hyaline calcareous foraminifers and the reddish-brown color of sediments at or near the surface clearly shows the depositional environments in the studied coring sites have normally been oxidized. This is also evident from the color changes in the sediment column, namely from reddish-brown at or near the surface to grayish-green at the subsurface.

3.2.2. GEOCHEMISTRY OF THE CORE SEDIMENTS

3.2.2.1. ORGANIC CARBON

The total organic carbon contents of the core sediments from the Sea of Marmara and its two straits ranged between 0.04 and 1.20 % (about 1 %, on the average; Figs. 3.56 to 3.62 and Tables 3.11 to 3.17). These values are normally comparable with those reported from the eastern Marmara basin (1.38 %; Evans *et al.*, 1989) and the deviations from them can be related to the possibly strong local changes and/or to the application of different analytical methods. Comparison of the organic carbon values obtained in this study with those from deep-sea sediments elsewhere in the Black Sea and Eastern Mediterranean reflects significant differences in organic matter production/deposition among these three seas. Due to its low primary productivity (Salihoğlu *et al.*, 1987) but high decay rates, the Mediterranean Sea is normally characterized by low organic carbon contents in the sediments (Emelyanov, 1972; Yılmaz, 1986; Bodur and Ergin, 1988), in contrast to the highly productive Black Sea waters (Ünlüata and Özsoy, 1986) which contribute higher organic carbon percentages to the bottom deposits (Rozanov *et al.*, 1974; Hirst, 1974; Calvert *et al.*, 1987). Consequently, the transitional Marmara Sea sediments exhibit average values of contents of sedimentary organic carbon from the Black Sea and Mediterranean. However, marked vertical changes occur in the distribution of organic carbon in the sediments from the investigated area. For example, sediments in Core BC-1, show increasing org.C contents, from 6 cm depth towards the surface. At these depths, the upward-increasing fine fraction of sediments may explain this pattern. Because, fine-grained sediments are known to be good traps for the accumulation of organic substances (*i.e.*, planktonic remains, humus matter). Of course, other reasons may also be relevant, such as changes in the source, rates of supply and post-depositional (diagenetic) processes which is beyond the scope of this work, thus, needs further research. As it can be seen from the Fig. 3.56, organic carbon contents below 6 cm depth of Core BC-1, gradually increase with depth, corresponding to the increasing biogenic $CaCO_3$ concentrations. Although these might be several reasons for this, changes in the carbonate supply and/or the post-depositional condition may deserve attention.

In Core BC-2, the general upward-increasing organic carbon contents would suggest either changes in the rate/sources of supply and/or diagenesis in the sediment. The vertical variations in the organic carbon contents (Fig. 3.57) seem to be related with changes in the carbonate contents of sediments which in turn is considered as part of diagenetic processes. As it has been known by numerous studies, organic carbon contents in the sediments normally decrease with depth due to increased decay of organic matter with the time (Kukal, 1971; Berner, 1982; Klinkhammer and Lambert, 1989).

In the deep-sea Core MBC-3, the organic carbon percentages are rather constant throughout the core (Fig. 3.58). This may reflect no major changes in the rate of supply and decay of organic matter.

Likewise, the deep-sea Core BC-3, reflects no important changes in the organic carbon distribution along the core (Fig. 3.59), although a slightly upward-increasing tendency can inferred probably being due to diagenesis.

A similar upward-increasing in the organic carbon contents was found in the deep-sea Core BC-4 (Fig. 3.60), where the diagenesis largely seems to control the organic matter distribution in the sediment.

The shallow-water Core BC-5 exhibits rather stable conditions of both deposition and decay of the organic matter (Fig. 3.61). The somehow upward-increasing organic carbon contents above 10 cm depth are interpreted as typical results of diagenesis.

The other shallow-water Core BC-6 from the south of Dardanelles display much different pattern. The organic carbon concentrations generally increase with depth, accompanied by the downward-increasing carbonate contents (Fig. 3.62). Obviously diagenesis plays an important role here again, whereby the rate of breakdown/decay of organic matter exceeds the rate of deposition.

3.2.2.2. TOTAL CARBONATE

Data from the carbonate measurements together with the results of microscopic examination of sediment particles revealed that the majority of carbonate concentrations of sediments must be derived from biogenic sources. Thus, the carbonate contents of sediments reflect the presence of the biogenic admixtures, especially molluscs shell remains. Carbonate materials are commonly found in the coarse-grained fractions, as can also be inferred from the significant correlation between $CaCO_3$, sand and gravel percentages (Tables 3.18 and 3.19).

The $CaCO_3$ distribution in Cores BC-1, BC-2, and BC-6 shows a general tendency of carbonate contents to decrease towards the surface, while $CaCO_3$ profiles in Cores MBC-3, BC-3, BC-4, and BC-5 are rather uniform (Figs. 3.56 to 3.62). This may be explained by the changes either in the rate of supply of biogenic carbonate or in the rate of dissolution of carbonates due to diagenesis within sediment.

The carbonate contents of core sediments from the eastern Marmara Sea basin obtained in this study (about 10 % $CaCO_3$ in Core MBC-3) are somewhat lower than those reported by Evans *et al.* (1989; 12-20 % $CaCO_3$). Much smaller $CaCO_3$ values are also known in this region (less than 5 %; Stanley and Blanpied, 1980). This can probably be resulted from the application of different analytical procedures or/and strong locally changes. A significant relationship is observed between the organic carbon and carbonate contents of sediments particularly in Cores BC-1 and BC-6 (Tables 3.18 and 3.24), both are from the strait systems of Bosphorus and Dardanelles, respectively. This correlation would be indicative of diagenesis in sediments, whereby the increased rate of organic carbon decay towards the more oxidizing sediment surface might have been accompanied by the dissolution of carbonates. Then it is known that the decomposition of organic matter in sediments usually produces organic acids which in turn are able to dissolve carbonates (Krauskopf, 1985).

The correlation coefficient matrices (Tables 3.19 and 3.20) also show that there is a strong relationship between $CaCO_3$ and depth, gravel and sand content, but it is inversely related with the org.C, silt and clay content in only for the Core BC-1 and BC-2 sediments. Those suggest that the carbonate contents in the sediments are supplied from the coarse fraction (>500 μ) which is dominated by pelecypods shell fragments and foraminifers with the subordinate amounts of other biogenous components

3.2.2.3. HEAVY METALS

3.2.2.3.1. IRON

Average iron concentrations in the studied core sediments varied between 1.08 % and 4.62 % (Total Fe). It seems that the contents of iron in the samples are mostly derived from the terrigenous sources, when compared with the average sedimentary rocks (Table 3.9).

In Core BC-1, above 4 cm, the iron contents of the samples (0.42-2.49 % Fe) increased gradually upward (Fig. 3.56) and below this depth they remained nearly constant representing background levels of Fe (about 1 %) in this core. The strongly positive correlation between Fe, and silt and clay contents may suggest the enrichment of Fe in the silt and clay fractions. On the other hand, the inverse relationship between Fe and $CaCO_3$ contents show the dilution effect of carbonate on the iron (Table 3.18).

Iron concentrations in Core BC-2 ranged between 2.15 and 3.32 % (avg. 2.53 %; Table 3.11). Fe profile shows that Fe contents are generally higher at 0-16 cm depths compared with the underlying core section (Fig. 3.57).

The correlation coefficient matrix (Table 3.19) shows that there is a significantly positive relationship between the contents of Fe, organic carbon, and to lesser extent of silt. From this, it appears that the elevated concentration of Fe in the upper core sections are resulted from the higher organic and silt fractions of sediments.

Table 3.18 : Correlation coefficient matrix of the various parameters measured in Core BC-1 (N=9, p=0.05, r=0.67).

	Deoth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	0.90	1.00													
Sand	0.73	0.68	1.00												
Silt	-0.79	-0.78	-0.99	1.00											
Clay	-0.84	-0.80	-0.98	0.99	1.00										
org.C	0.55	0.27	0.02	-0.04	-0.13	1.00									
CaCO	0.88	0.82	0.96	-0.97	-0.99	0.20	1.00								
Fe	-0.72	-0.68	-0.96	0.96	0.94	-0.03	-0.91	1.00							
Mn	-0.81	-0.79	-0.97	0.98	0.99	-0.03	-0.98	0.93	1.00						
Ni	-0.78	-0.79	-0.97	0.98	0.98	0.02	-0.97	0.93	0.997	1.00					
Zn	-0.80	-0.76	-0.97	0.98	0.98	-0.05	-0.98	0.94	0.995	0.99	1.00				
Cr	-0.79	-0.79	-0.97	0.99	0.98	-0.02	-0.96	0.96	0.99	0.99	0.99	1.00			
Co	0.03	0.09	-0.27	0.21	0.20	0.30	-0.20	0.21	0.19	0.18	0.18	0.13	1.00		
Cu	-0.64	-0.71	-0.94	0.96	0.93	0.23	-0.90	0.91	0.95	0.96	0.93	0.95	0.35	1.00	
Pb	-0.68	-0.74	-0.92	0.94	0.93	0.18	-0.91	0.88	0.94	0.94	0.92	0.93	0.41	0.98	1.00

Table 3.19 : Correlation coefficient matrix of the various parameters measured in Core BC-2 (N=23, p=0.05, r=0.41).

	Depth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	0.78	1.00													
Sand	0.93	0.84	1.00												
Silt	-0.77	-0.63	-0.74	1.00											
Clay	-0.48	-0.56	-0.62	-0.07	1.00										
org.C	-0.85	-0.59	-0.75	0.73	0.25	1.00									
CaCO	0.96	0.80	0.93	-0.77	-0.49	-0.83	1.00								
Fe	-0.65	-0.42	-0.59	0.50	0.27	0.74	-0.59	1.00							
Mn	0.00	0.02	0.10	0.08	-0.23	0.11	0.06	0.08	1.00						
Ni	-0.81	-0.60	-0.77	0.62	0.41	0.81	-0.76	0.66	0.06	1.00					
Zn	-0.58	-0.41	-0.44	0.56	0.002	0.56	-0.49	0.42	0.32	0.62	1.00				
Cr	-0.91	-0.58	-0.76	0.73	0.25	0.93	-0.84	0.74	0.14	0.77	0.67	1.00			
Co	-0.57	-0.48	-0.54	0.46	0.27	0.62	-0.53	0.82	0.20	0.57	0.28	0.60	1.00		
Cu	-0.87	-0.53	-0.73	0.75	0.19	0.92	-0.81	0.80	0.17	0.77	0.71	0.97	0.65	1.00	
Pb	-0.75	-0.41	-0.70	0.65	0.24	0.85	-0.73	0.80	0.19	0.74	0.60	0.83	0.69	0.90	1.00

Iron concentrations of sediments in Core MBC-3 vary from 3.49 to 4.46 % with an average of 4.10 % (Table 3.13). These values seem to be comparable with those reported from the eastern Marmara basin (4.13 % Fe; Evans et *al.*, 1989). The Fe profile did not show any significant variation throughout the core (Fig. 3.58).

Iron concentrations in Core BC-3 range between 2.87 and 5.71 % with an average value of 4.64 % (Table 3.14). Fe profile shows that the maximum iron content occurs at about 30 cm depth; from this depth towards the both surface and base of core, it gradually decreases (Fig. 3.59). Because there is no major fluctuations in the other sedimentary parameters, the iron distribution in this core must therefore be controlled largely by the diagenetic processes within sediment. As it will be shown the later, the role of diagenesis in this core is apparent from the fluctuations in Mn-profile.

Iron concentrations in Core BC-4 vary from 3.01 to 5.06 % with a mean value of 4.02 % (Table 3.15). The Fe profile (Fig. 3.60) shows that its value increases from a depth about of 20 cm towards the both surface and base of the core. A strongly positive correlation between the contents of Fe and clay suggests the association of Fe with the clay fractions.

The iron contents in Core BC-5 ranged between 3.92 and 5.23 % with an average value of 4.30 % (Table 3.16). The Fe values in the core increase slightly from the bottom towards the surface (Fig. 3.61). Changes in the diagenetic conditions can possibly explain this distribution pattern.

Iron concentrations in Core BC-6 from 0.73 to 2.15 % with a mean value of 1.44 % (Table 3.17). These values are comparably lower than those found in the previous Marmara cores, although other sedimentary parameters seem to be not related with this pattern. The detailed analysis of mineralogy would be very helpful in the future research. Thus, at this stage, it is difficult to determine the nature of this pattern. However, the somehow increased Fe contents above 12 cm depth, over a steady baseline would rather suggest the diagenetic reactions in the sediment to be significant in controlling the Fe distribution (Fig. 3.62).

3.2.2.3.2. MANGANESE

Average manganese concentrations in the studied core sediments ranged from 229 to 4903 μg/g (Table 3.9). Although the manganese ore deposit in the Istranca is the only one that is being mined among occurrences in the vicinities of Bursa, İstanbul, Çanakkale and Bilecik (Ternek, *et al.*, 1987), it seems that there is no any indicative deposition based on the petrographical examination of the bottom sediments. Therefore, these Mn levels can not solely be explained by the terrigenous influxes. In addition, other influences or post-depositional processes must be present to cause such high Mn levels in the sediments because no evidence exists for an anthropogenic input.

The manganese concentrations in Core BC-1 gradually decrease from the surface (415 μg/g) down to 6 cm (235 μg/g) and below this depth Mn remains almost constant (Table 3.11; Fig. 3.56). Mn gradient seems to follow silt and clay profiles suggesting close association of manganese in the fine sediment fractions. This is also shown by the strongly correlation between the Mn and the silt and clay percentages of the sediments (Table 3.18).

In Core BC-2, manganese concentrations ranged between 241 and 453 μg/g with a mean value of 384 μg/g (Table 3.12). It does not show any significant change along the core profile (Fig. 3.57). The correlation coefficient matrix shows that their concentrations are not related with the granulometric and other chemical parameters at a significant level ($N=23$, $p=0.05$, $r=0.41$; Table 3.18) in this core.

The manganese contents in Core MBC-3 from the eastern basin of the Marmara Sea show not only strong fluctuations but also anomalously high values (572-5166 μg/g; avg. 2381 μg/g Fig. 3.58 and Table 3.13). Such high Mn levels were previously reported in the same region (Ergin and Evans, 1988) but, with no further explanation. These values are considerably higher than those obtained in the sediments from shallower waters of the Sea of Marmara (253-1070 μg/g; Fig. 3.41). It seems that particular geological influxes or/and post-depositional processes are responsible for such high Mn concentrations in the sediments. Because other metals do not follow the same trend as that of Mn, distinct Mn phases must be present in the samples, most probably as a result of diagenesis in the sediment. Average sedimentary rocks contain much lesser Mn contents (Table 3.9).

In Core BC-3 from the central basin of Marmara Sea, like in the eastern basin, sediments contain anomalously high Mn contents ranging between 2071 μg/g and 9127 μg/g, with a mean value of 4903 μg/g (Table 3.14). Their values show strong fluctuations throughout the core (Fig. 3.59), although sediment texture does not follow the same trend. It thus appears that distinct Mn phases occur in the samples, probably due to diagenesis. Whether or not, particular hydrogenic, volcanogenic, and submarine-weathering processes also contributed to such Mn-enrichment, can not be confirmed at this stage.

In Core BC-4 from the western Marmara basin, the manganese concentrations vary from 950 μg/g to 8235 μg/g with an average value of 3010 μg/g (Table 3.15). Again here, the Mn concentrations of sediments are markedly higher than those obtained in surface sediments from the surrounding shallower waters (479-1070 μg/g Mn; Fig. 3.41). Mn values of sedimentary rocks are significantly low (Table 3.9).

The distribution of Mn in Core BC-5, from the Marmara Sea-Dardanelles Junction (Fig. 3.61), is different from those found in the deep-sea cores MBC-3, BC-3, and BC-4 (Figs. 3.58, 3.59 and 3.60). The manganese concentrations in Core BC-5 ranged between 456 µg/g and 1320 µg/g with an average value of 636 µg/g (Table 3.16). These values are comparatively much lower than those from the deep-sea cores (MBC-3, BC-3 and BC-4), but they seem to be similar to the most of the Mn values, measured in sediment from the shallower waters. Also comparison with the average sedimentary rocks showed consistency (Table 3.9).
Mn distribution is rather uniform along the core, except the slight increase at the surface (Fig. 3.61) may be due to diagenesis.

In Core BC-6, from the Dardanelles Strait-Aegean Sea Junction, manganese concentrations vary from 303 µg/g to 610 µg/g with an average of 408 µg/g (Table 3.17).
No significant changes in the downcore Mn distribution are observed (Fig. 3.62), suggesting Mn fluxes at nearly constant rate and with no remarkable diagenetic remobilization of this metal. In general, Mn levels of sediments in Core BC-6 are at natural levels when compared those with average sedimentary rocks (Table 3.9). Although, correlation coefficient matrix shows some positively correlation between the Mn and, Fe and Pb. They are not

supported by the graphic representation of data. Although manganese concentrations are inversely related with the core depth, org.C, and $CaCO_3$ contents through this core at a level of significance (N=14, p=0.05, r=0.53; Table 3.24).

3.2.2.3.3. NICKEL

Average Nickel concentrations in the studied core sediments ranged from 20 to 129 µg/g, being mostly comparable with the average sedimentary rocks (Table 3.9).

Nickel contents of sediments in Core BC-1 varied between 6 and 53 µg/g with an average value of 20 µg/g (Table 3.11). The profile shows an upward-increase in the metal contents of sediments above 6-8 cm and below this depth and they remain constant (Fig. 3.56). This Ni-gradient like many other metals coincides with the silt and clay profiles showing an upward-increase in the fine-grained fractions (Fig. 3.56). The significant correlations of Ni with the grain-size, and carbonate, but also with the other metal data reflect biogenically-controlled sediment texture which in turn, determines the amount of Ni in the sediments (Table 3.18).

In Core BC-2, nickel concentrations range from 45 to 62 µg/g with an average value of 53 µg/g (Table 3.12). These values are somehow higher than those in Core BC-1, probably due to grain-size effect. The downcore profile shows that a slight

increasing trend towards the surface (Fig. 3.57).
The Ni-values in Core BC-2 are largely comparable with the composition of average sedimentary rocks indicating the dominance of terrigenic influences. Also, the surface sediments from other stations in this part of the sea displayed similar Ni levels (Fig. 3.42). The correlation coefficient matrix shows that there is a positively correlation between the Ni, and the silt and organic carbon contents (Table 3.19). This may suggest an association of these parameters.

The nickel concentrations in Core MBC-3 (83-95 μg/g; avg. 89 μg/g; Table 3.13), are rather uniform along the core (Fig. 3.58). These values are comparable with those previously reported from the same region (Evans *et al.*, 1989).
In general, Ni levels measured in this core are typical for sedimentary rocks (Table 3.9). Apparently, the normally higher Ni contents in Core MBC-3 than those in Cores BC-1, and BC-2 are the result of presence of generally higher clay contents (Fig. 3.58). The presence of significant relationships between the Ni and org.C contents of samples (Table 3.20), is not remarkable on the Fig. 3.58.

Table 3.20 : Correlation coefficient matrix of the various parameters measured in Core MBC-3 (N=40, p=0.05, r=0.30).

	Depth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	0.00	0.00													
Sand	0.39	0.00	1.00												
Silt	0.07	0.00	-0.02	1.00											
Clay	-0.17	0.00	-0.25	-0.96	1.00										
org.C	0.25	0.00	-0.11	-0.14	0.16	1.00									
CaCO	0.27	0.00	0.16	-0.14	0.10	-0.22	1.00								
Fe	-0.04	0.00	-0.11	-0.13	0.16	-0.08	-0.10	1.00							
Mn	-0.05	0.00	0.15	-0.18	0.13	0.01	0.48	-0.20	1.00						
Ni	0.34	0.00	-0.02	0.11	-0.10	0.36	-0.04	0.19	-0.20	1.00					
Zn	-0.10	0.00	0.18	0.01	-0.06	0.09	0.02	-0.08	0.17	-0.04	1.00				
Cr	0.30	0.00	0.08	-0.07	0.05	0.41	-0.16	-0.01	0.12	0.40	0.06	1.00			
Co	-0.66	0.00	-0.31	0.04	0.05	-0.01	-0.29	-0.04	-0.26	-0.07	0.00	-0.19	1.00		
Cu	-0.72	0.00	-0.27	-0.11	0.17	0.12	-0.37	-0.11	0.15	-0.15	0.34	-0.01	0.48	1.00	
Pb	-0.31	0.00	-0.09	0.18	-0.15	-0.07	-0.07	-0.10	0.02	0.08	-0.12	-0.12	0.14	0.09	1.00

The concentrations of Ni in Core BC-3 ranged between 108 and 142 μg/g with an average of 129 μg/g (Table 3.14). In this core, the highest Ni concentrations are measured probably be resulted from the presence of higher clay contents in the samples (Fig. 3.59). Sedimentary rocks contain, on the average, 2-80 μg/g Ni. The nickel profile shows that there is an downward-increase in the contents, from surface to 6-8 cm, and below this depth, the Ni-level becomes rather constant. The slight fluctuations are more likely as a consequence of the lithologic differences in the samples. The correlation coefficient matrix shows that there is a significant relationship between the Ni, and clay and Fe contents (Table 3.21). From this, a close association of Ni can be infered in the Fe and clay fractions.

Table 3.21 : Correlation coefficient matrix of the various parameters measured in Core BC-3 (N=27, p=0.05, r=0.38).

	Depth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	-0.26	1.00													
Sand	0.09	-0.34	1.00												
Silt	-0.14	0.04	-0.31	1.00											
Clay	0.14	-0.04	0.23	-1.00	1.00										
org.C	-0.61	0.06	-0.40	0.21	-0.17	1.00									
CaCO	0.27	0.02	0.31	-0.30	0.27	-0.45	1.00								
Fe	0.39	0.04	0.27	-0.42	0.41	-0.09	0.39	1.00							
Mn	-0.16	0.06	0.06	0.11	-0.12	-0.13	0.67	-0.17	1.00						
Ni	-0.17	0.11	0.28	-0.40	0.38	0.25	-0.06	0.57	-0.23	1.00					
Zn	-0.51	0.16	-0.38	0.33	-0.30	0.56	-0.27	-0.20	0.03	-0.06	1.00				
Cr	0.24	-0.02	-0.40	0.26	-0.22	-0.05	-0.43	-0.22	-0.18	-0.02	-0.09	1.00			
Co	0.19	0.08	-0.34	0.06	-0.03	-0.21	0.12	-0.13	0.03	-0.34	-0.14	0.13	1.00		
Cu	-0.79	0.11	-0.22	0.28	-0.27	0.48	-0.63	-0.67	-0.08	-0.01	0.45	0.19	-0.16	1.00	
Pb	-0.11	0.29	-0.30	0.09	-0.07	0.38	-0.36	0.08	-0.25	0.42	-0.01	0.43	-0.05	0.27	1.00

The nickel concentrations in Core BC-4 varied from 111 to 128 µg/g with an average of 120 µg/g (Table 3.15). These values tend to be nearly uniform long the core with only little fluctuations (Fig. 3.60). The Ni contents in Core BC-4, like those in Core BC-3, are slightly higher than the average composition of sedimentary rocks (Table 3.9). The correlation coefficient matrix does not show any reliable relationship with the other parameters at a significant level (N=29, p=0.05, r=0.37; Table 3.22).

Table 3.22 : Correlation coefficient matrix of the various parameters measured in Core BC-4 (N=29, p=0.05, r=0.37).

	Depth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	0.14	1.00													
Sand	0.17	-0.10	1.00												
Silt	-0.34	-0.32	0.44	1.00											
Clay	0.26	0.26	-0.59	-0.98	1.00										
org.C	-0.72	0.04	-0.35	-0.07	0.13	1.00									
CaCO	0.62	0.40	0.24	-0.47	0.36	-0.52	1.00								
Fe	-0.06	-0.05	-0.29	-0.59	0.60	0.13	0.28	1.00							
Mn	0.15	0.64	-0.11	-0.58	0.52	0.00	0.68	0.42	1.00						
Ni	0.10	0.16	-0.28	0.13	-0.07	0.04	-0.35	-0.53	-0.20	1.00					
Zn	-0.34	-0.18	-0.14	0.15	-0.10	0.29	-0.30	-0.06	-0.23	0.14	1.00				
Cr	0.71	-0.15	0.34	0.03	-0.09	-0.72	0.37	0.01	-0.10	-0.14	0.05	1.00			
Co	0.30	0.09	-0.25	-0.51	0.51	0.06	0.24	0.43	0.32	0.11	-0.21	-0.11	1.00		
Cu	0.10	0.18	-0.56	-0.67	0.72	0.12	0.22	0.60	0.52	-0.10	0.07	0.09	0.38	1.00	
Pb	-0.25	0.37	-0.10	-0.40	0.37	0.57	0.08	0.41	0.43	-0.20	0.10	-0.36	0.27	0.33	1.00

In Core BC-5, the Ni concentrations vary from 107 to 120 µg/g with an average of 112 µg/g (Table 3.16). These Ni levels are comparable with the composition of average sedimentary rocks (Table 3.9). The positively correlation of Ni with the Co and Fe (Table 3.23) seems to be not sufficient to determine metal association in this core.

Table 3.23 : Correlation coefficient matrix of the various parameters measured in Core BC-5 (N=24, p=0.05, r=0.40).

	Depth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	0.41	1.00													
Sand	-0.42	0.14	1.00												
Silt	-0.24	-0.12	0.07	1.00											
Clay	0.24	0.09	-0.10	-1.00	1.00										
org.C	-0.27	-0.40	0.07	0.33	-0.32	1.00									
CaCO	0.59	0.29	-0.16	-0.22	0.22	-0.18	1.00								
Fe	-0.80	-0.42	0.40	0.27	-0.27	0.28	-0.77	1.00							
Mn	-0.80	-0.33	0.56	0.25	-0.25	0.39	-0.28	0.50	1.00						
Ni	-0.45	-0.06	0.07	0.22	-0.22	0.01	-0.42	0.49	0.14	1.00					
Zn	-0.33	0.29	0.37	0.07	-0.08	0.09	-0.36	0.44	0.24	0.31	1.00				
Cr	0.07	-0.06	-0.14	-0.37	0.37	-0.73	0.17	-0.11	-0.20	-0.23	-0.23	1.00			
Co	-0.61	0.01	0.36	0.13	-0.14	0.37	-0.28	0.45	0.46	0.61	0.57	-0.50	1.00		
Cu	-0.08	0.06	-0.18	-0.20	0.20	-0.59	-0.33	0.20	-0.11	0.04	0.02	0.57	-0.37	1.00	
Pb	-0.35	-0.20	0.25	0.32	-0.32	0.70	-0.27	0.29	0.38	0.37	0.17	-0.82	0.63	-0.58	1.00

The nickel concentrations in Core BC-6, ranged between 30 and 44 μg/g with a mean value of 40 μg/g (Table 3.17). These Ni-levels are comparatively lower than those from other cores, with the exception of BC-1. The lithologic and biogenic differences in the sample can be accounted for this. No major trend exists in the downcore distribution of Ni in Core BC-1 (Table 3.9).

3.2.2.3.4. ZINC

Average Zn contents of the studied core sediments (34-102 μg/g) are generally consistent with the average compositions of sedimentary rocks (Table 3.9). This implies that great portions of Zn in the cores are from the terrigenic sources.

The zinc concentrations in Core BC-1, vary from 20 to 72 μg/g with a mean value of 34 μg/g (Table 3.11). The Zn-levels increase upward above 8 cm in the core, in association with the fine sediment fractions, as is the case for many metals in this core (Fig. 3.56). The correlation of Zn with silt, clay, Fe, and Mn (Table 3.18) may suggest an association of these metals in the silt and clay fractions.

In Core BC-2, zinc concentrations (59-101 μg/g; avg. 76 ; Table 3.12) are slightly higher than those in Core BC-1, probably as a consequence of abundant fine materials in the samples. The Zn profile (Fig. 3.57) shows that its values slightly but generally increase from bottom to surface, although the grain-size do not follow the same trend. However, organic carbon and iron contents which also increase upwards in the core, may be responsible for the Zn increases. The correlation coefficient matrix may confirm the association of zinc with the org.C, and Fe (Table 3.19).

In Core MBC-3, from the eastern deep basin, the zinc concentrations ranged between 79 and 120 μg/g with an average of 102 μg/g (Table 3.13). These values are similar to those previously found in the same region (Evans *et al.*, 1989) (Table 3.9). The Zn profile shows that its values tend to be rather constant throughout the core, except minor fluctuations (Fig. 3.58).

In Core BC-3, from the central deep-basin, the Zn concentrations varied between 75 and 111 μg/g with a mean value of 92 μg/g (Table 3.14). The Zn-profile shows that there seems to be an increasing trend in the contents, from about 20 cm towards the surface in this core (Fig. 3.59). As it is seen on the correlation coefficient matrix, the Zn concentrations are correlated with the org.C contents at a significant level (Table 3.21).

The zinc concentrations in Core BC-4, from the western, deep-basin, ranged between 64 and 180 μg/g with an average of 95 μg/g (Table 3.15). The Zn-profile shows that its values seem to be constant throughout the core, except for strongly fluctuations at depths of 14-34 cm and 38-44 cm (Fig. 3.60). The correlation coefficient matrix shows that there is no any reliable relationship between Zn and other parameters at significant levels (N=29, p=0.05, r=0.37; Table 3.22).

The Zn concentrations in Core BC-5, from the Dardanelles Strait-Marmara Sea Junction varies from 64 to 99 μg/g with a mean value of 84 μg/g (Table 3.16). These values are slightly lower than those obtained in the deep-sea Cores MBC-3, BC-3, and BC-4 (Figs. 3.58, 3.59 and 3.60), probably due to grain-size effect. No significant changes of Zn contents were observed along the profile (Fig. 3.61), except slight fluctuations which are most probably be due to lithologic differences in the samples. The correlation coefficient matrix shows that the Zn-values are correlated with the Fe values at significant levels (Table 3.23). This may indicate that the Zn concentrations are, in part, associated with the Fe-phase.

In Core BC-6, the zinc concentrations ranged between 31 and 54 μg/g (avg. 44 μg/g; Table 3.17). The Zn-profile seems to be usually constant with some minor fluctuations, as a consequence of lithologic differences (Fig. 3.62). There exists no significant correlation between Zn and other sedimentary parameters (Table 3.24).

Table 3.24 : Correlation coefficient matrix of the various parameters measured in Core BC-6 (N=14, p=0.05, r=0.53).

	Depth	Gravel	Sand	Silt	Clay	org.C	CaCO	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb
Depth	1.00														
Gravel	0.47	1.00													
Sand	-0.51	-0.14	1.00												
Silt	-0.47	-0.62	0.07	1.00											
Clay	0.62	0.55	-0.47	-0.91	1.00										
org.c	0.96	0.59	-0.46	-0.55	0.65	1.00									
CaCO	0.94	0.43	-0.48	-0.55	0.68	0.94	1.00								
Fe	-0.90	-0.33	0.32	0.59	-0.66	-0.86	-0.94	1.00							
Mn	-0.61	-0.11	0.36	0.31	-0.43	-0.53	-0.67	0.79	1.00						
Ni	0.53	0.42	-0.56	-0.32	0.50	0.56	0.36	-0.23	0.08	1.00					
Zn	-0.10	0.02	-0.49	0.25	-0.03	-0.13	-0.26	0.37	0.10	0.49	1.00				
Cr	-0.39	-0.22	-0.05	0.16	-0.11	-0.47	-0.51	0.46	0.38	0.27	0.35	1.00			
Co	0.41	0.27	-0.24	-0.72	0.75	0.46	0.47	-0.50	-0.37	0.34	0.02	-0.04	1.00		
Cu	0.80	0.46	-0.50	-0.57	0.70	0.82	0.71	-0.64	-0.36	0.73	0.23	-0.24	0.71	1.00	
Pb	-0.50	-0.03	0.19	0.22	-0.28	-0.42	-0.55	0.71	0.83	0.20	0.31	0.33	-0.36	-0.25	1.00

3.2.2.3.5. CHROMIUM

Average Cr contents in the studied cores were between 32 and 145 μg/g (Table 3.9), being mostly consistent with the average composition of sedimentary rocks. This shows the terrigenous source to be main supplier of Cr in the samples.

The chromium concentrations in Core BC-1 varied in a wide range, from 5 to 111 μg/g (avg. 32 μg/g; Table 3.11). The values rapidly decrease from surface to 6-8 cm and below this depth, Cr contents remain rather uniform along the core (Fig. 3.56). The generally high Cr contents in the upper core sections seem to be affected by the presence of larger fine fractions in the samples (Fig. 3.56). This is also evident from the close correlation of Cr with the silt and clay percentages of samples (Table 3.18).

In Core BC-2, the chromium concentrations ranged between 64 and 124 μg/g (avg. 86 μg/g Table 3.12). The Cr-profile shows that its values are almost constant below 18-20 cm depth of core, but tend to increase towards the surface (Fig. 3.57). The increasing Cr contents coincide with the increasing fine-grained fraction of samples, as shown by the correlation coefficient matrix (Table 3.19).

In Core MBC-3, the Cr contents of samples varied from 88 to 131 μg/g with an average value of 106 μg/g (Table 3.13). These values are also in harmony with those previously reported from the same region (Evans *et al.*, 1989). The Cr-profile shows that there are little fluctuations in the contents but they remain within a narrow range (Fig. 3.58).

The chromium concentrations in Core BC-3, from the central basin, (90-139 μg/g; avg. 113 μg/g; Table 3.14), are widely consistent with those from the eastern deep basin. Fig. 3.59 shows a strong fluctuations at the bottom core.

The chromium concentrations in Core BC-4 ranged between 118 and 174 μg/g (avg. 141 μg/g; Table 3.15). These values seem to be somewhat higher than the other deep-sea Cores MBC-3 and BC-3 (Table 3.9). The downcore Cr distribution shows no major changes (Fig. 3.60).

The Cr concentrations in Core BC-5 vary from 129 to 169 μg/g with an average of 145 μg/g (Table 3.16). The Cr profile (Fig. 3.61) shows that the metal values tend to decrease slightly, from about 14 cm depth down to base of the core but also they decrease generally, from the 14 cm interval towards the surface. However, the grain-size distribution does not follow the same trend, which suggests no major influences of the grain-size on chromium in this core. On the other hand, it has been observed that there exists a tendency of Cr to decrease in the concentrations, from the Dardanelles Strait- Marmara Sea Junction (Core BC-5) to Bosphorus region (Core BC-1) (Figs. 3.61 to 3.56). This finding is not confirmed by the surface sediments from the grab samplers (Fig. 3.61). The available metal data in combination with the petrographic results obtained in this study reveals that some changes in the metal sources or/and in the nature of diagenesis might have occurred at the times of deposition of subsurface sediment layer. This needs further research with the emphasize on X-ray mineralogy.

The chromium concentrations in Core BC-6 ranged between 63 and 81 μg/g with an average of 73 μg/g (Table 3.17). The Cr profile (Fig. 3.62) tends to be nearly constant throughout the core except some minor fluctuations due to lithologic variations.

3.2.2.3.6. COBALT

In Core BC-1, the cobalt concentrations ranged from 7 to 16 μg/g with an average of 11 μg/g (Table 3.11). The Co profile shows somewhat fluctuations but they are not affected by the grain-size (Fig. 3.56). This is also supported by the lack of significant correlations (Table 3.18).

The cobalt concentrations in Core BC-2 ranged from 7 to 16 μg/g with an average of 10 μg/g (Table 3.12). The Co profile shows an increasing tendency in the metal contents above about 16 cm depth of the core (Fig. 3.57). Below this depth, the Co values seem to be generally constant, with some minor fluctuations. The correlation coefficient matrix shows a positively and significant relationship between the Co and organic carbon and Fe contents which could be an indication for chemical diagenesis in the presence of organic matter.

The cobalt concentrations in Core MBC-3 (9-21 μg/g; avg. 15 μg/g ; Table 3.13), are marked by fluctuations all along the core (Fig. 3.58). In general, the Co levels of this core are similar to those previously obtained in the same region (Evans *et al.*, 1989). The abrupt fluctuations in the Co contents in this core obviously reflect lithogenic and diagenetic changes in the region studied.

The Co concentrations in Core BC-3 vary from 10 to 20 μg/g with an average of 20 μg/g (Table 3.14). The Co profile (Fig. 3.59) shows slight fluctuations in the metal contents along the core. This is probably due to lithogenic and diagenetic variations in the region.

In Core BC-4, the Co contents (9-24 μg/g; on average, 18 μg/g; Table 3.15) showed that there are marked fluctuations with the lower values between 8 and 30 cm intervals of the core (Fig. 3.60). These low Co levels are apparently related to the lower clay, and Mn contents of the samples suggesting possible lithogenic and diagenetic effects in the core.

The cobalt concentrations in Core BC-5, ranged between 15 and 26 μg/g with an average of 20 μg/g (Table 3.16), increasing at 0-12 and 22-32 cm intervals (Fig. 3.61). This must be resulted from the lithogenic and diagenetic variations in the region.

In Core BC-6, the cobalt concentrations ranged from 9 to 18 μg/g (avg. 13 μg/g; Table 3.17). Abrupt changes in the metal contents occur at 12-14 cm and 20-22 cm depths, obviously due to diagenetic and lithogenic effects. The inferred correlation coefficients between the Co and clay contents (Table 3.24) are not not apparent on their concentration profiles (Fig. 3.62).

3.2.2.3.7. COPPER

Average concentrations of copper in the studied cores (14 to 40 μg/g Cu; Table 3.9) are widely consistent with the average metal levels of sedimentary rocks. Thus, the Cu values of this study can be considered as being mainly of lithogenic origin.

The copper concentrations in Core BC-1 (6-26 μg/g; avg. 14 μg/g; Table 3.11) reflect the predominantly lithologic materials in some varying proportions. This is evident from the increasing Cu and clay and silt contents of sediments in the upper core section (Fig. 3.56). The correlation coefficient matrix shows a strongly positive correlation of Cu with the silt and clay, but also with Fe (Table 3.18).

In Core BC-2, the copper concentrations varied from 22 to 40 μg/g with an average value of 29 μg/g (Table 3.12). These values are slightly higher than those from Core BC-1 resulted from grain-size effects (*i.e.*, abundant fine materials). However, the Cu profile (Fig. 3.57) shows that the higher Cu concentrations above about 20-22 cm depth follow the increasing Fe and org.C contents in the core. This could be indicative of an association of Cu in the Fe and organic phases. The correlation coefficient matrix shows a strongly positive correlation with the org.C, and Fe (Table 3.19).

In Core MBC-3, the copper concentrations of MBC-3 (36-46 μg/g; avg. 40 μg/g; Table 3.13) are found to be similar to those previously reported from the same region (Evans *et al.*, 1989). Except for some upward-increase in the upper sections, the most of the samples are uniform in their Cu contents (Fig. 3.58).

The Cu concentrations in Core BC-3 ranged between 32 and 47 μg/g with an average of 39 μg/g (Table 3.14). As shown in Fig. 3.59, copper contents exhibit an increasing tendency at or near the surface, although sediment lithology remains unchanged. The correlation coefficient matrix shows a strongly and positively significant correlation of Cu with the org.C contents (Table 3.21).

The copper concentrations in Core BC-4 (33-42 μg/g avg. 37 μg/g; Table 3.15) seem to be mostly constant with only minor fluctuations (Fig. 3.60). The presence of a strongly and positively correlation with the clay and Fe percentages reflects an association of Cu with the clay and Fe portions of samples.

In Core BC-5, the copper concentrations ranged between 31 and 36 μg/g with an average of 33 μg/g (Table 3.16), being are nearly constant throughout the core (Fig. 3.61).

The concentrations of copper in Core BC-6 (10-19 μg/g; avg. 16 μg/g; Table 3.17) show a decreasing trend from about 16 cm towards the surface (Fig. 3.62). The presence of the significant correlation between the Cu and org.C contents (Table 3.24) seems to be an indication for close relationship between Cu and organic matter in the sediments.

3.2.2.3.8. LEAD

Average lead concentrations in the studied core sediments (15-49 μg/g) are slightly higher than those normally found in sedimentary rocks (Table 3.9) but they are still at natural levels.

The lead concentrations in Core BC-1 ranged between 8 and 28 μg/g (avg. 15 μg/g; Table 3.11). The Pb profile like many other metals increasing values from about 6-8 cm depth shows a tendency to increase towards the surface and below this interval they usually remain uniform downcore (Fig. 3.56). In particular, the correlation of Pb and clay contents followed by Fe (Table 3.18) may explain the lithogenic control on Pb distribution in the core.

In Core BC-2, the lead concentrations (20-51 μg/g; avg. 34 μg/g; Table 3.12) are generally higher in the upper 20 cm of core but rather constant below this depth (Fig. 3.57). These increased Pb levels in the core follow those of the organic carbon and iron. It therefore appears that Pb is mainly associated with the organic and iron phases in samples. This is also shown by the presence of a strongly positive correlation between the Pb and org.C, and Fe contents (Table 3.19).

In Core MBC-3, the lead concentrations ranged from 31 to 69 μg/g with an average value of 49 μg/g (Table 3.13). These values are comparable with those previously reported from the same region (Evans *et al.*, 1989). The downcore profile of Pb shows marked fluctuations with no major trend throughout the core (Fig. 3.58).

The lead concentrations in Core BC-3 (21-55 μg/g; avg. 38 μg/g; Table 3.14) shows a slightly increasing tendency with strong fluctuations from bottom to the upper part of this core depth about 6 cm level, and their concentrations suddenly decrease from this level to uppermost part of Core BC-3 (Fig. 3.59).

The lead concentrations in Core BC-4 (16-60 μg/g; avg. 40 μg/g; Table 3.15) are marked by fluctuations with no downcore gradients of this metal (Fig. 3.60).
The correlation coefficient matrix shows that the lead concentrations are positively correlated with the clay, org.C, Fe, and Mn contents (Table 3.22) which may suggest an association of these parameters.

In Core BC-5, the lead concentrations ranged from 15 to 65 μg/g with an average of 45 μg/g (Table 3.16). The Pb profile shows remarkably fluctuations in the upper 24 cm of the core, where both increasing and decreasing tendencies of the values are observed (Fig. 3.61). This is probably accounted for the presence of both lithogenic and diagenetic variations in the region.

The lead concentrations in Core BC-6 (15-44 μg/g; avg. 27 μg/g; Table 3.17) are slightly high between about 2 to 12 cm depths (Fig. 3.62) and no significant changes are observed in the texture of the samples. This is presumably as a result of the diagenetic effects.

3.2.2.3.9. CONCLUSION

In comparison with the worldwide average composition of sedimentary rocks, the heavy metals data obtained in this study have shown that the concentrations of Fe, Ni, Zn, Cr, Co, Cu, and Pb in the studied sediment cores are largely at natural levels. And, the variations in the metal contents are interpreted as results of variations in the sediment texture and mineralogy, as well as, the changes in diagenetic processes. The role of diagenesis seems to be effective in the distribution of Fe, Mn, and Co, which showed great fluctuations throughout the cores, although sediment texture did not vary greatly. The surface- or near shore-enrichment of the redox-sensible metals Fe and Mn was also confirmed by the field observations on the cores, where the reddish colors of top sections of the cores were changing to greenish-gray in the subsurface, due to changes in the redox-conditions within the sediment, from oxidizing to reducing, respectively.

However, the exceptionally high Mn concentrations (up to 9127 $\mu g/g$) found in deep-sea Cores (MBC-3, BC-3, and BC-4) presumably reflect input from particular but presently-unknown sources or/and specific diagenetic processes.

The average Cr levels in the cores slightly tend to decrease from the Dardanelles-Marmara Junction to the Bosphorus region, as a result of the presence of varying clay proportions in the sediments. Such as an enrichment is shown by other metals (Fe, Ni, Zn, Cu, and Pb), particularly in Core BC-1, where sediments contained high clay percentages.

Thus, the levels of most elements which are elevated above baseline (values from deeper core sections) shown the importance of both lithogenesis and diagenesis within the given depositional environment. However, the somewhat higher Cu, Pb, and Zn, concentrations in the upper sections of core BC-2, from the southern Bosphorus exit may be explained, to some degree, by the anthropogenic effluents.

Detrital silicates and oxides/hydroxides are the main carrier substances of the studied heavy metals, as inferred from the petrographic investigations.

CHAPTER FOUR

4. SUMMARY AND CONCLUSIONS

The studied surficial sediments from the Sea of Marmara and its straits are composed of materials of a wide range of grain size, from <1 to 95 % of gravel, <1 to 98 % of sand and from <1 to 98 % of mud.

The gravel fractions of the grab sediments are made of both terrigenic and biogenic materials in varying proportions. Of these, the pelecypods (*Mytillus galloprovincialis*, *Modiolus barbatus*, *Corbula gibba*, *Gafrarium minima* and *Venus ovata*) and the calcareous *Rhodophyceae* are important biogenic admixtures. The sand portions of the grab sediments generally vary inversely with depth in the open sea depositional environments. However, relatively high sand contents (>30 %) are found in the nearshore and shallow-water areas especially along the Bosphorus and Dardanelles Straits and their open-sea junctions. This fraction is mainly composed of the terrigenous materials with lesser amounts of the biogenics. Terrigenous components include quartz grains, mica flakes, and metamorphic (schist and quartzite), basic/ultrabasic, and sedimentary rock fragments and also organic debris (plant-, wood-tissues in mostly fibreous form, coal, slug and tarball particles). The mineral grains and rock fragments reflect their sources most probably to be the surrounding land masses of the Sea of Marmara. Mud (silt and clay) contents in the grab sediments range from less than 1 to 100 % and increase significantly with water depth. They are predominantly concentrated in the offshore (10 km away from the coast) areas and especially in the deep basins of the Sea of Marmara and the Bay of Gemlik.

On the other hand, the slight fluctuations in the clay and silt contents of sediments along the cores are generally attributed to the changes in the erosional and depositional conditions. In particularly, occurrences of high sand and gravel percentages below 2 cm depth of Core BC-1, as well as, the generally downward increasing sand contents in the Core BC-2 are consistent with the increased benthogenic activities within the Bosphorus channel system. This suggests that some environmental changes must have occurred in the most recent times during which the benthic-biogenic activities are interrupted by the deposition of fine-sediments. The biogenic fractions in the core sediments constituted various species of foraminifers, pelecypods, pteropods and echinoids in most of the cores. Bioturbation by the polychaetes was characteristic in the upper sections of the cores. The presence of hyaline calcareous foraminifers and the reddish-brown color of deep-sea sediments at or near the surface clearly show that the depositional environments in the studied coring sites have normally been oxygenated. This is also evident from the color changes in the sediment column, namely from reddish-brown at or near the surface to grayish-green at the subsurface.

The moisture content of the grab sediments ranges from 23 to 137 % with a mean of 80 %. In the core sediments their values range between 31 and 176 % with a mean about of 77 %. The high moisture percentages are usually related to the presence of clay fractions in the samples, especially in the deep basins and Gemlik Bay. The high absorbance capacity of the clay minerals explains the moisture contents of the studied samples.

The organic carbon concentrations of the grab sediments in the Sea of Marmara and its straits reflect marked lateral variations, being low towards the Aegean Sea but high towards the Black Sea (0.70 % at BS; 1.13 % at BMJ; 1.06 % at NSM; 1.01 % at SSM; 0.93 % at MDJ and 0.57 % at DAJ). This is interpreted to be the result of differences in the primary production rates between the two seas. However, the distribution of organic carbon within the sediments may also be affected by the grain-size in different ways. In particularly, at the Marmara Sea-Bosphorus Strait Junction, where benthogenic -shelly gravel and sand were predominant deposits-sediments may bear large amounts of organic matter. Otherwise, the organic carbon contents of the sediments were confined to their fine texture.

The organic carbon contents of the core sediments ranged between 0.04 and 1.20 % (about 1 %, on the average). The vertical variations in the organic carbon contents normally seem to be related to the changes in the benthogenic carbonate contents of sediments which in turn is considered as part of diagenesis. The other shallow-water Core BC-6 from the south of Dardanelles display much different pattern. Its org.C contents generally increase with depth, accompanied by the downward-increasing carbonate contents.

The overall $CaCO_3$ distribution in the grab sediments (2 to 90 %; avg. 20 %) represent the amount of biogenic shell fragments in the samples. The average values of $CaCO_3$ decrease from the Bosphorus Strait towards the Dardanelles Strait (37 %, at BS; 29 %, at MBJ; 14 %, at NSM; 14 %, at SSM; 12 %, at MDJ and 26 %, at DAJ) but suddenly increases at the Dardanelles Strait and its Aegean Sea exit. Of the carbonates, the branched and rounded forms of calcareous algae (encrusted with *melobesid* and other calcareous shell fragments) are most characteristic.

The carbonate concentrations range between 8 and 21 % in most of the core sediments, which are represented by coarse-grained carbonaceous shell materials. Exceptions are the two cores from the northern Bosphorus and southern Dardanelles Straits (their concentrations reach to 48 %). The $CaCO_3$ distribution in Cores BC-1, BC-2, and BC-6 shows a general tendency of carbonate contents to decrease towards the surface, while $CaCO_3$ profiles in Cores MBC-3, BC-3, BC-4, and BC-5 are rather uniform. This may be explained by the changes either in the rate of supply of biogenic carbonate or in the rate of dissolution of carbonates due to diagenesis within sediment.

The heavy metal data showed that the concentrations of Fe, Ni, Zn, Cr, Co, Cu and Pb in the samples are largely at natural levels when compared with their baseline in the deeper core sediments and their probable source rocks in the region.
Also, they are similar in their values to the composition of average sedimentary rocks worldwide. From this it appears that the terrigenous materials from land-based sources (directly or indirectly) are the main supplier of these metals to the sediments. However, the exceptionally high Mn concentrations (up to 9127 μg/g) found in deep-sea cores (MBC-3, BC-3, and BC-4) presumably reflect input from particular but presently-unknown sources or/and specific diagenetic processes.
The average Cr levels in the cores slightly tend to decrease from the Dardanelles-Marmara Junction to the Bosphorus region, as a result of the presence of varying clay proportions in the sediments. Such as an enrichment is shown by other metals (Fe, Ni, Zn, Cu, and Pb), particularly in Core BC-1, where sediments contained high clay percentages. Thus, the levels of most elements which are increased above baseline (values from deeper core sections) shown the importance of both lithogenesis and diagenesis within the given depositional environment. However, the somewhat higher Cu, Pb, and Zn, concentrations in the upper sections of core BC-2, from the southern Bosphorus exit may be explained, to some degree, by the anthropogenic effluents. Detrital silicates and oxides/hydroxides are the main carrier substances of the studied heavy metals, as inferred from the petrographic investigations.

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APPENDICES

Appendix 1.1 : Moisture contents of some grab sediment samples from the Sea of Marmara and its Straits (Bosphorus and Dardanelles).

	Wt	W	Wd	Ww=W-Wd	Ws=Wd-Wt		m=Ww/Ws *100		
STATION NAME	TARE WG	TARE & WT.WG	TARE & DR.WG	WATER WG	DRY SMP. WG	WT.SMP WG	MOIST. CONT.	WET/DRY RATIO	DRY/WET RATIO
M1	36.41	50.14	44.08	6.06	7.67	13.73	79	1.79	0.56
K26K24	36.66	46.03	40.61	5.43	3.95	9.38	137	2.37	0.42
K25L02	36.56	49.44	42.32	7.13	5.75	12.88	124	2.24	0.45
E2	39.15	58.52	52.46	6.05	13.32	19.37	45	1.45	0.69
M6	36.66	50.15	44.37	5.78	7.71	13.49	75	1.75	0.57
M2	39.05	53.59	46.50	7.09	7.44	14.54	95	1.95	0.51
K28K30	38.28	55.77	47.64	8.13	9.36	17.49	87	1.87	0.54
E14	37.69	58.32	52.78	5.54	15.09	20.63	37	1.37	0.73
K33K40	37.68	53.89	46.94	6.94	9.27	16.21	75	1.75	0.57
C2X(2)	36.87	57.05	46.88	10.17	10.00	20.18	102	2.02	0.50
C2S(2)	39.82	60.53	51.23	9.30	11.41	20.71	81	1.81	0.55
K33J17	40.18	56.73	48.20	8.53	8.02	16.55	106	2.06	0.48
K25K50	38.10	51.14	44.55	6.59	6.45	13.04	102	2.02	0.49
M15	38.02	60.10	52.71	7.39	14.69	22.08	50	1.50	0.67
K40K52	37.21	51.21	45.01	6.20	7.80	14.00	80	1.80	0.56
K30K26	37.54	57.60	47.56	10.04	10.02	20.06	100	2.00	0.50
M7	39.04	61.56	51.63	9.93	12.59	22.52	79	1.79	0.56
K50J53	37.25	44.37	40.39	3.98	3.14	7.12	127	2.27	0.44
K45K30	39.84	46.14	42.56	3.59	2.72	6.31	132	2.32	0.43
K40K10	38.64	48.70	43.46	5.24	4.81	10.05	109	2.09	0.48
M14	36.37	51.44	45.24	6.20	8.87	15.07	70	1.70	0.59
M8	36.59	50.77	44.66	6.10	8.07	14.18	76	1.76	0.57
K32K20	38.66	51.79	44.89	6.90	6.22	13.12	111	2.11	0.47
K24K57	39.94	54.90	46.32	8.57	6.39	14.96	134	2.34	0.43
K27K54	39.36	55.81	46.16	9.65	6.80	16.45	142	2.42	0.41
M3	39.53	54.18	48.96	5.23	9.42	14.65	55	1.55	0.64
K40K40	36.58	51.63	43.41	8.21	6.83	15.05	120	2.20	0.45
K27L04	39.64	53.71	45.98	7.73	6.34	14.06	122	2.22	0.45
K40L00	39.63	54.03	47.11	6.93	7.48	14.40	93	1.93	0.52
M13	36.74	49.73	43.56	6.17	6.83	13.00	90	1.90	0.53
C2Z(2)	37.49	51.18	44.48	6.70	6.99	13.69	96	1.96	0.51
K25J40	36.95	46.59	41.53	5.06	4.57	9.64	111	2.11	0.47
B10	40.32	56.18	52.09	4.09	11.77	15.87	35	1.35	0.74
K33J34	36.78	49.99	42.97	7.01	6.19	13.21	113	2.13	0.47
K25K08	40.80	53.69	47.36	6.33	6.56	12.89	96	1.96	0.51
L00K15	43.25	59.28	50.93	8.35	7.68	16.03	109	2.09	0.48
K33J48	43.18	54.20	48.20	5.99	5.02	11.02	119	2.19	0.46
K34J25	45.36	65.27	54.23	11.04	8.87	19.91	124	2.24	0.45
K57K34	44.64	57.46	51.53	5.93	6.88	12.82	86	1.86	0.54
K34K00	42.14	60.99	54.56	6.42	12.42	18.85	52	1.52	0.66
K30J27	43.32	56.55	51.08	5.47	7.76	13.23	70	1.70	0.59

Appendix 1.1 : Continued.

C2Y(2)	44.62	59.12	51.82	7.31	7.19	14.50	102	2.02	0.50
K38J22	42.86	57.35	49.25	8.10	6.39	14.49	127	2.27	0.44
N1	44.05	59.42	55.07	4.34	11.02	15.37	39	1.39	0.72
N2	45.92	60.69	53.36	7.32	7.45	14.77	98	1.98	0.50
K40K20	45.76	58.76	52.00	6.76	6.24	13.00	108	2.08	0.48
K35J15	41.84	57.02	49.43	7.59	7.59	15.18	100	2.00	0.50
N3	42.67	60.49	50.98	9.51	8.31	17.82	114	2.14	0.47
K40K00	41.99	64.15	56.53	7.63	14.54	22.16	52	1.52	0.66
N4	38.63	59.57	51.77	7.80	13.14	20.94	59	1.59	0.63
K22J57	41.37	58.17	51.36	6.81	9.99	16.81	68	1.68	0.59
K26J29	37.39	62.34	52.35	9.99	14.96	24.95	67	1.67	0.60
K30J17	44.31	63.91	53.65	10.26	9.34	19.60	110	2.10	0.48
BC-5	40.98	60.24	50.47	9.77	9.49	19.26	103	2.03	0.49
M12	42.61	57.07	51.65	5.42	9.03	14.45	60	1.60	0.62
M13	44.14	61.81	53.09	8.72	8.94	17.67	98	1.98	0.51
M11	45.30	61.18	54.74	6.44	9.43	15.88	68	1.68	0.59
M1	45.12	65.07	56.34	8.73	11.22	19.95	78	1.78	0.56
M8	45.82	63.71	55.93	7.78	10.11	17.89	77	1.77	0.57
M16	45.63	60.12	53.09	7.03	7.46	14.49	94	1.94	0.51
M6	55.15	73.98	65.74	8.24	10.59	18.83	78	1.78	0.56
M4	40.82	59.82	51.19	8.63	10.37	19.00	83	1.83	0.55
V1	36.50	49.30	44.30	5.00	7.80	12.80	64	1.64	0.61
V2	44.40	61.65	53.30	8.35	8.90	17.25	94	1.94	0.52
V3	42.90	65.10	55.00	10.10	12.10	22.20	83	1.83	0.55
V4	38.50	61.90	54.40	7.50	15.90	23.40	47	1.47	0.68
V5	44.80	61.90	53.00	8.90	8.20	17.10	109	2.09	0.48
V6	40.00	53.00	47.40	5.60	7.40	13.00	76	1.76	0.57
V7	39.60	58.40	51.30	7.10	11.70	18.80	61	1.61	0.62
V8	36.60	56.70	46.10	10.60	9.50	20.10	112	2.12	0.47
V9	39.60	55.45	47.40	8.05	7.80	15.85	103	2.03	0.49
V10	38.90	58.10	48.00	10.10	9.10	19.20	111	2.11	0.47
V12	44.30	66.40	55.80	10.60	11.50	22.10	92	1.92	0.52
V13	41.20	55.20	47.90	7.30	6.70	14.00	109	2.09	0.48
V14	36.80	59.10	47.60	11.50	10.80	22.30	106	2.06	0.48
V15	37.60	56.10	48.50	7.60	10.90	18.50	70	1.70	0.59
V16	41.80	64.70	55.50	9.20	13.70	22.90	67	1.67	0.60
V17	45.10	63.30	56.90	6.40	11.80	18.20	54	1.54	0.65
V18	40.30	63.50	51.80	11.70	11.50	23.20	102	2.02	0.50
V19	38.90	61.50	50.20	11.30	11.30	22.60	100	2.00	0.50
V20	39.20	61.70	50.80	10.90	11.60	22.50	94	1.94	0.52
V21	37.30	57.50	46.90	10.60	9.60	20.20	110	2.10	0.48
V22	40.20	66.90	58.00	8.90	17.80	26.70	50	1.50	0.67
V25	36.50	50.90	44.50	6.40	8.00	14.40	80	1.80	0.56
V26	37.00	58.40	51.20	7.20	14.20	21.40	51	1.51	0.66
V27	43.20	71.30	61.00	10.30	17.80	28.10	58	1.58	0.63
V30	43.10	61.60	57.20	4.40	14.10	18.50	31	1.31	0.76
V31	40.70	59.70	51.60	8.10	10.90	19.00	74	1.74	0.57
V32	42.30	50.70	47.20	3.50	4.90	8.40	71	1.71	0.58
V33	36.80	64.10	55.20	8.90	18.40	27.30	48	1.48	0.67
V34	40.80	63.50	53.80	9.70	13.00	22.70	75	1.75	0.57

Appendix 1.1 : Continued.

V35	39.10	60.90	53.90	7.00	14.80	21.80	47	1.47	0.68
V36	40.20	62.50	55.30	7.20	15.10	22.30	48	1.48	0.68
V37	40.70	66.00	59.10	6.90	18.40	25.30	38	1.38	0.73
V38	45.10	62.80	59.20	3.60	14.10	17.70	26	1.26	0.80
V39	36.70	57.90	52.90	5.00	16.20	21.20	31	1.31	0.76
V40	36.70	68.40	58.90	9.50	22.20	31.70	43	1.43	0.70
V41	36.40	56.80	51.30	5.50	14.90	20.40	37	1.37	0.73
V42	37.20	59.70	53.30	6.40	16.10	22.50	40	1.40	0.72
V43	38.30	62.80	55.50	7.30	17.20	24.50	42	1.42	0.70
V44	37.30	71.40	60.70	10.70	23.40	34.10	46	1.46	0.69
V45	50.90	73.40	62.90	10.50	12.00	22.50	88	1.88	0.53
V46	37.30	59.50	48.60	10.90	11.30	22.20	96	1.96	0.51
V47	43.10	66.10	55.50	10.60	12.40	23.00	85	1.85	0.54
V48	38.30	55.80	47.10	8.70	8.80	17.50	99	1.99	0.50
V49	38.90	62.40	50.60	11.80	11.70	23.50	101	2.01	0.50
V50	44.10	62.30	54.50	7.80	10.40	18.20	75	1.75	0.57
V51	37.60	57.20	50.50	6.70	12.90	19.60	52	1.52	0.66
V52	41.10	57.90	49.20	8.70	8.10	16.80	107	2.07	0.48
V53	40.50	64.20	52.70	11.50	12.20	23.70	94	1.94	0.51
V54	40.70	59.80	51.40	8.40	10.70	19.10	79	1.79	0.56
B5	48.80	74.50	68.80	5.70	20.00	25.70	29	1.29	0.78
B7	42.50	63.20	55.80	7.40	13.30	20.70	56	1.56	0.64
B11	43.60	69.20	57.70	11.50	14.10	25.60	82	1.82	0.55
M4	44.41	81.69	67.48	14.21	23.07	37.28	62	1.62	0.62
M5	44.98	83.12	69.52	13.60	24.54	38.13	55	1.55	0.64
M16	44.87	74.30	62.68	11.61	17.82	29.43	65	1.65	0.61
M17	45.52	69.17	59.66	9.51	14.14	23.65	67	1.67	0.60
M18	42.96	65.38	56.17	9.21	13.21	22.42	70	1.70	0.59
M19	44.66	69.44	58.39	11.05	13.73	24.78	80	1.80	0.55
M20	44.36	67.28	57.64	9.63	13.29	22.92	72	1.72	0.58
M21	44.19	64.20	55.35	8.85	11.16	20.01	79	1.79	0.56
KC4	44.86	65.73	56.28	9.45	11.42	20.88	83	1.83	0.55
K28K08	45.21	70.57	59.94	10.63	14.72	25.36	72	1.72	0.58
K24J47	45.36	71.57	61.68	9.90	16.31	26.21	61	1.61	0.62
K27L00	44.36	66.24	56.73	9.52	12.36	21.88	77	1.77	0.56
B.L.	44.48	62.54	57.51	5.03	13.03	18.06	39	1.39	0.72
K33J20	36.66	54.34	46.33	8.01	9.67	17.68	83	1.83	0.55
K56K15	36.56	46.84	42.20	4.64	5.63	10.28	82	1.82	0.55
K34J28	39.15	58.83	48.39	10.44	9.25	19.68	113	2.13	0.47
K40J24	39.05	52.41	46.36	6.05	7.31	13.36	83	1.83	0.55
K38J55	38.28	44.12	41.45	2.67	3.17	5.85	84	1.84	0.54
K39J16	37.69	54.62	47.85	6.78	10.15	16.93	67	1.67	0.60
K46J28	37.68	40.41	39.89	0.52	2.21	2.74	24	1.24	0.81
K30J11	37.86	53.05	45.81	7.23	7.95	15.19	91	1.91	0.52
K43J22	39.82	55.78	48.77	7.01	8.95	15.96	78	1.78	0.56
K53J32	40.18	56.84	48.29	8.55	8.10	16.66	106	2.06	0.49
K40J30	38.10	56.59	47.54	9.05	9.45	18.50	96	1.96	0.51
K25J00	38.02	64.67	51.96	12.71	13.94	26.65	91	1.91	0.52
K37J25	37.21	58.80	48.58	10.22	11.37	21.59	90	1.90	0.53

Appendix 1.1 : Continued.

N25	39.57	55.22	47.27	7.95	7.70	15.65	103	2.03	0.49
K30J22	39.23	58.21	48.69	9.52	9.46	18.99	101	2.01	0.50
K28J13	37.25	65.25	52.55	12.70	15.30	28.00	83	1.83	0.55
K33J10	39.84	59.34	49.48	9.87	9.64	19.51	102	2.02	0.49
N26	40.84	56.79	48.96	7.82	8.12	15.95	96	1.96	0.51
K33J34	36.37	49.77	44.06	5.71	7.70	13.40	74	1.74	0.57
N27	38.35	50.64	44.56	6.08	6.21	12.29	98	1.98	0.51
N24	38.66	56.41	48.87	7.54	10.21	17.75	74	1.74	0.58
K53J42	39.94	51.11	45.18	5.93	5.25	11.18	113	2.13	0.47
K46J37	39.36	52.38	45.36	7.02	6.00	13.02	117	2.17	0.46
N23	39.53	58.37	50.46	7.92	10.93	18.84	72	1.72	0.58
K57K00	36.58	74.77	61.81	12.96	25.23	38.19	51	1.51	0.66
N22	39.64	60.86	55.25	5.61	15.60	21.22	36	1.36	0.74
N21	39.63	59.12	50.37	8.75	10.74	19.49	81	1.81	0.55
N20	36.74	61.64	51.02	10.62	14.28	24.90	74	1.74	0.57
K30K15	37.48	61.91	49.20	12.71	11.72	24.43	108	2.08	0.48
K35K15	36.95	59.87	47.56	12.30	10.61	22.91	116	2.16	0.46
N19	40.32	61.41	55.19	6.22	14.87	21.09	42	1.42	0.71
L02K15	36.78	60.59	48.40	12.19	11.62	23.81	105	2.05	0.49
N18	40.80	61.37	50.57	10.79	9.78	20.57	110	2.10	0.48
K59K30	43.25	64.47	53.79	10.69	10.54	21.22	101	2.01	0.50
K56K30	43.18	65.50	56.22	9.28	13.04	22.32	71	1.71	0.58
K38K30	45.36	69.62	58.67	10.95	13.31	24.26	82	1.82	0.55
K35J09	44.64	73.34	59.28	14.06	14.64	28.70	96	1.96	0.51
N17	42.14	77.28	60.09	17.19	17.95	35.14	96	1.96	0.51
N16	43.32	61.94	56.27	5.66	12.95	18.62	44	1.44	0.70
K26K45	44.62	66.36	55.12	11.24	10.49	21.74	107	2.07	0.48
N15	42.86	62.63	52.86	9.78	10.00	19.77	98	1.98	0.51
N14	44.05	61.06	51.59	9.47	7.54	17.01	126	2.26	0.44
N13	45.91	72.09	59.07	13.02	13.16	26.18	99	1.99	0.50
N12	45.76	77.32	68.63	8.68	22.88	31.56	38	1.38	0.72
K35K45	41.84	70.93	56.74	14.19	14.90	29.09	95	1.95	0.51
K40K45	42.67	65.11	53.83	11.28	11.16	22.44	101	2.01	0.50
N11	41.99	73.98	59.47	14.50	17.48	31.98	83	1.83	0.55
N10	38.63	71.32	59.59	11.74	20.96	32.69	56	1.56	0.64
M10	41.37	66.34	61.06	5.28	19.69	24.98	27	1.27	0.79
M9	37.39	65.58	55.93	9.66	18.53	28.19	52	1.52	0.66
N7	44.31	82.46	66.39	16.07	22.08	38.15	73	1.73	0.58
B15	39.17	65.14	60.29	4.85	21.12	25.96	23	1.23	0.81
N6	43.16	74.00	61.42	12.58	18.27	30.84	69	1.69	0.59
N5	43.21	76.08	66.51	9.56	23.30	32.86	41	1.41	0.71
B14	36.65	45.71	43.82	1.89	7.17	9.06	26	1.26	0.79
B7-A	37.55	59.47	54.05	5.42	16.50	21.92	33	1.33	0.75
B2	41.62	71.21	65.29	5.91	23.68	29.59	25	1.25	0.80
B0	43.76	80.80	72.59	8.21	28.83	37.04	28	1.28	0.78
Avg.							80	1.80	0.57

Appendix 2.1 : Moisture contents of Core BC-1.

SMP. NUMBER	DEPTH (CM)	Wt TARE WG.	W TARE WT.WG	Wd TARE DR.WG	Ww=W-Wd WATER WG.	Ws=Wd-Wt DRY WG.	WET WG.	m=Ww/Ws *100 MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	41.91	61.61	53.43	8.18	11.52	19.70	71	1.71	0.58
2	02-04	42.04	67.15	58.73	8.41	16.70	25.11	50	1.50	0.66
3	04-06	42.42	74.38	66.22	8.16	23.80	31.96	34	1.34	0.74
4	06-08	42.31	68.60	62.39	6.22	20.07	26.29	31	1.31	0.76
5	08-10	43.35	77.83	67.71	10.11	24.36	34.48	42	1.42	0.71
6	10-12	43.06	68.42	60.07	8.35	17.00	25.36	49	1.49	0.67
7	12-14	41.86	79.77	68.72	11.06	26.85	37.91	41	1.41	0.71
8	14-16	43.93	76.24	66.77	9.47	22.84	32.31	41	1.41	0.71
9	16-18	41.43	70.81	63.58	7.23	22.15	29.39	33	1.33	0.75
Avg.								44	1.44	0.70

Appendix 2.2 : Moisture contents of Core BC-2.

SMP. NUMBER	DEPTH (cm)	TARE WG.	TARE WT.WG	TARE DR.WG	WATER WG.	DRY WG	WET WG	MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	38.64	71.59	56.27	15.32	17.63	32.95	87	1.87	0.54
2	02-04	36.66	73.87	57.39	16.48	20.74	37.21	79	1.79	0.56
3	04-06	36.56	84.20	62.60	21.60	26.04	47.64	83	1.83	0.55
4	06-08	39.15	78.63	60.56	18.07	21.41	39.48	84	1.84	0.54
5	08-10	36.66	86.50	63.67	22.83	27.01	49.84	85	1.85	0.54
6	10-12	39.05	99.50	72.74	26.76	33.69	60.45	79	1.79	0.56
7	12-14	38.28	74.91	59.31	15.59	21.04	36.63	74	1.74	0.57
8	14-16	37.69	82.47	63.47	19.01	25.77	44.78	74	1.74	0.58
9	16-18	37.68	87.32	66.09	21.23	28.41	49.64	75	1.75	0.57
10	18-20	38.35	94.90	72.02	22.88	33.67	56.55	68	1.68	0.60
11	20-22	39.82	96.65	75.08	21.57	35.26	56.83	61	1.61	0.62
12	22-24	40.18	83.16	66.63	16.53	26.45	42.98	62	1.62	0.62
13	24-26	38.10	105.83	81.19	24.64	43.10	67.74	57	1.57	0.64
14	26-28	38.02	82.91	66.30	16.61	28.28	44.89	59	1.59	0.63
15	28-30	37.21	88.25	68.53	19.72	31.32	51.04	63	1.63	0.61
16	30-32	37.54	105.04	79.52	25.52	41.98	67.50	61	1.61	0.62
17	32-34	39.04	96.77	75.81	20.96	36.77	57.73	57	1.57	0.64
18	34-36	37.25	95.61	74.13	21.47	36.89	58.36	58	1.58	0.63
19	36-38	39.84	102.05	79.16	22.89	39.32	62.22	58	1.58	0.63
20	38-40	40.84	88.57	71.96	16.61	31.13	47.74	53	1.53	0.65
21	40-42	36.37	82.47	67.09	15.38	30.72	46.10	50	1.50	0.67
22	42-44	36.59	105.70	82.71	23.00	46.12	69.11	50	1.50	0.67
23	44-46	38.66	121.92	95.88	26.04	57.22	83.26	46	1.46	0.69
Avg.								66	1.66	0.60

Appendix 2.3 : Moisture contents of Core MBC-3.

SMP. NUMBER	DEPTH (cm)	TARE WG.	TARE WT.WG	TARE DR.WG	WATER WG.	DRY WG	WET WG	MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	38.64	50.29	44.82	5.47	6.18	11.65	89	1.89	0.53
2	02-04	36.66	47.18	42.40	4.78	5.75	10.53	83	1.83	0.55
3	04-06	36.56	47.35	42.47	4.88	5.90	10.78	83	1.83	0.55
4	06-08	39.15	51.22	45.85	5.36	6.71	12.07	80	1.80	0.56
5	08-10	36.66	52.41	45.47	6.94	8.81	15.75	79	1.79	0.56
6	10-12	39.05	52.24	46.24	6.00	7.19	13.18	83	1.83	0.55
7	12-14	38.28	52.13	46.08	6.05	7.80	13.85	78	1.78	0.56
8	14-16	37.69	49.67	44.39	5.28	6.69	11.97	79	1.79	0.56
9	16-18	37.68	50.75	45.06	5.69	7.38	13.08	77	1.77	0.56
10	18-20	38.35	52.55	46.44	6.11	8.10	14.21	76	1.76	0.57
11	20-22	39.82	55.83	49.14	6.69	9.32	16.01	72	1.72	0.58
12	22-24	40.18	52.79	47.39	5.40	7.21	12.61	75	1.75	0.57
13	24-26	38.10	51.92	46.12	5.80	8.02	13.82	72	1.72	0.58
14	26-28	38.02	52.62	46.46	6.16	8.44	14.60	73	1.73	0.58
15	28-30	37.21	53.43	46.63	6.80	9.42	16.22	72	1.72	0.58
16	30-32	37.54	52.54	46.26	6.28	8.72	15.00	72	1.72	0.58
17	32-34	39.04	53.04	47.14	5.90	8.10	14.00	73	1.73	0.58
18	34-36	37.25	54.78	47.45	7.33	10.20	17.53	72	1.72	0.58
19	36-38	39.84	55.83	49.23	6.60	9.39	15.99	70	1.70	0.59
20	38-40	40.84	59.20	51.74	7.46	10.91	18.36	68	1.68	0.59
21	40-42	36.37	52.73	46.11	6.62	9.75	16.36	68	1.68	0.60
22	42-44	36.59	58.93	49.89	9.04	13.30	22.34	68	1.68	0.60
23	44-46	38.66	58.56	50.56	8.00	11.89	19.90	67	1.67	0.60
24	46-48	39.94	58.11	50.78	7.33	10.84	18.17	68	1.68	0.60
25	48-50	39.36	54.55	48.25	6.30	8.89	15.19	71	1.71	0.59
26	50-52	39.53	57.42	50.20	7.22	10.67	17.89	68	1.68	0.60
27	52-54	36.58	56.08	48.18	7.90	11.60	19.50	68	1.68	0.59
28	54-56	39.64	58.84	51.18	7.66	11.54	19.20	66	1.66	0.60
29	56-58	39.63	57.82	50.45	7.37	10.82	18.19	68	1.68	0.59
30	58-60	36.74	56.50	48.57	7.93	11.83	19.76	67	1.67	0.60
31	60-62	43.32	60.51	53.85	6.66	10.53	17.19	63	1.63	0.61
32	62-64	36.95	56.97	49.36	7.61	12.41	20.01	61	1.61	0.62
33	64-66	40.32	58.54	51.22	7.32	10.90	18.22	67	1.67	0.60
34	66-68	36.78	55.22	48.02	7.19	11.24	18.43	64	1.64	0.61
35	68-70	45.92	63.72	56.62	7.11	10.70	17.81	66	1.66	0.60
36	70-72	43.25	58.17	52.16	6.01	8.91	14.92	67	1.67	0.60
37	72-74	43.18	59.44	52.96	6.48	9.78	16.26	66	1.66	0.60
38	74-76	45.36	56.66	51.67	4.98	6.31	11.29	79	1.79	0.56
39	76-78	44.64	65.44	57.75	7.69	13.11	20.80	59	1.59	0.63
40	78-80	42.14	63.40	55.67	7.73	13.53	21.26	57	1.57	0.64
Avg.								71	1.71	0.58

Appendix 2.4 : Moisture contents of Core BC-3.

SMP. NUMBER	DEPTH (cm)	TARE WG.	TARE WT.WG	TARE DR.WG	WATER WG.	DRY WG	WET WG	MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	36.74	54.97	45.21	9.76	8.47	18.23	115	2.15	0.46
2	02-04	37.49	52.97	44.88	8.09	7.40	15.48	109	2.09	0.48
3	04-06	36.95	57.07	46.41	10.65	9.46	20.11	113	2.13	0.47
4	06-08	40.32	64.79	52.09	12.70	11.77	24.47	108	2.08	0.48
5	08-10	36.78	58.47	47.34	11.12	10.56	21.69	105	2.05	0.49
6	10-12	40.80	61.59	51.15	10.43	10.35	20.79	101	2.01	0.50
7	12-14	43.25	65.97	54.58	11.39	11.34	22.72	100	2.00	0.50
8	14-16	43.18	61.60	52.50	9.09	9.33	18.42	98	1.98	0.51
9	16-18	45.36	65.67	55.53	10.14	10.17	20.31	100	2.00	0.50
10	18-20	44.64	68.00	56.37	11.63	11.73	23.36	99	1.99	0.50
11	20-22	42.14	60.23	51.18	9.05	9.04	18.08	100	2.00	0.50
12	22-24	43.32	64.65	54.15	10.50	10.84	21.33	97	1.97	0.51
13	24-26	44.62	67.66	56.52	11.14	11.90	23.04	94	1.94	0.52
14	26-28	42.86	64.35	55.68	8.67	12.82	21.49	68	1.68	0.60
15	28-30	44.05	69.86	57.41	12.46	13.35	25.81	93	1.93	0.52
16	30-32	45.92	69.78	58.37	11.41	12.45	23.86	92	1.92	0.52
17	32-34	45.76	73.18	60.38	12.80	14.62	27.42	88	1.88	0.53
18	34-36	41.84	70.82	57.15	13.67	15.31	28.98	89	1.89	0.53
19	36-38	42.67	71.19	57.76	13.43	15.09	28.52	89	1.89	0.53
20	38-40	41.99	68.62	56.20	12.42	14.21	26.63	87	1.87	0.53
21	40-42	38.63	69.31	55.05	14.26	16.42	30.68	87	1.87	0.54
22	42-44	41.37	67.23	54.92	12.31	13.56	25.86	91	1.91	0.52
23	44-46	37.39	68.79	54.06	14.73	16.67	31.40	88	1.88	0.53
24	46-48	44.31	72.59	59.48	13.11	15.17	28.28	86	1.86	0.54
25	48-50	39.17	69.18	55.41	13.77	16.24	30.00	85	1.85	0.54
26	50-52	45.82	78.87	64.03	14.83	18.21	33.05	81	1.81	0.55
27	52-54	45.63	81.26	65.02	16.24	19.39	35.63	84	1.84	0.54
Avg.								94	1.94	0.52

Appendix 2.5 : Moisture contents of Core BC-4.

SMP. NUMBER	DEPTH (cm)	TARE WG.	TARE WT.WG	TARE DR.WG	WATER WG.	DRY WG	WET WG	MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	36.41	57.22	43.95	13.27	7.53	20.81	176	2.76	0.36
2	02-04	36.66	61.08	45.72	15.37	9.06	24.43	170	2.70	0.37
3	04-06	36.56	57.17	45.11	12.06	8.54	20.60	141	2.41	0.41
4	06-08	39.15	63.96	48.68	15.29	9.53	24.82	160	2.60	0.38
5	08-10	36.66	68.67	48.65	20.02	11.99	32.00	167	2.67	0.37
6	10-12	39.05	57.23	47.44	9.79	8.39	18.18	117	2.17	0.46
7	12-14	38.28	61.11	48.65	12.46	10.37	22.83	120	2.20	0.45
8	14-16	37.69	51.09	43.51	7.59	5.81	13.40	131	2.31	0.43
9	16-18	37.68	59.42	47.96	11.46	10.29	21.74	111	2.11	0.47
10	18-20	36.87	60.37	47.74	12.63	10.86	23.50	116	2.16	0.46
11	20-22	39.82	61.24	50.58	10.66	10.76	21.42	99	1.99	0.50
12	22-24	40.18	60.76	49.59	11.17	9.40	20.58	119	2.19	0.46
13	24-26	38.10	65.32	51.32	14.00	13.22	27.22	106	2.06	0.49
14	26-28	38.02	67.77	52.78	14.99	14.76	29.75	102	2.02	0.50
15	28-30	37.21	63.88	50.92	12.96	13.71	26.67	95	1.95	0.51
16	30-32	37.54	54.43	46.01	8.42	8.46	16.89	100	2.00	0.50
17	32-34	39.04	64.14	52.38	11.77	13.34	25.10	88	1.88	0.53
18	34-36	37.25	61.51	49.35	12.16	12.10	24.26	100	2.00	0.50
19	36-38	39.84	64.87	51.46	13.41	11.62	25.04	115	2.15	0.46
20	38-40	38.64	63.02	49.62	13.40	10.97	24.37	122	2.22	0.45
21	40-42	36.37	59.60	47.12	12.48	10.75	23.23	116	2.16	0.46
22	42-44	36.59	56.27	45.40	10.87	8.81	19.68	123	2.23	0.45
23	44-46	38.66	65.94	51.70	14.24	13.03	27.28	109	2.09	0.48
24	46-48	39.94	64.05	51.89	12.16	11.95	24.11	102	2.02	0.50
25	48-50	39.36	66.01	54.23	11.78	14.87	26.65	79	1.79	0.56
26	50-52	39.53	66.69	54.82	11.87	15.29	27.16	78	1.78	0.56
27	52-54	36.58	65.65	53.05	12.60	16.47	29.06	77	1.77	0.57
28	54-56	39.64	60.85	51.43	9.42	11.79	21.20	80	1.80	0.56
29	56-58	39.63	69.01	55.77	13.24	16.14	29.38	82	1.82	0.55
Avg.								114	2.14	0.47

Appendix 2.6 : Moisture contents of Core BC-5.

SMP. NUMBER	DEPTH (cm)	TARE WG.	TARE WT.WG	TARE DR.WG	WATER WG.	DRY WG	WET WG	MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	39.94	98.39	72.91	25.48	32.97	58.45	77	1.77	0.56
2	02-04	39.36	89.30	67.67	21.62	28.31	49.94	76	1.76	0.57
3	04-06	39.53	97.62	72.56	25.06	33.03	58.09	76	1.76	0.57
4	06-08	36.58	89.44	66.04	23.41	29.46	52.86	79	1.79	0.56
5	08-10	39.64	93.58	70.36	23.21	30.72	53.94	76	1.76	0.57
6	10-12	39.63	86.49	66.71	19.78	27.08	46.86	73	1.73	0.58
7	12-14	36.74	91.08	69.18	21.90	32.44	54.34	68	1.68	0.60
8	14-16	37.49	96.18	73.31	22.87	35.82	58.69	64	1.64	0.61
9	16-18	36.95	89.67	69.57	20.11	32.61	52.72	62	1.62	0.62
10	18-20	40.32	98.59	75.97	22.62	35.65	58.27	63	1.63	0.61
11	20-22	36.78	98.63	75.17	23.46	38.39	61.84	61	1.61	0.62
12	22-24	40.80	103.02	79.05	23.97	38.25	62.22	63	1.63	0.61
13	24-26	43.25	106.25	79.85	26.40	36.60	63.00	72	1.72	0.58
14	26-28	43.18	107.48	80.49	26.99	37.31	64.31	72	1.72	0.58
15	28-30	45.36	104.02	79.24	24.79	33.88	58.66	73	1.73	0.58
16	30-32	44.64	99.25	76.66	22.59	32.02	54.61	71	1.71	0.59
17	32-34	42.14	104.38	78.69	25.70	36.55	62.24	70	1.70	0.59
18	34-36	43.32	99.46	76.67	22.79	33.35	56.14	68	1.68	0.59
19	36-38	44.62	97.66	75.90	21.76	31.28	53.04	70	1.70	0.59
20	38-40	42.86	99.81	76.73	23.08	33.87	56.95	68	1.68	0.59
21	40-42	44.05	108.78	83.07	25.71	39.02	64.73	66	1.66	0.60
22	42-44	45.92	127.70	95.15	32.55	49.24	81.79	66	1.66	0.60
23	44-46	45.76	112.71	86.71	26.00	40.95	66.96	63	1.63	0.61
24	46-48	41.84	107.81	81.72	26.09	39.88	65.97	65	1.65	0.60
Avg.								69	1.69	0.59

Appendix 2.7 : Moisture contents of Core BC-6.

SMP. NUMBER	DEPTH (cm)	TARE WG.	TARE WT.WG	TARE .DR.WG	WATER WG.	DRY WG	WET WG	MOIST. CONT.	WT/DR RATIO	DR/WT RATIO
1	00-02	42.67	115.85	95.81	20.04	53.15	73.18	38	1.38	0.73
2	02-04	41.99	105.84	86.92	18.92	44.93	63.85	42	1.42	0.70
3	04-06	38.63	122.84	99.81	23.04	61.18	84.21	38	1.38	0.73
4	06-08	41.37	131.80	108.45	23.34	67.09	90.43	35	1.35	0.74
5	08-10	37.39	137.68	111.20	26.48	73.80	100.29	36	1.36	0.74
6	10-12	44.31	132.78	108.98	23.80	64.67	88.47	37	1.37	0.73
7	12-14	39.17	112.67	92.62	20.05	53.44	73.49	38	1.38	0.73
8	14-16	43.16	125.70	102.77	22.94	59.61	82.54	38	1.38	0.72
9	16-18	38.37	133.44	106.07	27.37	67.70	95.07	40	1.40	0.71
10	18-20	36.65	123.63	99.55	24.08	62.90	86.98	38	1.38	0.72
11	20-22	37.55	124.32	99.93	24.39	62.39	86.78	39	1.39	0.72
12	22-24	41.62	120.32	98.51	21.81	56.89	78.70	38	1.38	0.72
13	24-26	43.76	142.70	115.16	27.54	71.40	98.94	39	1.39	0.72
14	26-28	40.81	167.99	133.01	34.98	92.20	127.18	38	1.38	0.72
Avg.								38	1.38	0.72

VITA

I was born in Gaziantep, TÜRKIYE, in 1957. I attend primary and high schools in Gaziantep, in 1964-1975. I entered the Middle East Technical University (METU) in Ankara and in 1977. I received a Bachelor of Science degree in Geological Engineering from this University. I transferred to the Institute of Marine Sciences, METU, in Erdemli, IÇEL, as a research assistant and then was admitted to the M.Sc. program in this Institute in 1984. I received a M.Sc. degree in Marine Geology and Geophysics, from this Institute in 1987. The M.Sc. thesis concerned "Recent Inshore Sedimentation in the Bay of Mersin".