ISTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCE

OXYGEN AND CARBON ISOTOPE ANALYSES AND GEOCHEMISTRY OF MOLLUSC SHELLS IN SEDIMENT CORES FROM NORTHERN SHELF OF THE MARMARA SEA

M. Sc. Thesis by
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Registration Number: 601991008

Date of submission: May 2003

Date of defence examination: May 2003

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MAY 2003

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to all the individals and organizations that contributed to this study.

I would like to thank all the people who helped me develop in interest in sedimentology, natural science and marine geology. I am indebted to Namık ÇAĞATAY, my thesis advisor, for all his efforts, advice and guidance throughout both the progress of this investigation and master programme.

I would like to thank Mehmet Sakınç who helped me define foraminifers. I also would like to thank Andrey Tchapalyga who defined molluscs in my thesis cores.

I would like to thank Ümmühan SANCAR and Seda ŞİMŞEK. I express my sincere gratitudes to them for their unending support and friendship.

Finally I would like to express the deepest appreciation to my parents, who made every effort for my education and happiness.

MAY 2003 Demet BİLTEKİN

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SUMMARY

The objective of this thesis is to investigate paleoclimatic and paleoceanographic conditions during Late Glacial-Holocene period, using stable oxygen- and carbon-isotope and Ca-Mg-Sr analyses of mollusc shells, and paleontological and mineralogical analyses of sediments two cores on the northen shelf of the Marmara Sea.

Both cores intersect bioherm-like sediments. Core C1 sediments are rich in Mediterranean euryhaline marine molluscs and foraminifers, demonstrating that the core sediments was deposited in a marine environment during Holocene period. $\delta^{18}O$ profile of core C1 demonstrates an upward increasing trend starting from the base with an age of about 11.7 kyr BP. The $\delta^{18}O$ data and both foraminifer and mollusc distributions display that marine conditions gradually developed over a period of 1500-2000 years after the onset of the marine transgression at about 12 kyr BP.

The core C17 includes three units. The most recent one (Unit 1) was deposited in the last 12 kyr BP. This unit includes euryhaline Mediterranean molluscs and foraminifers. Unit 2 contains lacustrine molluscs , and was deposited under fresh-brackish water conditions between 12-36 kyr BP. Unit 3 contains a mixture of brackish and marine mollusc together with minor foraminifera, indicating a marine connection of the Marmara Sea during early part of marine isotopic stage 3 (>36 kyr BP). This is supported by increased values of $\delta^{18}O$. Mollusc shells in Unit 1 of core C17 have heavy $\delta^{18}O$ values supporting the connection during it deposition, whereas mollusc shells in Unit 2 have light $\delta^{18}O$ values, indicating lacustrine conditions and disconnection from the Mediterranean.

These conclusions are supported by high Sr/Ca in mollusc shells in Unit 1 and Unit 3 relative to those in Unit 2. Generally low $\delta^{13}C$ values during the deposition of Unit 1 suggest deep water upwelling. Skeletal Mg/Ca of core C1 shows elevated values in the upper part representing the last 4000 yr BP and suggests increased temperatures during this period.

ÖZET

Tezin amacı, Geç Buzul-Holosen zamanındaki paleoklimatik ve paleoşinografik koşulları, marmara denizi'nin kuzey şelfinden alınan karotlarda oksijen-carbon izotopları, jeokimyasal analizler, paleontolojik ve mineralojik yöntemlerle belirlemektir.

Karot C1 Akdeniz kökenli molusk ve foraminifer içeriği bakımından zengindir. Bu durum karot C1' nın Holosen zamanında denizel koşullar altında oluştuğunu göstermektedir. Karot C1'in oksijen izotop profili yaklaşık 11,700 yıl öncesinden başlayarak karotun üst kısımlarına doğru artış göstermektedir. $\delta^{18}O$ verisi ve foraminifer ve molusk toplulukları denizel koşulların yaklaşık olarak 12,000 bin yıl önce denizel transgresyonun başlamasından sonra dereceli olarak geliştiğini göstermektedir.

Karot C17 birbirinden farklı 3 birim içermektedir. Birim 1 günümüzden 12,000 bin yıl önce oluşmuştur. Bu birim Akdeniz molusk ve foraminiferleri içermektedir. Birim 2 ise lakustrine molusklan içermektedir ve 12,000-36,000 bin yıllık bir zaman aralığında acı-su koşulları altında çökelmiştir. Birim 3 hem denizel hemde acı-su molusklan ve az miktarda foraminifer içermektedir. Bu birim içindeki molusk ve foraminiferlerin varlığı denizel izotopik evre 3'ün erken safhası esnasında Marmara denizi'nin deniz bağlantısını desteklemektedir (>36,000 yıl önce). Bu durum artan oksijen değerleri ile desteklenmektedir.

Birim 1 denizel bağlantı nedeni ile daha pozitif değerler sergilemektedir. Birim 2 ise daha negatif değerlere sahiptir. Bu birimin acı-su koşulları altında çökeldiğini göstermektedir. Bu sonuçlar birim 1 ve birim 3 içindeki molusk kavkılarındaki yüksek Sr/Ca oranı ilede desteklenmektedir. Genellikle birim 1'in çökelimi esnasında düşük değerlere sahip olan $\delta^{13}C$ dip su upwelling'ini desteklemektedir. Kor C1'in Mg/Ca oranı korun üst kısımlarında yüksek değerler göstermektedir. Bu durum bu zaman esnasındaki artan sıcaklıkları göstermektedir.

1. INTRODUCTION

1.1. Oceanography and Recent Sedimentary History of the Sea of Marmara

The Sea of Marmara Basin is a 210-km long and 75-km wide intracontinental sea between the Mediterranean and the Black seas (Fig 1.1). Marmara Sea is connected to Black Sea (S =18‰) via the Bosphorus Strait and to the Aegean Sea (S =38.5‰) via the Dardanelles Strait. Sill depths of these straits are –65 and –35 m, respectively. The topographic restriction of these straits results in a permanent two-layer flow system in the Sea of Marmara basin and also prevents the efficient circulation of the sub-pycnocline layer (Ünlüata et al., 1990).

The dissolved oxygen content of the Marmara bottom waters decreases by microbial oxidation of organic matter from 7-10 mg/l near the Dardanelles Strait to 1-2 mg/l in the deep basins. However, it increases again from 2.5 to 5 mg/l near the Bosphorus Strait (Ünlüata and Özsoy, 1986). Biga, Gönen and Kocasu rivers flow into the Sea of Marmara from the south. These rivers discharge a total of $2.2x10^6$ t/yr of suspended sediment and 5.80 km^3/yr freshwater to the basin (EİE, 1993). Kocasu river is the largest river among them. This rivers discharge about 90% of the total riverine suspended sediment and 80% of the total riverine freshwater discharges. The riverine freshwater discharge is much less than the low salinity surface water influx of 605 km^3/yr from the Black Sea through the Bosphorus Strait and the saline water influx of 376 km^3/yr from the Aegean Sea through the Dardanelles Strait (Ünlüata et al., 1990). During the last glacial maximum, global sea level was ~ 120 m below its present level (Fairbanks, 1989), and the Marmara Sea (as well as the Black Sea) was seperated from the Mediterranean. During the last deglaciation as sea level rose to ca. –70 m, a marine connection was first established with the Mediterranean through the Dardanelles.

As sea level rose to the depth of the Bosphorus sill (-40 m), an effective marine connection was eventually established with the Black Sea once two-way flow developed (Lane-Serff et al., 1997). Quaternary palaeoceanographic studies on the sea of Marmara Basin based on sedimentary core analyses are few (Stanley and Blanpied., 1980; Alavi et al., 1988; Evans et al., 1989; Ergin et al., 1997., Görür et al., 1997; Çağatay et al., 1999, 2000; Kaminski et al., 2002; Aksu et al., 2002; Sperling et al., 2002).

Stanley and Blanpied (1980) interpreted the sequence of events that probably induced differences in the timing of sapropel accumulation in Aegean and Black Seas, and also evaluate differences between Late Quaternary Lithofacies sequences deposited in the two regions. Four University of Miami gravity cores recovered in 1965 (RV pillsbury cruise P6507) in the eastern Sea of Marmara were used for their study. The investigation of these cores included X-radiography, radiocarbon dating and petrological examination of 44 core samples. They postulated that physical oceanographic conditions presently measured in the Sea of Marmara, including the two-way exchange of water masses through the Bosphorus and Dardanelles, were established at ~ 3.000 yr BP.

Çağatay et al.(2000) studied to investigate the palaeoceanographic conditions during the Late Glacial – Holocene and provide evidence for timing of the water exchange between the Mediterranean and Black Seas during this time. These investigations are based on sediment cores that were obtained during the cruises of R/V S*eismic* and R/V *Arar* between 1995 and 1997. The study also involved stratigraphic analysis of borehole cuttings that were obtained from three holes drilled in the Bosphorus by The Turkish State Waterworks (DSI). Core studies included, ^{14}C dating, calcium carbonate, total organic matter, foraminiferal and mollusc analyses. These studies shows that the sediments can be subdivided into an upper marine (Unit 1) and a lower lacustrine (Unit 2). A 10 cm thick yellow-brown oxic zone marks the top of Unit1. This unit contains marine (Mediterranean) fossils, such as foraminifera, molluscs, echinoderms and fish bones, which indicate this unit was deposited after the transgression of the Marmara Sea by the Mediterranean waters at about 12,000 yrs BP. Unit 1 includes two sapropelic layers deposited during 10.6-6.4 kyr and 4.7-3.2 kyr intervals.

The older sapropelic layer being broadly the time equivalent of the S1 sapropel in the Mediterranean (Çağatay et al., 2000). Unit 2 is the locally laminated, iron monosulfide banded, gray to dark gray mud, with freshwater ostracods and Neoeuxinian Black Sea molluscs. The faunal content and ^{14}C stratigraphy of Unit 2 shows that it was deposited during fresh/brackish water (salinity<6‰) lake phase of the Marmara Sea during the Late Glacial time until 12 kyr BP (marine isotope stage 2).

Tolun et al. (1999) studied the organic geochemistry of the Marmara Sea sapropels in DM-13 and GM-7 using elemental C/N analysis, Rock Eval Pyrolsis and C-isotope analysis.The profiles, in particular $\delta^{13}C$, strongly suggest that the organic matter in Unit 2 is predominantly of terrestrial origin and that the terrestrial component decreases, with a corresponding increase in the marine component, from the base to the top of Unit 1. In both cores, light $\delta^{13}C$ values and high C/N ratios within the transition interval between Units 1 and 2 (12.5 to12.0 yrBP) suggest a high terrestrial organic matter input.

Alavi (1988) studied the benthic foraminiferal assemblages of two cores from the Late-Holocene organic-carbon-rich and carbonate poor, deep sea sediments of the eastern depression of the Sea of Marmara. The cores were raised by boomrang corers from a depth about 1200 m on board the R/V *Bilim* of the I.M.S.(M.E.T.U.) in November, 1984. Although surficial deep sea sediments of the Sea of Marmara cannot be considered as sapropels in the strict sense of the term (Kidd, 1976; Anastasakis and Stanley, 1984; and Calvert, 1983), their microfaunal contents reflect continuous sedimentation under dysaerobic conditions (Savrda et al., 1984).

Alavi (1988) concluded that these sediments were deposited subsequent to the establishment of an estuarine circulation in the Marmara Sea, but owing to the lack of absolute age determinations, he was unable to provide a chronology for his cores. In addition, Meriç et al. (1995) studied descriptions of upper Pliocene to Holocene foraminifera from geotechnical bore-holes in the Gulf of İzmit.

Kaminski et al. (2002) studied benthic foraminifera from four cores collected during the MAR97 and MAR98 cruises of the R/V Koca Piri Reis of the Institute of Marine Sciences and Technology, Dokuz Eylül University. Analyses reveal that the Holocene sea-level rise did not result in a catastrophic flooding event as proposed by Ryan et al. 1997, whereby well-oxygenated, saline Mediterranean waters rapidly inundated a low-lying low salinity 'Black Sea Lake' at ~7.15 ka. Rather, the benthic foraminiferal data confirm the hypothesis that the Dardanelles sill was breached by the Mediterranean at ~12 ka, allowing saline waters to penetrate the Marmara Sea. The initial colonisation of the Marmara Sea by benthic foraminifera is essentially synchronous with the re-establishment of marine connections through the Dardanelles Strait at ~12 ka.

Sperling, et al. (2002) studied Black Sea impact on the formation of eastern Mediterranean sapropel S1. One of the piston core was taken from the Marmara Sea during the *Meteor* cruise M44/1. The other piston core obtained from the southeastern Levantine Basin during *Meteor* cruise M44/3 in April 1999. Studies included chronology, total organic carbon, planktic foraminifera and oxygen isotope analyses. Dating of cores are based on accelerator mass spectrometry (AMS) ^{14}C dates performed at the Leibniz Laboratory for Radiometric Dating and Stable Isotope Research in Kiel with a precision of ± 40 to ± 60 years standard deviation. High-resolution record of SSS (sea surface salinity) and SST (sea surface temperature) in the Marmara Sea and the eastern Mediterranean was used to investigate the timing of the Black Sea out flow during the Holocene and its effect on the sapropel deposition. High $\delta^{18}O$ values and high SSS found in the Marmara Sea are in strong contrast to the isotopic depletion found in the Levantine Basin during S1. This shows that the Black Sea was not likely a major contributor to the surface water freshening during S1 sapropel deposition in the eastern Mediterranean Sea. Moreover, the paleoclimatic evolution of the Mediterranean Sea was synchronous to that of the Marmara Sea in terms of SST with a thermal maximum occuring during deposition of S1, but asynchronous with respect to the SSS evolution. This is possibly due to the marine flooding of the Black Sea shelf at 8.7 ka by saline Mediterranean waters.

Aksu et al.(2002) studied Last-glacial-Holocene paleoceanography of the Black Sea and Marmara Sea. Cores were obtained from the north-eastern Aegean Sea, south-western Black Sea and the Sea of Marmara during the MAR94(1994), MAR97(1997), MAR98(1998) and MAR00(2000) cruises of the RV *Koca Piri Reis* of the Institute of Marine Sciences and Technology. The cores were studied for micro-paleontological and stable isotopic studies. He concluded that two sapropel layers are observed in the Marmara Sea. These are sapropels (M2 and M1) were deposited between ~29.5 and 23.5 ka, ~10.5 and 6 ka. Stable isotope values and micro-paleontological data display that the surface water salinities were reduced during deposition of these sapropel layers. Benthic foraminifers suggest that deep water conditions during deposition of M1 must have been close to anoxic conditions.

As can be seen from the foregoing discussion, the Late Glacial – Holocene sediments in the Marmara Sea has been the subject of numerous studies. The objective of this thesis is to investigate paleoclimatic and palaeoceanographic conditions during Late Glacial-Holocene period, using stable oxygen and carbon isotopes and Ca-Mg-Sr analyses of mollusc shells from two cores on the northen shelf of the Marmara Sea. Paleontological and sedimentological studies were also carried out. The samples were studied for their macrofossil content and under microscope for their mineral composition and nanno- and micro- fossil contents. Distribution of these parameters along the depth of the cores were interpreted in terms of palaeoclimatic and paleoceanographic evolution of the Sea of Marmara during Late Glacial-Holocene period.

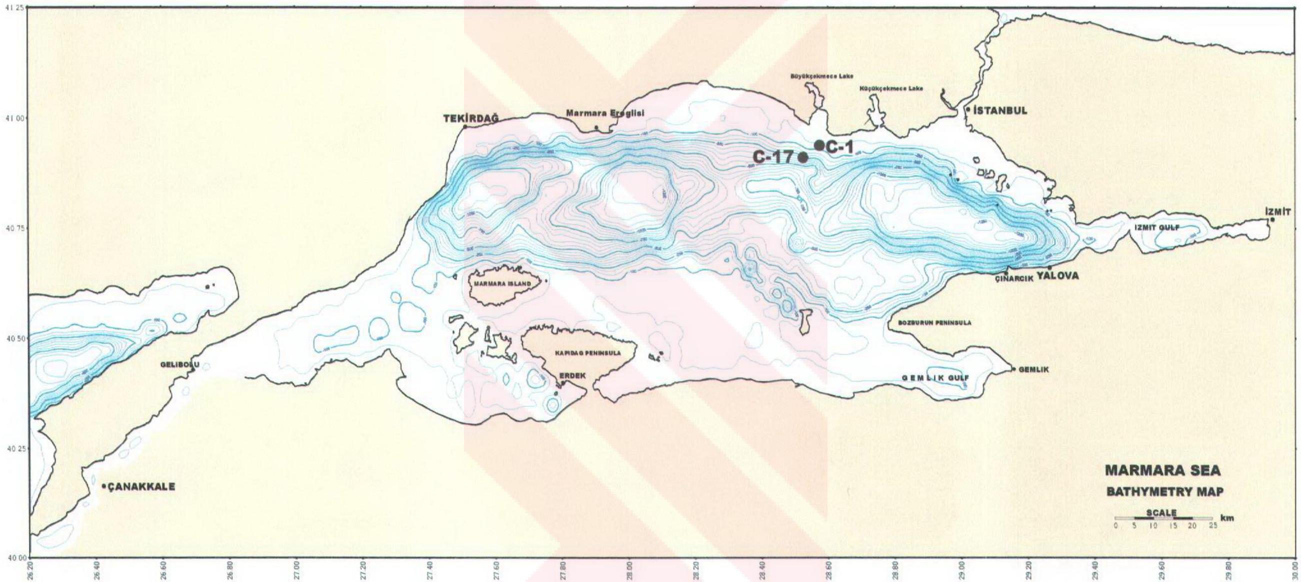


Fig.1.1. Map showing location of studied cores of the Sea of Marmara.

2. METHODS OF STUDY

2.1. Sample Collection

Two cores were studied from the northen shelf of Marmara Sea (Fig.1.1). These two gravity cores were recovered in 73.4 and 91.1 meters of water on board the R/V Seismic-1 of the General Directorate of the Mineral Research and Exploration (MTA) in 2001 (Table 1.1).

Table 1.1. Marmara Sea Cores.

Core Name	Latitude	Longitude	Water depth (m)	Length(m)
C 1	40° 55.604′	28° 41.054′	73.4	1.49
C 17	40° 54.876′	28° 31.374′	91.1	4.86

2.2. Sample Preparation

Cores C1 and C17 have a total length about 1.49 and 4.86 meters, respectively. These cores were lithologically described and subsampled at about 10 cm interval with each sample representing 3 cm thick-slice in core C 1, and 2 cm thick-slice in core C 17.

Parts of each sample were washed and studied for mollusc and foraminifera populations, and the mollusc shells were used for oxygen and carbon isotopes analyses; Ca, Mg, Sr, analyses and carbon dating. The mollusc shells for isotopes, geochemical and C-14 analyses were carefully cleaned to remove any surface coatings, and then studied under microscope to ensure that they were diagenetically unaltered.

2.3. Oxygen and Carbon Isotope Analyses

$\delta^{18}O$ and $\delta^{13}C$ of carbonates were measured using an automated carbonate preparation device (KIEL-III) coupled to a gas – ratio mass spectrometer (Finnigan MAT 252). Powdered samples were reacted with dehydrated phosphoric acid under vacuum at 70°C. The isotope ratio measurement is calibrated based on repeated measurements of NBS-19 and NBS-18 and precision is ±0.1 ‰ for $\delta^{18}O$ and ±0.06‰ for $\delta^{13}C$(1 sigma)

2.4. Geochemical Analyses

0.1 gr shells were dissolved in 1-2 ml concentrated HCl and diluted with 50 ml distilled water.

2.4.1. Ca Analysis

Ca content of the samples was determined by Flame Photometry. Flame Photometry was adjusted for Ca analyses and emission values of blank, standards and samples were determined and concentration of Ca in samples were determined from the calibration graph.

2.4.2. Mg Analysis

Mg content of the samples was determined by Flame Atomic Absorption Spectroscopy. Firstly, 1000 mg/l Mg standard was diluted to prepare standard Mg solutions. Air-Acetylene Flame was used for excitation of atoms. Adsorption at 285.2 nm wavelength was determined for blank, standard and sample solutions. Absorption values of the samples were compared with absorption values of Mg Standard solutions to calculate the Mg concentration in the samples.

2.4.3. Sr Analysis

Sr content of the samples was determined by Flame Atomic Absorption Spectroscopy. Firstly, 1000 mg/l Sr standard stock solutions was diluted to prepare standard Sr solutions. Air-Acetylene Flame was used in the Flame Atomic Absorption mode at 460.7 nm wavelength to determine the absorption values of blank, standard and sample solutions. Absorption values of the samples were compared with absorption values of Sr standard solutions to calculate Sr concentration in the samples.

2.5. C-14 Dating

Conventional and AMS (Accelerator Mass Spectrometry) carbon dating were carried out in seven samples at the Isotope Geochemistry Laboratory of the University of Arizona. These samples are marine and freshwater molluscs (Table 2.1). Ages were calculated as ^{14}C years BP, corrected for ^{13}C, and expressed at the $\pm$ 1 σ level for analytical confidence.

Table 2.1. ^{14}C dates in the Sea of Marmara sediment cores. AMS ^{14}C dates are shown in bold italic.

Location, water depth(m)	Intervals(cm)	Samples	Age(yr BP)
C 1, northern shelf, -73.4 m	40-43 cm	Ostrea edulis	3965yr
C 1, northern shelf, -73.4 m	113-117 cm	Mytilus edulis	10,978 yr+175/–170
C 1, northern shelf, -73.4 m	143-147 cm	Mytilus edulis	11,655 yr+165/–160
C 17, northern shelf, -91.1 m	***60-62 cm***	Turritella sp.	***10,520 yr***
		Bittium sp.	
		Dreissena rostriformis	
		Corbula gibba	
C 17, northern shelf, -91.1 m	330-332 cm	Dreissena rostriformis	34,7 kyr+3300/–2300
C 17, northern shelf, -91.1 m	456-458 cm	Dreissena rostriformis	44,1 kyr (apparent age)

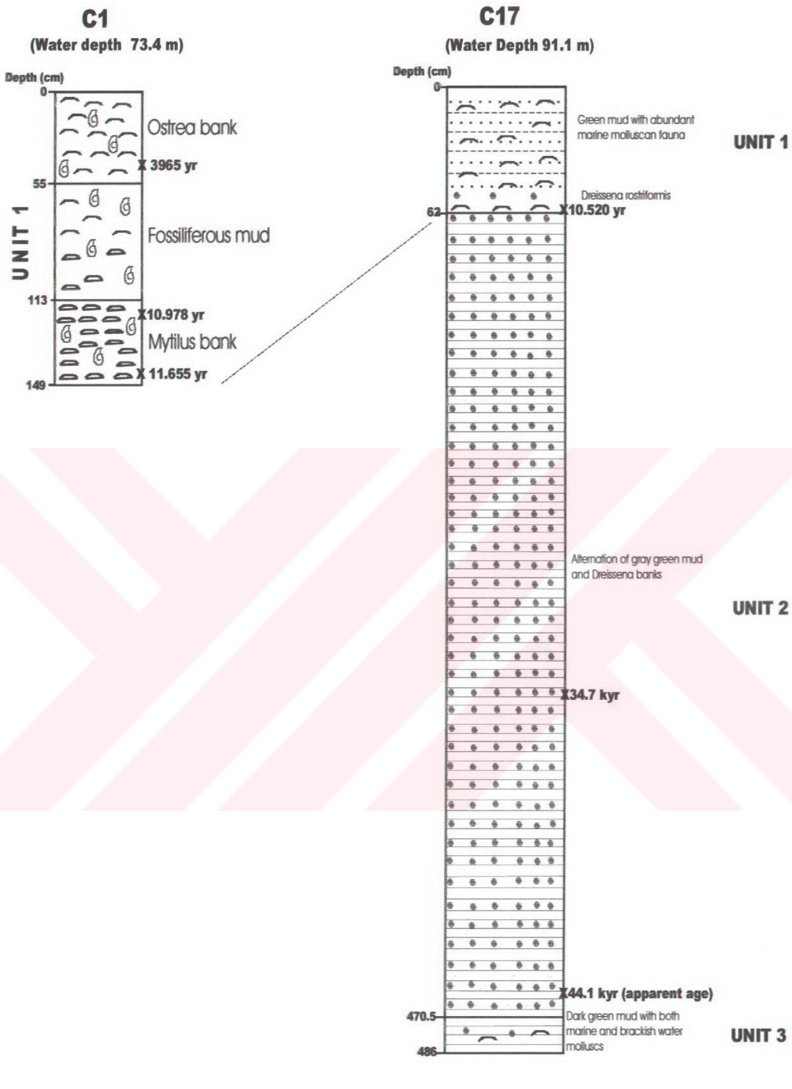


Fig.2.1. Lithological logs of studied cores of the northern shelf of the Marmara Sea.

3. RESULTS

3.1 Lithological Description of the Cores

3.1.1. Core C1

Core C1 represents a bioherm and includes three different facies, all containing a marine fauna (Fig.2.1). The top 55 cm of the core consists of abundant molluscs and serpulid with small amount of ligt-green mud matrix. In this intervals *Ostrea edulis* is so abundant that it forms an Ostrea bank. The bank also includes planktic and benthic foraminifers.

Between 55 cm and 113 cm depths, while the amount of *Ostrea edulis* decrease, the amounts of other molluscs, vermetus and mud matrix increase. Foraminiferal assemblages in this intervals include planktic and benthic foraminifers.

The bottom unit at the base of the core from 113 cm to 147 cm depth is a Mytilus bank. The bank consists mainly of *Mytilus edulis* in a dark green mud matrix. It also contains some *Ostrea edulis* shells and benthic foraminifers. The foraminiferal assemblage shows low salinity conditions. Foraminiferal abundances increase toward the top of the core.

3.1.2. Core C17

In core C17, three stratigraphic units can be distinguished based on fossil assemblage. This units are Unit 1, Unit 2 and Unit 3 (Fig.2.1). Unit 1 is a 62 cm-thick, green mud unit with abundant marine molluscan fauna. The first 2 cm consits of semi-liquid, brown mud. Between 50-52 cm, it contains brackish water molluscs (mainly *Dreissena rostriformis*) indicating a possible return to brackish water lacustrine conditions during 10-11 kyr BP.

The middle unit (Unit 2) consists of alternation of gray green mud and Dreissena banks, each having 10-15 cm in thickness. Unit 3 is a dark green mud unit with both marine and brackish water molluscs. It also contains minor benthic foraminifers. The fossil assemblage suggests deposition of this unit under brackish-marine conditions.

3.2. Mineralogy

3.2.1. Core C 1

The top 4 cm in core C 1 is composed of detrital calcite, quartz and minor amount of opaque minerals, biotite and plagioclase. The size of quartz grains is between 10 and 40 μm. They are angular, and form major amount of the total sample. The size of detrital calcite grains varies 30 and 50 μm They are subrounded and constitute abundant of total samples. The other type of calcite is mainly of biogenic origin consisting of mollusk, foraminifer, coccolith tests. The size of coccolithic tests is approximately a few 2 μm in diameter.

The grain size of opaque minerals is about 50 μm. They are subrounded and includes about < 1 % of total samples. The size of biotite is about 20 μm, angular and contains lesser amount of the total samples. The grain size of plagioclase is approximately 30 μm, angular and constitutes lesser amount of total sample. Minor orthoclase with carlsbad twinning is also present.

Between 10-40 cm depth, the sediments consists of quartz, detrital calcite, plagioclase, chlorite, opaque minerals and minor Biotite. The size of detrital calcite grains varies 20 μm and 90 μm. They are subrounded and forms most of total samples. Quartz is angular with a grain size between 10 and 50 μm. It composes most of total sediment. Biotite is about 20 μm, angular. They consist of lesser amount of total sediment. Plagioclase, chlorite and opaque minerals constitute minor amount of the samples. Plagioclase is angular and about 40 μm in size. Chlorite occurs as angular grains with about 20 μm size. Opaque minerals are about 20 μm in diameter and usually rounded. Most of the opaques consists of pyrite which occurs as rounded grains having a diameter of ~20 μm.

In 40-43 cm, 50-53 cm and 53,5-56 cm depths consist of mainly quartz and detrital calcite. The size of calcite is 10 and 50 μm, subrounded and make up most of the samples. There is no significant change in the grain size of detrital calcite. Quartz grains are angular have 10 and 50 μm diameter. It forms most of total sediment. Between 133-136 cm and 143-147 cm depths, the size of calcite is about 10 and 40 μm. It is subangular and constitutes most of the total sediments.

Quartz minerals in this interval have no change in grain size and percentage compared to those in the above interval. In this interval, the size of quartz grains ranges between 10 and 40 μm. They are angular, and forms most of the total sample. However, between 143-147 cm depth, grain size of quartz varies between 10 and 80 μm. It is angular and forms most of the samples. Plagioclase is found in 103-106 cm and 113-117 cm depths. Its grain size is 30-40 μm, angular. There is lesser amount of plagioclase in this intervals. Biotite is rarely present in 63-66 cm, 93-96 cm and from 113 to 147 cm depths. Its grain size varies between 10 and 30 μm. Chlorite is found in 83-86 cm, 93-96 cm, and from 122 to 147 cm depths. Its size is 20-30 μm. The grains are angular and present in minor amounts (<1%) in these levels.

3.2.2. Core C17

The first 2 cm-thick in core C 17 consists mainly of quartz, detrital calcite, plagioclase, chlorite and biotite. The grain size of quartz is between 10 and 50 μm. It is angular and makes up most of the total sediment. The size of detrital calcite is between 10 and 30 μm. The calcite grains are angular and contain amost of the total sediment. Biotite mineral varies between 10 and 20 μm. The grains are angular and form minor amount of the total sediment.

Plagioclase exists as angular grains of 60 μm size. It is a minor constituent of the sediment. Chlorite is between 10 and 20 μm. It consists of angular grains and forms about 1 % of the total sample. There is no important change in the size and percentage of quartz from the core top to 62 cm depth. Grain size of quartz varies between 10 and 50 μm. It is angular and constitutes major amount of the sediment. The size of detrital calcite in the top 62 cm of the core varies between 20 and 40 μm. It forms major amount of the entire sediment.

Plagioclase is found in 14-16 cm depth, with 50 μm average grain size. The grains are angular and constitute a minor amount of total samples. Opaque minerals and biotite occur in minor amounts in this interval. The size of opaque minerals is between 10 and 20 μm. They are angular shape. The grain size of biotite is 10-20 μm. The amount of chlorite is about 2 % of the total samples in 28-30 and 34-36 cm depths.

The grain size of quartz has no significant change from 62 cm to the bottom of core. It varies from about 10 to 30 μm. The percentage of detrital calcite makes up most of entire sediment from 60 cm to 156 cm depths and also in 255 cm, 265 cm, 275 cm, 285 cm, 295 cm depths. Grain size changes between 20 and 30 μm. They are angular shape. The abundance of detrital calcite decreases from 156 cm to the bottom of core. Chlorite occurs in subordinate amounts along the core. Its angular grains varies between 10 and 20 μm in diameter.

Biotite is present in 66 cm, 101 cm, 145 cm, 164-196 cm, 225 cm, 245 cm, 265 cm, 301 cm, 311 cm, 370-402 cm, 424-436 cm, 456-462,5 cm depths. The grain size of biotite is between 10 and 20 μm. The grains are angular, and occur in minor amounts. Plagioclase is found at 71 cm, 145 cm and 301 cm depths as 30 μm angular grains. Opaque minerals occur in minor amounts along the core. Their grain size is about 10 μm on average and they are of angular shape.

470-483 cm interval at the base of the core in Unit 3 contains gypsum (Fig.3.6f), which occurs as euhedral hexagonal grains with diameters of 0.2 mm to 0.9 mm. The gypsum may have formed by oxidation of pyrite in the sediment, providing SO_4^{-2} ions which could then combine with porewater Ca^{+2} to form the gypsum (Marr, 1959; Siesser, 1978). Alternatively the gypsum might have formed on a coastal plain by evaporation of seawater under relatively arid conditions (Wardlaw and Schwerdtner, 1966). Sulfur isotope analysis of the gypsum would be useful to decide on the origin of the gysum crystal in core C-17.

3.3. Paleontology

3.3.1. Core C1

Core C 1 was studied for molluscs and foraminifer populations. The core is highly rich in Mediterranean marine molluscs, echinoderms and fish bones. Distribution of fossil content is given in Table.3.1. The core also contains coccolith tests of *Scyphosphaera sp.*, and to a lesser extent *Braarudosphaera bigelowi* (Grand and Braarud). *Braarudosphaera bigelowi* is observed only in the first 4 cm. However, *Scyphosphaera sp.* is found from the top of core to 76 cm in this core.

From top of the core to 55 cm interval includes *Ostrea edulis* (Fig.3.1i), *Serpula sp.*, *Corals* (Fig.3.1h), *Turritella sp.* (Fig.3.2l), *Dentalium sp.*, *Vermetus sp.* (Fig.3.2k), *Cyathara (M.) alteunata* (Montagu) (Fig.3.2m), brachiopoda, *Nucula (N.) nucleus* (Fig.3.1g), *Chlamys (F.) glabra* (Linne) (Fig.3.1f), *Gibbula maga* (Fig.3.2o), *Patella sp.* (Fig.3.1b), *Mactra subtruncata* (Fig.3.1d), *Corbula (V.) gibba* (Olivi), some fragments of *Mytilus edulis* and crabs. Corals show high salinity environments. Its salinity is higher than *Ostrea edulis*. *O. Edulis* in this level is very abundant.

The interval between 53 cm and 113 cm contains *Vermetus sp., Anadara sp.* (Fig.3.2j), *Nucula nucleus, Cardium sp., Bittium sp.* (Fig.3.2n), *Dentalium sp., Corbula gibba, Serpula sp., Mactra subtruncata, Turritella sp., Cardium cf. Exiquum* (Fig.3.1e), *Scrobicularia sp.* (Fig.3.1c), *Mytilus sp.* fragments, *Cyathara alteunata, Patella sp.*, fragments of *Ostrea edulis, Nassarius sp., Hiatella sp.* (Fig.3.1a), *Gibbula maga*, brachiopoda fragments and echinoids spine. *Vermetus sp.* in this intervals is very abundant. *Anadara sp.* is found in 53,5-56 cm, 73-76 cm, 83-86 cm, 93-96 cm depths. After this level, *M. Edulis* increases towards bottom of core, and mud matrix also increase toward the base of the core. A large number of studies show that the respiration rate of *M. Edulis* is constant when measured in field-ambient salinities ranging from 5-30 ‰ (Remane and Schlreper, 1971). 122-126 cm depth interval contains only *Mytilus edulis* shells. This interval is a truly Mydian Bank. 133 and 136 cm depth interval is composed of *Mytilus edulis, Nassarius reticulatus and Scrobicularia sp.* The interval between 143-147 cm includes *Ostrea edulis, M. Edulis, Vermetus sp.* This level is represented by Oyster-Mydian Bank, which includes many *Ostrea edulis* shells.

Table 3.1. Marine molluscs content in the core C 1. The sample weight used is 60 gr.

Depths (cm)	2	12	21,5	31,5	41,5	51,5	54,7	64,5	74,5	84,5	94,5	104,5	115	124	134,5	145
Genus and Species																
Anadara sp.							●	●	●	●	●	●				
Bittium sp.							●		●		●	●				
Brachiopoda sp.			●	●	●		●									
Cardium sp.							●	●	●							
Cardium cf. exiquum								●		●						
Chlamys glabra				●												
Corbula gibba					●	●	●	●	●	●		●				
Cyathara alteunata			●		●				●							
Dentalium sp.				●			●									
Gibbula maga				●	●				●	●		●				
Hiatella sp.								●		●						
Mactra subtruncata					●			●		●						
Mytilus edulis			●	●	●	●		●	●	●	●	●	●	●	●	●
Nassarius reticulatus															●	
Nassarius sp.											●					
Nucula nucleus				●	●		●		●							●
Ostrea edulis	●	●	●	●	●	●					●	●				●
Patella sp.				●				●	●		●	●	●			
Scrobicularia sp.										●	●	●	●		●	
Serpula sp.	●	●		●	●	●		●								
Turritella sp.		●		●	●			●								
Vermetus sp.			●		●	●	●	●	●	●	●	●				●

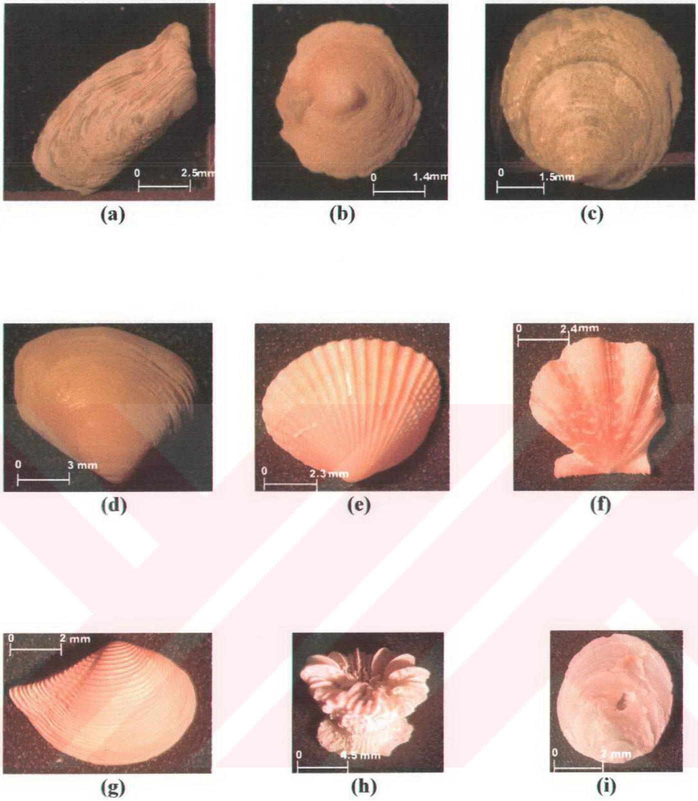
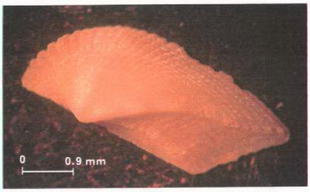
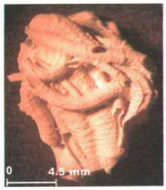


Fig.3.1. Photo of molluscs in core C 1,

(a) *Hiatella sp.,* 63-66 cm
(b) *Patella sp.,* 63-66 cm
(c) *Scrobicalaria sp.,* 133-136 cm
(d) *Mactra subtruncata,*40-43 cm
(e) *Cardium exiquum,* 83-86 cm
(f) *Chlamys* (F.) *glabra* (Linne), 30-33 cm
(g) *Nucula* (N.) *nucleus* (Linne), 30-33 cm
(h) *Coral*, 6 mm, 20-23 cm
(İ) *Ostrea edulis,* 20-23 cm



(j)

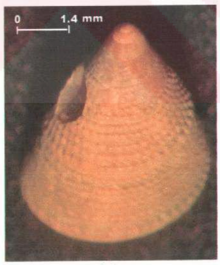


(k)

(l)

(m)

(n)



(o)

Fig.3.2. Photo of other molluscs species in core C 1.

(j) *Anadara sp.*, 63 - 66 cm
(k) *Vermetus sp.*, 53,5 -56 cm
(l) *Turritella sp.*, 40 - 43 cm
(m)*Cyathara* (M.) *alteunata* (Montagu)., 40- 43 cm
(n) *Bittium sp.,* 40 - 43 cm
(o) *Gibbula maga.*, 40 - 43 cm

Foraminiferal assemblages of core C1 include both planktic and benthic species. Among them 41 genus are recognized. Foraminifers are listed in Table.3.2. At the same time, distribution of pelagic and benthic foraminiferal abundances and some abundant forams (*Brizalina spathulata, Ammonia parkinsonia, Cassidulina carinata, Elphidium crispum, Globoratalia sp., Bulimina marginata*) in this core are shown in Fig.3.3. and in Fig.3.4. Foraminifers in the lower part of the core are represented by marine-brackish water fauna of family of Textulariidae, Spiroloculinidae, Globigerinidae, Haureninae, Lageniidae, Ellipsolagenidae, Cassidulinidae, Siphogenerinoididae, Elphidiidae, Rotaliidae, Buliminidae, Bolivinidae, Uvigerinidae, Marginulininae, Asterigerinatidae, Miliolinellinae, Fursenkoinidae, Planulinidae, Cibicididae, Sigmoilinitinae, Acervulinidae and Stainforthiidae species.

The first 4 cm of core contains planktic and benthic foraminifers, such as *Globigerinoides sp.* (Fig.3.3a), *Globoratalia sp.* (Fig.3.3b), *Bulimina marginata* (d'orbigny, 1826) (Fig.3.3v), *Brizalina spathulata* (Williamson, 1858) (Fig.3.3t), *Brizalina alata* (Sequenza, 1862), *Cassidulina carinata* (Silvestri, 1896) (Fig.3.3g), *Pyrgo anomola* (Schlumberger, 1891) (Fig.3.3n), *Quinqueloculina seminula* (Linne, 1758) (Fig.3.3q), *Spiroloculina excavata* (d'orbigny, 1846) (Fig.3.3i), *Amphicoryna scalaris* (Batsch, 1971) (Fig.3.3s), *Ammonia beccarii* (Linne, 1758) (Fig.3.3e). From this level to bottom of the core foraminiferal assemblage consists of *Globigerinoides sp., Globoratalia sp., Brizalina spathulata* (Williamson, 1858), *Brizalina alata* (Sequenza, 1862), *Cassidulina carinata* (Silvestri, 1896), *Pyrgo anomola* (Schlumberger, 1891), *Quinqueloculina seminula* (Linne, 1758), *Spiroloculina excavata* (d'orbigny, 1846), *Amphicoryna scalaris* (Batsch, 1971), *Asterigerinata mamilla* (Williamson, 1858) (Fig.3.3d), *Biloculinella deprassa* (Wiesner, 1923), *Bulimina elongata* (d'orbigny, 1846) (Fig.3.3u) *Bulimina marginata* (d'orbigny, 1826), *Cibicides sp.* (Fig.3.3c), *Dentalina sp., Favulina hexagona* (Montagu, 1803), *Favulina sp., Fursenkonia complanata, Hyalina baltica* (Schroeter, 1783) (Fig.3.3h), *Lagena sp., Lobatula lobatula* (Walker & Jockop, 1798) (Fig.3.3j), *Orbulina universa, Planorbulina mediterranenesis* (d'orbigny, 1826) (Fig.3.3k), *Pyrgo sp., Rectuvigerina phlegri* (Le Calvez, 1959) (Fig.3.3w), *Sigmoilina sigmoidea* (Brady, 1884) (Fig.3.3l), *Sphaerogypsina globula* (Reuss, 1848), *Spiroloculina sp., Stainforthia concava* (Höglund, 1947), *Uvigerina mediterranea* (Hofker, 1932) (Fig.3.3r),

Table.3.2. Numbers of planktic and benthic foraminiferal species in 60 g sample in core C1.

Depths in centimetres	2	11,5	21,5	31,5	41,5	51,5	54,7	64,5	74,5	84,5	94,5	104,5	115	124	134,5	145
Genus and Species																
Ammonia beccarii	1	9	3	7	2	15	9	5		3	2	5	1			
Ammonia parkinsonia					9				2	8	9	138	129	82	44	2
Ammonia sp.			6	5	29	7	12									
Amphicoryna scalaris	1	3	3		16		1									
Asterigerinata mamilla				3			1	2	7	182	164	211	5		1	1
Biloculinella deprassa												2				
Brizalina alata	6	1	1		6											
Brizalina spathulata	141	203	307	799	1419	587	562	123	19	15	1	1	3	3	6	11
Bulimina elongata					1		2									
Bulimina marginata	12	5	4	16	75	39	93	28	6	6	2	8	1		1	1
Cibicides sp.			3				6				1	2				
Cassidulina carinata	15	27	82	299	301	133	76	4	20	151	280	582	8	4	3	5
Dentalina sp.					1											
Elphidium crispum					3	1	21	47	25	44	41	115	62	43	30	4
Elphidium sp.												9				
Favulina hexagona						1	1					1				
Favulina sp.									1		1					
Fursenkonia complanata					1											
Globigerinoides sp.	16		4	3	4	1										
Globoratalia sp.	92	36	27	285	417	135	148	113	7	4	2	4	4	1	2	4
Hyalina baltica		3	3	5	21	6	14	5		4	2	1		1	1	
Lagena sp.							1									
Lobatula lobatula			4	3	3	3	2	2	3	34	14	160		1	1	
Orbulina universa		1		4	3	1	1		1							
Planorbulina mediterranensis		1		2	2				2	49	31	51				
Pyrgo anomola	5			15	6	2						4				
Pyrgo sp.		1														
Quinqueloculina seminula	2	4		6	5	2	2	1	2	8	5	14				
Rectuvigerina phlegri			1		7	3	1									
Sigmoilina sigmoidea		1														
Sphaerogypsina globula												1	1			
Spiroloculina excavata	1	3	9	13	9	3	6	2	2	5	5	6				1
Spiroloculina sp.		1	3													
Stainforthia concava				2												
Textularia agglutinans				1		1						5				
Textularia bocki							1	5	23	2		5				
Textularia conica				3	3	2	5		1	3		11	1			
Textularia sp.			2				1		6	23	12					
Textularia truncata				1			3	4	10	36	7	6				
Uvigerina mediterranensis			1	1		1	1									
Planktonic foraminifera	108	37	31	292	425	137	149	113	8	4	2	4	4	1	2	4
Benthic foraminifera	187	262	429	1186	1920	806	821	228	129	573	577	1339	211	134	88	24

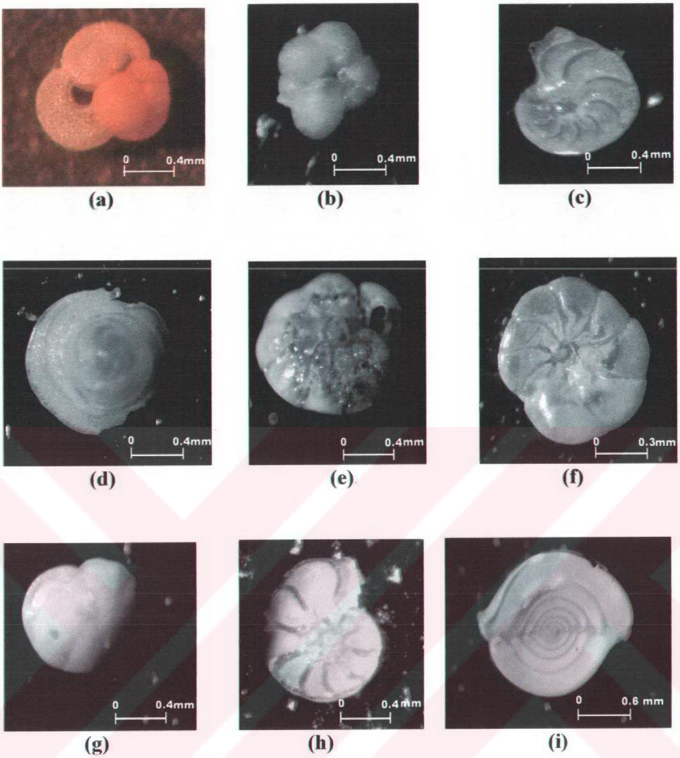


Fig.3.3. Foram species in core C 1.

(a) *Globigerinoides sp.* , 40-43 cm
(b) *Globoratalia sp.*, 40-43 cm
(c) *Cibides sp.*, 40-43 cm
(d) *Asterigerinata mamilla* (Williamson, 1858), 83-86 cm
(e) *Ammonia beccarii* (Linne , 1758), 40-43 cm
(f) *Ammonia parkinsonia* (d'orbigny, 1839), 133-136 cm
(g) *Cassidulina carinata* (Silvestri, 1896), 40-43 cm
(h) *Hyalina baltica* (Schroeter, 1783), 40-43 cm
(i) *Spiroloculina excavata* (d'orbigny, 1846), 40-43 cm

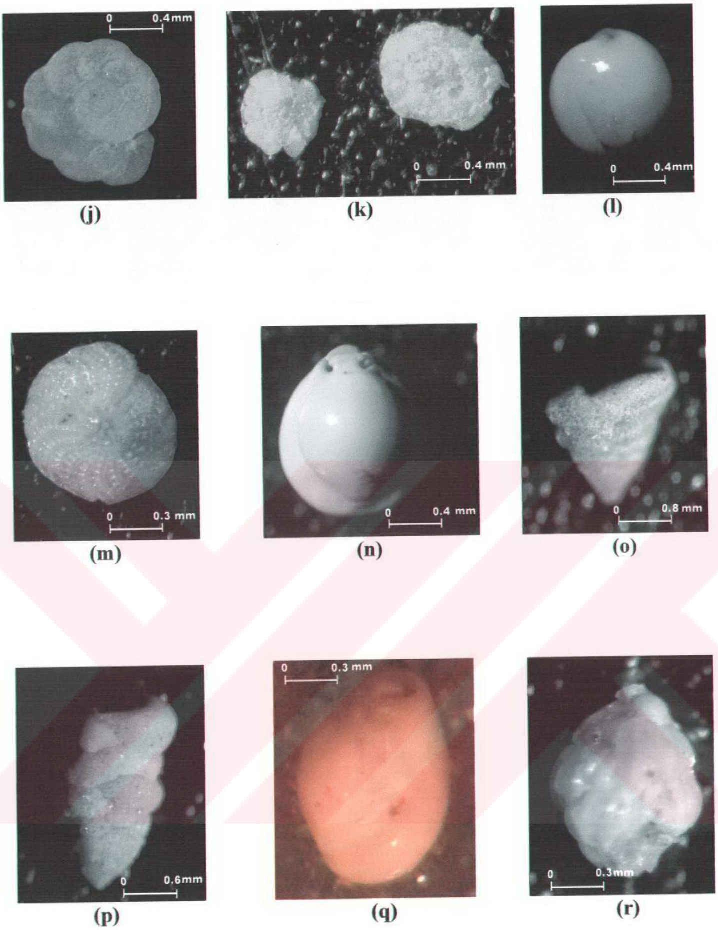


Fig.3.3. Foram species in core C 1.(continued)

(j) *Lobatula lobatula* (Walker & Jockop, 1798), 73-76 cm
(k) *Planorbulina mediterranenesis* (d'orbigny, 1826), 93 - 96 cm
(l) *Sigmoilina sigmoidea* (Brady, 1884), 40-43 cm
(m) *Elphidium crispum* (Linne , 1758), 73-76 cm
(n) *Pyrgo anomola* (Schlumberger, 1891), 40-43 cm
(o) *Textularia conica* (d'orbigny, 1839), 73-76 cm
(p) *Textularia bocki* (Höglund, 1947), 53,5-56 cm
(q) *Quinqueloculina seminula* (Linne , 1758), 40-43 cm
(r) *Uvigerina mediterranea* (Hofker,1932), 20-23 cm

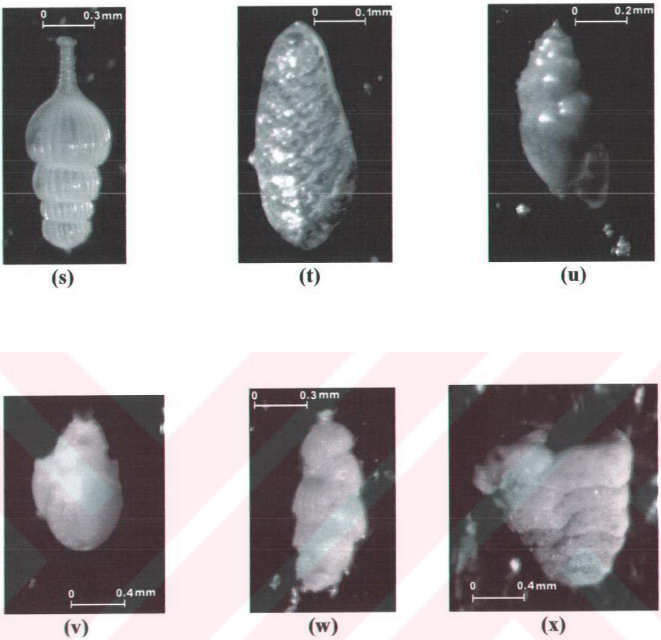


Fig.3.3. Foram species in core C 1.(continued)

(r) *Amphicoryna scalaris* (Batsch, 1971), 40-43 cm
(s) *Brizalina spathulata* (Williamson, 1858), 40-43 cm
(t) *Bulimina elongata* (d'orbigny, 1846), 40 - 43 cm
(u) *Bulimina marginata* (d'orbigny, 1826), 40-43 cm
(v) *Rectuvigerina phlegri* (Le Calvez, 1959), 40 -43 cm
(w) *Textularia truncata* (Höglund, 1947), 73-76 cm

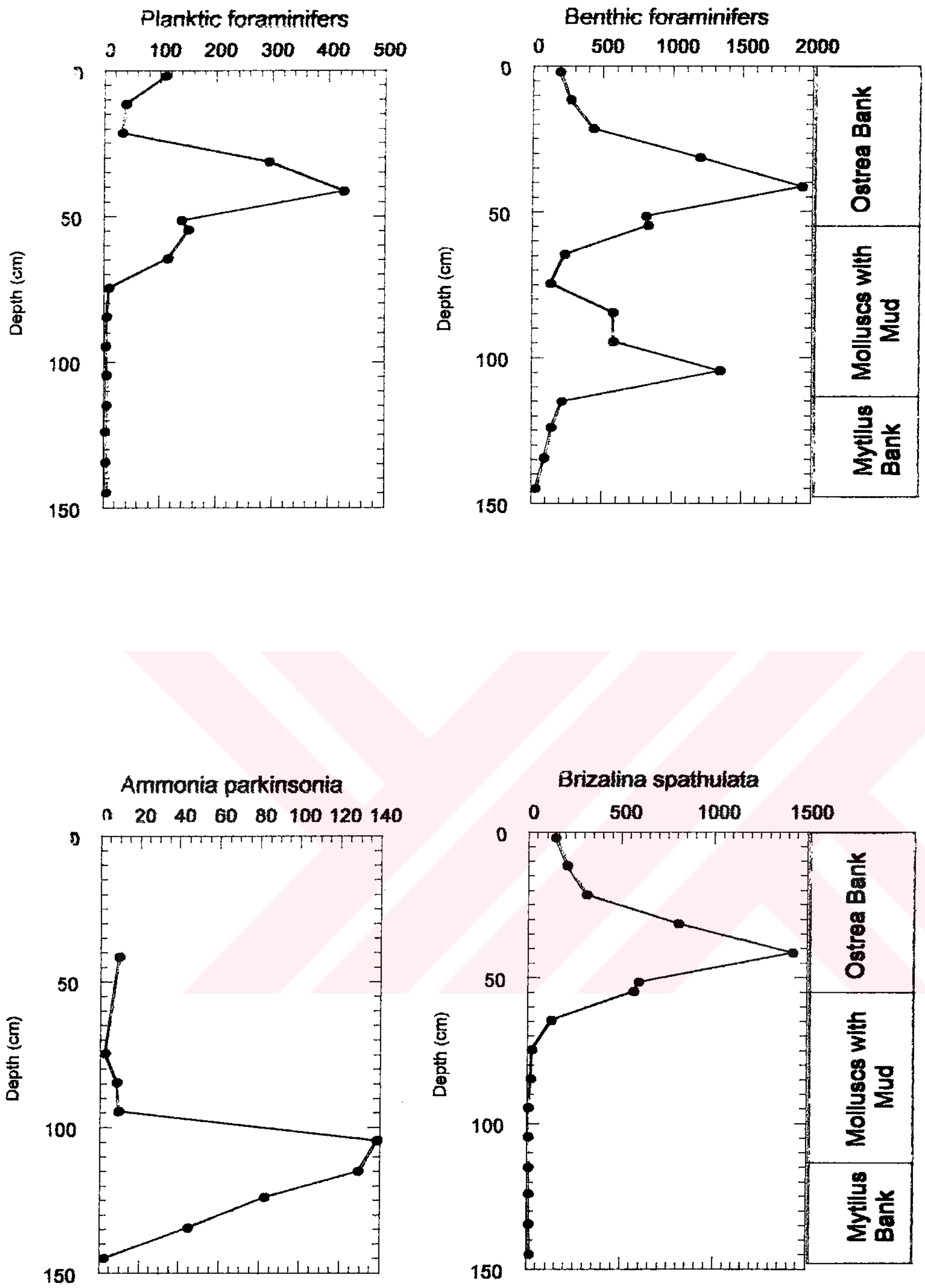


Fig.3.4. **Distribution of total planktic and benthic foraminifers and some abundant benthic foraminifers in 60 gram samples in core C1.**

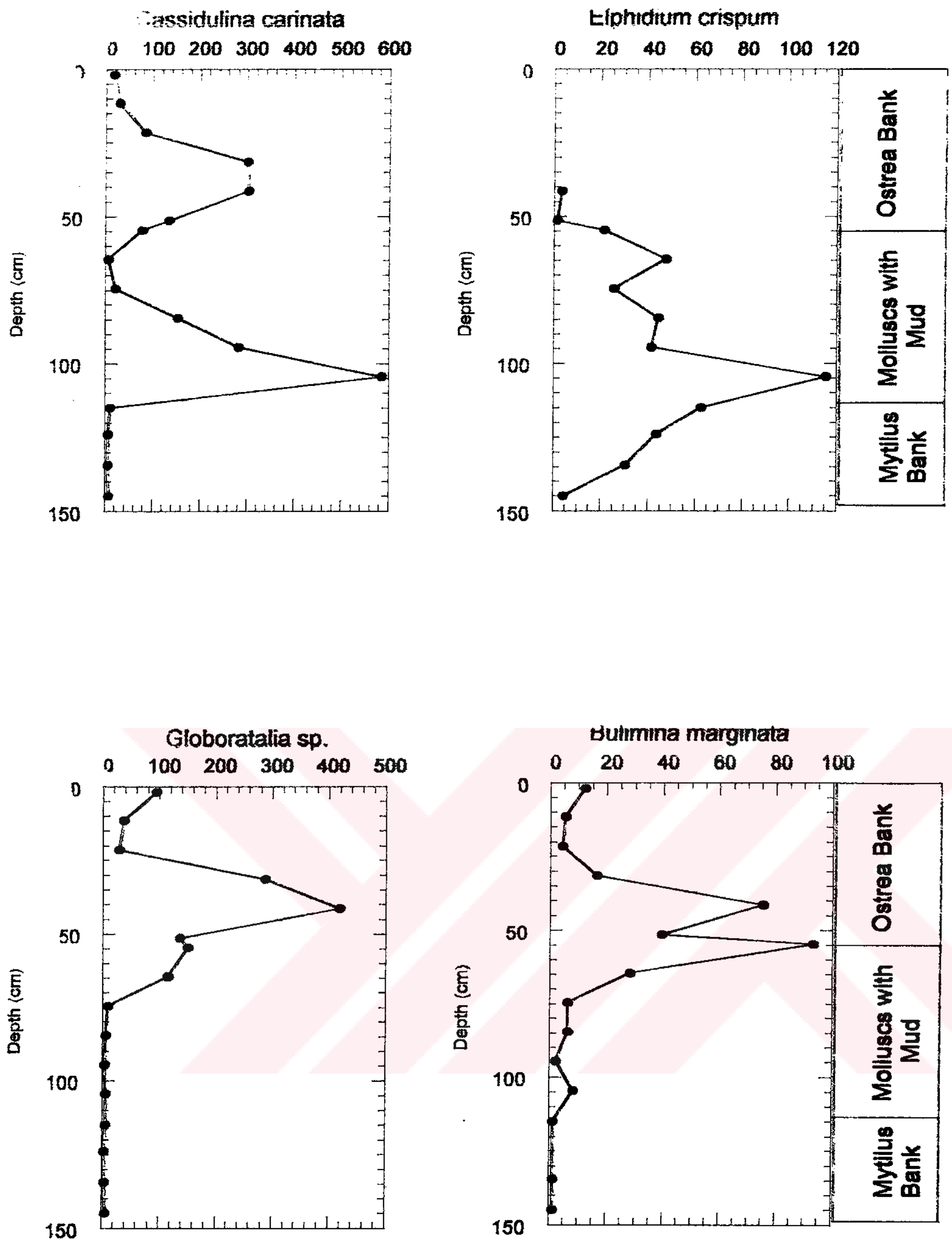


Fig.3.5. Some abundant foraminifer species in 60 gram samples in core C 1.

Textularia agglutinans (d'orbigny, 1839), *Textularia bocki* (Höglund, 1947) (Fig.3.3p), *Textularia conica* (d'orbigny, 1839) (Fig.3.3o), *Textularia sp., Textularia truncata* (Höglund, 1947) (Fig.3.3x), *Ammonia beccarii* (Linne, 1758), *Ammonia parkinsonia* (d'orbigny, 1839) (Fig.3.3f), *Ammonia sp., Elphidium crispum* (Linne, 1758) (Fig.3.3m), *Elphidium sp.*

Brizalina spathulata (Williamson, 1858) is present in all levels, but it is most abundant between 10 cm and 66 cm. Below this level, number of *Brizalina spathulata* decreases. *Bulimina elongata* is rarely abundant. It is only found in 41,5 cm and 54,7 cm depths. *Bulimina marginata* is common in the upper and the middle part of the core.

The genera *Bulimina* and *Brizalina* are characteristic of fully marine conditions and currently extremely rare within the modern Black Sea (Yanko and Troitskaja, 1987). *Cibicides sp.* is present in 31,5 cm, 54,7 cm, 94,5 cm and 104,5 cm depths. *Fursenkonia complanata* is only found in 41,5 cm depth. *Cassidulina carinata* is common the upper part and between 84,5-104,5 cm depths. *Cassidulina carinata* display the behaviour of 'pioneering' species which can initially colonise a barren substrate in large numbers.

The initial recolonization is followed by increase in *Brizalina* and *Bulimina* in 74,5 cm depth. The assemblage recovered from upper level and middle level of the core is dominated by *Brizalina spp., Bulimina spp., Cassidulina carinata*, indicating that marine conditions were rapidly established. *Hyalina baltica* is common in middle part of the core.

This species lives below 70 m depth in the Gulf of Naples (Sgarrella and Moncharmont Zei, 1993), and its appearance in the Marmara Sea reflects the deepening of water over the Dardanelles sill as sea level rose further during the later Holocene. It also indicates high flux of organic matter to the sediments. *Globigerinoides sp., Brizalina spathulata, Cassidulina carinata and Hyalina baltica* characterizes suboxic to dysoxic bottom water conditions.

Most of benthic foraminifers in the core are diagnostic of suboxic-dysoxic bottom water conditions and high Corg flux (Jorissen et al., 1995; Schmiedl et al., 2000). *Dentalina sp.* is found only 41,5 cm depth. Above 41,5 cm, *Elphidium crispum and Ammonia parkinsonia* are not observed. Foraminifera in the lower part of the core are abundant, and highly dominated by *Ammonia spp.*, *Textularia spp.*, and *Elphidium* spp.

This impoverished assemblage (^{14}C dated at 11655 yr BP at 145 cm) is interpreted as reflecting shallow-water and low salinity conditions. On the modern Black Sea shelf, foraminiferal fauna with > 80% *Ammonia* characterise very shallow deltaic or lagoonal environments (water depths of 2-3 m) with salinities below ~ 4- 5 ‰ (Yanko and Troitskaja, 1987; Yanko, 1990).

Planktic foraminifer is abundant in upper part of the core, but, decreases from 74,5 cm to bottom of the core (Fig.3.4). From 74,5 cm to 21,5 cm abundance of planktic foraminifer reflects increasing salinity and probably a decrease in the Black Sea out-flow. Benthic foraminiferal assemblages in core C 1 reflect a history of increasing water depth through time, as Holocene sea level rose and became increasingly more marine.

Benthic foraminifers are dominated in the upper and lower levels, giving two peaks seperated by a low-abundance interval at 115-145 cm below sea floor. The increase in abundance of both the benthic and planktic foraminifers toward the top of the core shows gradual effect of the Mediterranean transgression in the Marmara Sea starting at ~ 12 kyr.

Origin of most of benthic foraminifers in core C-1 is Mediterranean Sea. Some brackish benthic foraminifera belonging to Elphidiidae and Rotaliidae families (e.g. *Elphidium crispum, Ammonia parkinsonia and Ammonia beccarii*) in the lower part of the core are brackish water foraminifers that live in low salinity conditions at the begining of the marine transgression.

3.3.2. Core C17

C 17 was studied for molluscs and foraminiferal abundances. Sediments of the core can be subdivided into an upper marine (Unit 1), a middle lacustrine (Unit 2) and a lower brackish-marine (Unit 3) units (Fig.2.1). The Unit 1/Unit 2 boundary is based on the first appearance of the Mediterranean molluscan and foraminiferal marine fauna in this core. It also observed coccolith *Scyphosphaera sp.* in the upper 62 cm marking the influence of marine waters in the Marmara Sea.

Mediterranean marine molluscs and foraminifers are rich from top of the core to 65 cm depth (Unit 1). Molluscs are listed in Table.3.3. Marine molluscs fauna of Unit 1 contains *Cardium sp.*, pelecypoda fragments, *Corbula gibba (Olivi)* (Fig.3.6e), *Scrobicularia sp.*, *Nucula (N.) nucleus* (Linne), *Venus sp.* (Fig.3.6a), *Mactra sp.*, *Turritella sp.*, *Serpula sp.*, *Cardita sp.* (Fig.3.6d), *Gibbula maga*, *patella sp.*, *N. nucleus* (Linne). Between 50 and 52 cm depths includes marine and freswater molluscs. This are *Dreissena rostriformis distincta* (Fig.3.6b) and *Corbula gibba (Olivi)*, *Serpula sp.*

Foraminiferal assemblages of in the top 62 cm of core C 17 include both planktic and benthic foraminifers. Among them 33 genus are recognized. Foraminifers are listed in Table.3.4. At the same time, distribution of pelagic and benthic foraminiferal abundances and some abundant foraminifer assemblages (*Brizalina spathulata*, *Globoratalia sp.*, *Hyalina baltica*, *Bulimina marginata*, *Cassidulina carinata*, *Brizalina alata*) are shown in Fig.3.7. and Fig3.8. Foraminifers are represented by marine-brackish water fauna of containing family of Textulariidae, Spiroloculinidae, Globigerinidae, Haureninae, Lageniidae, Buliminidae, Bolivinidae, Uvigerinidae, Marginulininae, Asterigerinatidae, Planulinidae, Cibicididae, Acervulinidae, Siphotextulariinae.

Table 3.3. Marine and Freshwater molluscs in 15 gram samples in core C 17.

Genus and species / Depths (cm)	*Bittium sp.*	*Cardium sp.*	*Cardita sp.*	*Corbula gibba*	*Dreissena rostriformis*	*Gibbula maga*	*Mactra sp.*	*Micromelaina sp.*	*Monodacna sp.*	*Nucula nucleus*	*Patella sp.*	*Pelecypoda spp.*	*Serpula sp.*	*Scrobicularia sp*	*Turritella sp.*	*Venus sp.*
1		●										●				
7				●								●		●		
15				●								●		●		
22				●										●		
29		●		●			●			●						●
35		●		●									●		●	
39			●	●									●		●	
44			●	●		●				●					●	
51				●	●								●			
57				●								●		●	●	
61				●	●						●				●	
66					●											
71					●			●								
79					●			●	●							
87					●			●								
93					●			●								
101	●				●			●								
110					●			●								
116					●			●								
127					●											
135					●			●								
145					●	●										
155	●	●			●											
165					●			●								
175		●			●			●								
185					●											
195					●											
205					●											
215					●			●								
225					●											
235	●				●			●				●				
245					●			●								
255					●			●								
265					●			●								
275					●			●								
285					●			●								
291					●			●								
301					●											
311					●											
321					●			●								
331		●			●			●								
341					●											
351					●											
361					●											
371					●			●								
381					●											
391					●											
401					●											
413,5					●											
425					●											
435					●											
445					●			●								
457					●											
462,5					●											
470,5				●	●											
477					●											
483					●											

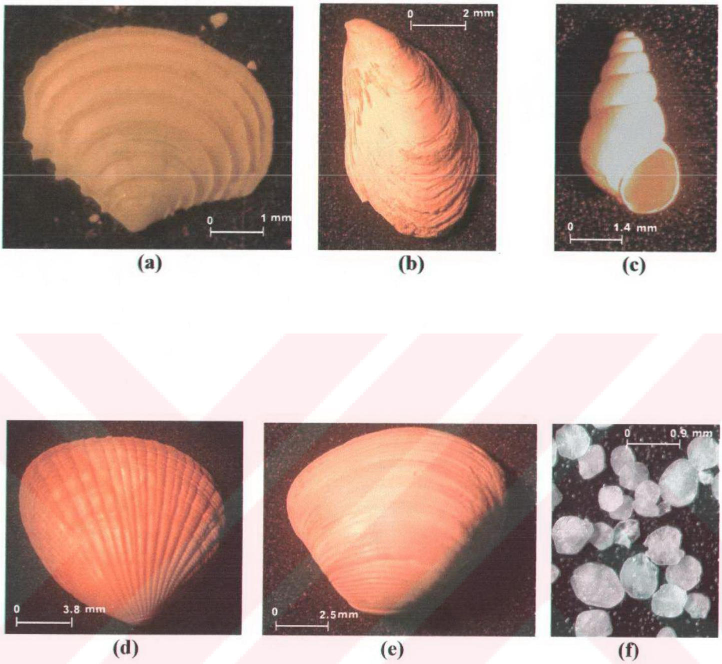


Fig.3.6. Photo of marine and lacustrine molluscs and gypsum grains in core C 17.

(a) *Venus sp.,* 28-30 cm
(b) *Dreissena rostriformis,* 144-146 cm
(c) *Micromelania sp.,* 370-372 cm
(d) *Cardita sp.,* 38-40 cm
(e) *Corbula gibba* (Olivi), 43-45 cm
(f) Gypsum grains, 476-478 cm

Table3.4. Numbers of planktic and benthic foraminiferal species in 15 gram samples in core C17.

Genus and species / Depths (cm)	*Ammonia beccarii*	*Ammonia sp.*	*Amphicoryna scalaris*	*Asterigerinata mamilla*	*Brizalina alata*	*Brizalina spathulata*	*Bulimina elongata*	*Bulimina marginata*	*Cibicides sp.*	*Cassidulina carinata*	*Dentalina sp.*	*Elphidium crispum*	*Elphidium sp.*	*Favulina hexagona*	*Globigerinoides sp.*	*Globoratalia sp.*	*Hyalina baltica*	*Lagena sp.*	*Lobatula lobatula*	*Orbulina universa*	*Planorbulina mediterranensis*	*Pyrgo anomola*	*Pyrgo sp.*	*Quinqueloculina seminula*	*Rectuvigerina phlegri*	*Siphotextularia concava*	*Sphaerogypsina globula*	*Spiroloculina excavata*	*Textularia bocki*	*Textularia conica*	*Textularia sp*	*Textularia truncata*	*Uvigerina mediterranensis*
1	3		12	1	8	944	3	119	18	144	2	3		1	8	529	47		1	1	2			4	1		2	7	4				2
7			6	1	6	614	8	57	12	54		1		2	4	431	24		2		2	1			2			5	2	1			
15	2		5		12	1003		28	9	150	1	3		2	8	484	14				3			1	7			6			3		
22			4		3	748		28	3	75					1	400	5		5	1	2			1	3	1		4	1	1			1
29			2		6	474		7	3	40	2		1		5	211	11		2		1				2			1	1		1		
35	3		6	3	88	894	1	60	11	92		1	3		9	348	20		4		1			5	4			5	2		1	1	1
39	4		6	2	3	890		36	4	157	1		5	2	2	261	18		2		1			2	1			3	1			1	1
44	1	1	6		2	394	8	17	6	194		5	1		1	163	7		1					1				6	3	1			2
51			2	2	5	158	2	8	1	114		10	1	2		32	3		1									1	1				
57	3		8	3		644	4	31	5	157		2		1	2	257	16		2	3			1		6			4	4	1		1	1
61				2		91		4	1	32		3	2			39	2	1	1										1	1			
66		1				36		2	1	21						12	3													2			
71						9		1		2						5																	
79										4						2	1				1							1					
87		4				30		1		14		1				5																	
93						4				1																							
101						7				1		1	1																				
110	1					6						1					1																
116						5				1		1																					
127		1																															
135						4																											
145		1								2		2																					
155						1				1																							
165		2				1																											
175						2																											
185		1				1																											
195						1		1																									
205										1																							
215																1																	

Table3.4. (Continued).

Genus and species / Depths (cm)	*Ammonia beccarii*	*Ammonia sp.*	*Amphicoryna scalaris*	*Asterigerinata mamilla*	*Brizalina alata*	*Brizalina spathulata*	*Bulimina elongata*	*Bulimina marginata*	*Cibicides sp.*	*Cassidulina carinata*	*Dentalina sp.*	*Elphidium crispum*	*Elphidium sp.*	*Favulina hexagona*	*Globigerinoides sp.*	*Globoratalia sp.*	*Hyalina baltica*	*Lagena sp.*	*Lobatula lobatula*	*Orbulina universa*	*Planorbulina mediterranensis*	*Pyrgo anomola*	*Pyrgo sp.*	*Quinqueloculina seminula*	*Rectuvigerina phlegri*	*Siphotextularia concava*	*Sphaerogypsina globula*	*Spiroloculina excavata*	*Textularia bocki*	*Textularia conica*	*Textularia sp*	*Textularia truncata*	*Uvigerina mediterranensis*
225						1										3																	
235						1										2																	
245		1								1						2																	
255		1														1	2																
265		1										1																					
275						1																											
285		1								1																							
291		2											1																				
301																																	
311										1																							
321																																	
331						1				1																							
341		1														1																	
351																																	
361																																	
371																																	
381																																	
391						1																											
401																																	
413,5																																	
425																																	
435																																	
445																																	
457																																	
462,5																																	
470,5						3				1		1																					
477						1				1																							
483						3																											

Foraminiferal assemblages are *Globigerinoides sp., Globoratalia sp., Brizalina spathulata* (Williamson, 1858), *Brizalina alata* (Sequenza, 1862), *Cassidulina carinata* (Silvestri, 1896), *Pyrgo anomola* (Schlumberger, 1891), *Quinqueloculina seminula* (Linne, 1758), *Spiroloculina excavata* (d'orbigny, 1846), *Amphicoryna scalaris* (Batsch, 1971), *Asterigerinata mamilla* (Williamson1858), *Bulimina elongata* (d'orbigny, 1846), *Bulimina marginata* (d'orbigny, 1826), *Cibicides sp., Dentalina sp., Favulina hexagona* (Montagu, 1803), *Hyalina baltica* (Schroeter, 1783), *Lagena sp., Lobatula lobatula* (Walker & Jockop, 1798), *Orbulina universa, Planorbulina mediterranenesis* (d'orbigny, 1826), *Pyrgo sp., Rectuvigerina phlegri* (Le Calvez, 1959), *Sphaerogypsina globula* (Reuss, 1848), *Siphotextularia concava (Karrer, 1868), Uvigerina mediterranea* (Hofker, 1932), *Textularia bocki* (Höglund, 1947), *Textularia conica* (d'orbigny, 1839), *Textularia sp., Textularia truncata* (Höglund, 1947), *Ammonia beccarii* (Linne, 1758), *Ammonia sp., Elphidium crispum* (Linne, 1758), *Elphidium sp.*

Lagena sp. and *Siphotextularia concava* are present only 61 cm and 22 cm depths, respectively. While *Brizalina spathulata* is very abundant upper level of core, from 66 cm, they begins decreasing to lower of core. Planktic foraminifers is common along Unit 1, but after this level they decreases. *Pyrgo anomola* and *Pyrgo sp.* is present only 7 cm and 57 cm depths.

The freshwater molluscs include *Dreissena rostriformis*, *Micromelaina sp.* (Fig.3.6c) in all levels, with few foraminiferal species. They show demi-fresh basin in levels to be abundant. This basin characterizes > 2 < 8 ‰ salinity conditions. *Micromelaina sp.* shows 2-6 ‰ salinity variations. Some marine molluscs are found in some levels of Unit 2. Small juvenile shell of *Bittium sp.* is between 100-102 cm, 154-156 cm, 234-236 cm depths. Small fragments of *Cardium sp.* is present in 174-176 cm and 330-332 cm depths. Planktic foraminifers are rare or absent some levels of Unit 2. They are rare between 215-255 cm depth, and absent from 255 to bottom of the core.

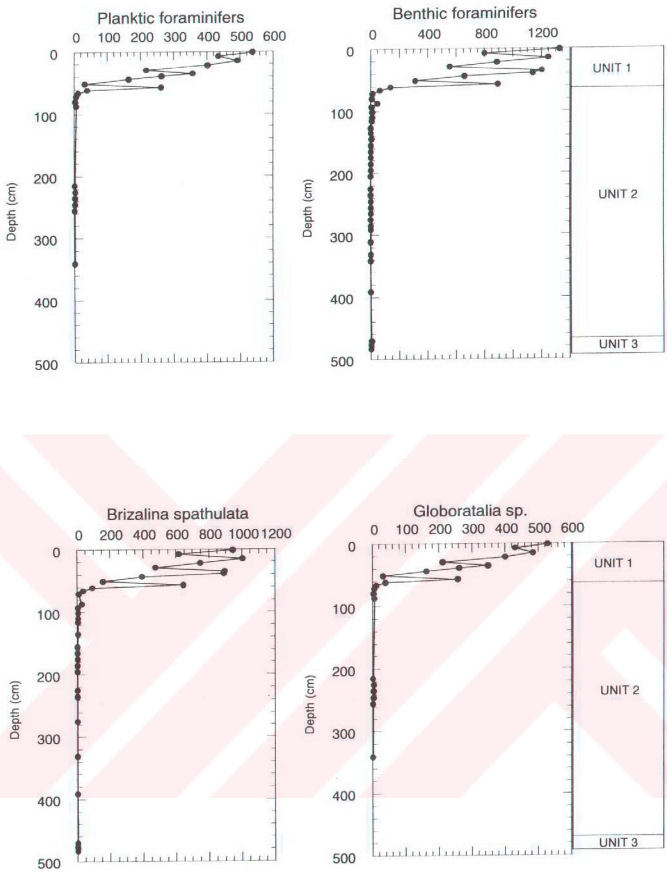


Fig.3.7. Distribution of planktic and benthic foraminifers and some abundant benthic foraminifer species in 15 gram samples in Core C 17.

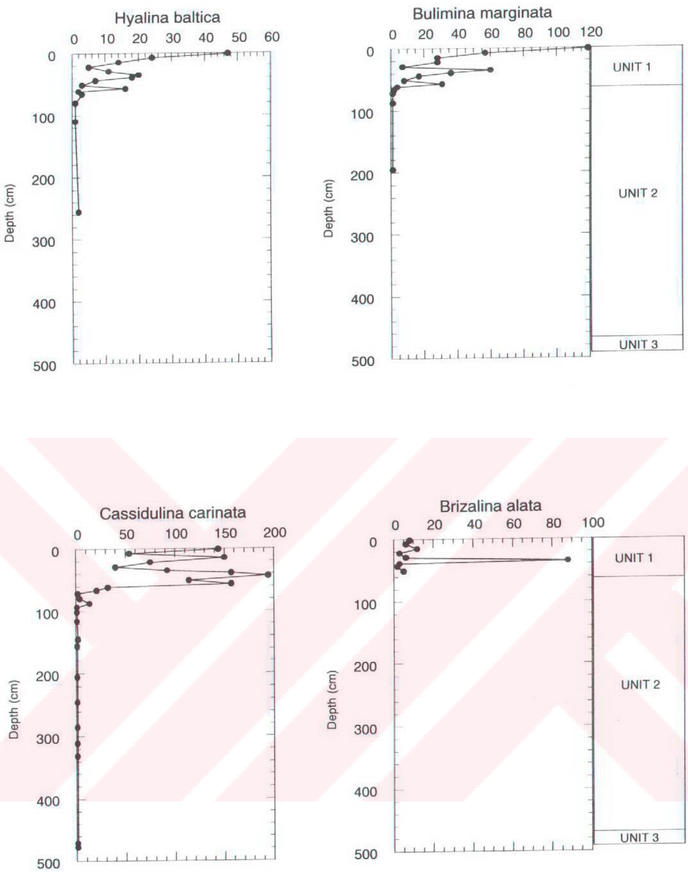


Fig.3.8. Some abundant benthic foraminifer assemblages in 15 gram samples in core C 17.

Benthic foraminifers have less amount in this Unit 2. They are absent from 391 to 462,5 cm depth. However, between 470,5 and 483 cm depth interval (Unit 3) are observed again, having less amount. This benthic foraminifers are *Brizalina spathulata, Cassidulina carinata* and *Elphidium crispum*. This forams may be observed that is related to warming climate during this period. Abundances of *Dreissena rostriformis* decreases to bottom of core.

As indicated by its foraminiferal and molluscan fauna, Unit 1 was deposited in a fully marine environment The foramiferal abundances show fluctuations. These fluctuations may reflect variations in salinity and bottom water oxygen conditions. The faunal content of Unit 2 indicates that the Sea of Marmara was a large freshwater lake during the deposition of this unit before 12.000yr BP. Over most of this time, the lake must have been connected to the Black Sea as indicated by its Neoeuxinian fauna. Unit 3 indicates brackish-marine conditions during this time.

3.4. Stable Isotopes

3.4.1. Oxygen and Carbon Isotope Analyses of Marine Molluscs Shells in Core C 1

Oxygen isotopic data for mollusc shells (fossil or modern) have been previously reported by Urey et al. (1951), Epstein et al. (1953), Epstein and Lowenstom (1953), Clayton and Degens (1959), Keith et al.(1960, 1963) and Andreasson et al.(1996, 2000) and Abell et al.(2000). Investigations of the carbon isotope ratio have been reported by Craig (1953, 1954), Jeffery et al. (1955) and Broecker and Olson (1961) for marine mollusc shells. Revelle and Fairbridge (1957) quote Harmon Craig to the effect that marine invertebrate tests appear to contain a mixture of carbon derived from metabolic activity and carbon derived from sea water bicarbonate. Wilbur (1960) concludes that the metabolic pathway is the more important one in molluscs.

Omitting marine limestones, with $\delta^{13}C$ near zero (Chicago PDB scale), the principal inorganic reservoirs or sources of carbon in order of decreasing $\delta^{13}C$ content are: (1) ocean-water bicarbonate with $\delta^{13}C$ about −2 per mil, (2) atmospheric carbon dioxide with $\delta^{13}C$ about −7 per mil, and (3) fresh-water bicarbonate with widely variable $\delta^{13}C$, generally less than −8 per mil (Keith and Weber, 1963).

Detailed oxygen ($\delta^{18}O$) and carbon isotopes ($\delta^{13}C$) analyses have been performed on marine shells of Holocene age from northen shelf of the Sea of Marmara. Carbon and oxygen isotopic data for marine shells are given in Table 3.5. and shown graphically in Fig.3.9.

The $\delta^{18}O$ values in core C 1 range between −0.20 and +3.10 ‰ (average = +2.14 ‰), respectively (Table 3.5). The $\delta^{18}O$ of the mollusc shells shows an increasing trend from bottom to the top of the core starting with Mediterranean floding of the Marmara Sea at about 12 kyr at the core base (Fig 3.9). Between core top and 84,5 cm interval, the $\delta^{18}O$ values of *Corbula gibba*, *Ostrea edulis* and gastropod shells remain relatively stable 2.6-2.8 ‰ increase with a peak value of 3.1‰ at 21 cm depth.

From 94,5 to bottom of the core, oxygen isotopic data is based on *Mytilus edulis* which can tolerate relatively wide salinity conditions (salinity: 5-30‰). In this interval the $\delta^{18}O$ values of *Mytilus edulis* varies between –0.20 ‰ at the base to +2.30 ‰ at 94.5 cm. This indicate gradually increasing salinity conditions with time.

This conclusion is supported by the change in foraminiferal species and abundances in this interval. Here, the benthic foraminifer abundance, represented mainly by *Ammonia parkinsonia* and *Elphidium crispum*, increase upward from the base of the core. These foraminifer species represent brackish water conditions and their increasing number upward from the base of the core indicate gradually increasing salinity conditions (Fig.3.9).

These benthic foraminifer species are replaced by normal marine salinity foraminifer species (*Brizalina spathulata*, *Cassidulina carinata*, *Bulimina marginata*, *Globoratalia sp.*, *Brizalina spathulata*, *Bulimina marginata* and *Cassidulina carinata*) between 30 and 65 cm interval. In the same interval the pelagic foraminifer abundance also increases and peaks at about 4 kyr BP, all suggesting relatively high surface salinity and suboxic-dysoxic bottom-water conditions.

The $\delta^{13}C$ values of mollusc shells change between –2.40 ‰ and + 2.00 ‰ (average = + 1.7 ‰) (Table 3.5). The $\delta^{13}C$ values of shells show pronounced fluctuations along the core which are in part due to the use of different species in the analysis (Fig.3.9). Between 2 cm and 31,5 cm depths, the $\delta^{13}C$ values of *Ostrea edulis* which are suspension feeders, range between + 1.70 ‰ and + 2.00 ‰.

Below this level, in 41,5 cm and 51,5 cm depths, the $\delta^{13}C$ values decrease. The decrease in $\delta^{13}C$ in this levels can be related interspecies variations. In this interval, corresponding to about 4 kyr BP, $\delta^{13}C$ isotopic data are based on *Corbula gibba*, which gives relatively low $\delta^{13}C$ values (-0.70 to –2.40‰). Then, between 55 cm and 74,5 cm depths, the $\delta^{13}C$ values of *Mactra subtruncata* and *Turritella sp.* increases and the numbers of planktic foraminifer decreases (Fig.3.9).

Table 3.5. Oxygen and carbon isotopic data of marine mollusc shells in core C 1.

Depth(cm)	Samples	$\delta^{13}C$ PDB	$\delta^{18}O$ PDB
2	Ostrea edulis	2.00	2.60
11,5	Ostrea edulis	2.00	2.70
21,5	Ostrea edulis, Gastropod	1.70	2.50
31,5	Ostrea edulis	1.80	3.10
41,5	Corbula gibba	-1.60	2.50
51,5	Corbula gibba	-1.40	2.60
55	Bivalv, Turritella sp	1.20	2.60
64,5	Bivalv,Turritella sp., Mactra subtruncata	1.20	2.60
74,5	Corbula gibba	-0.70	2.60
84,5	Corbula gibba	-2.40	2.60
94,5	Mytilus edulis	0.70	2.00
104,6	Mytilus edulis	0.70	2.30
115	Mytilus edulis	-0.40	2.00
124	Mytilus edulis	0.00	1.70
134,5	Mytilus edulis	-0.90	1.50
145	Mytilus edulis	-1.20	0.70
C-CATCH 155	Mytilus edulis	-1.30	-0.20

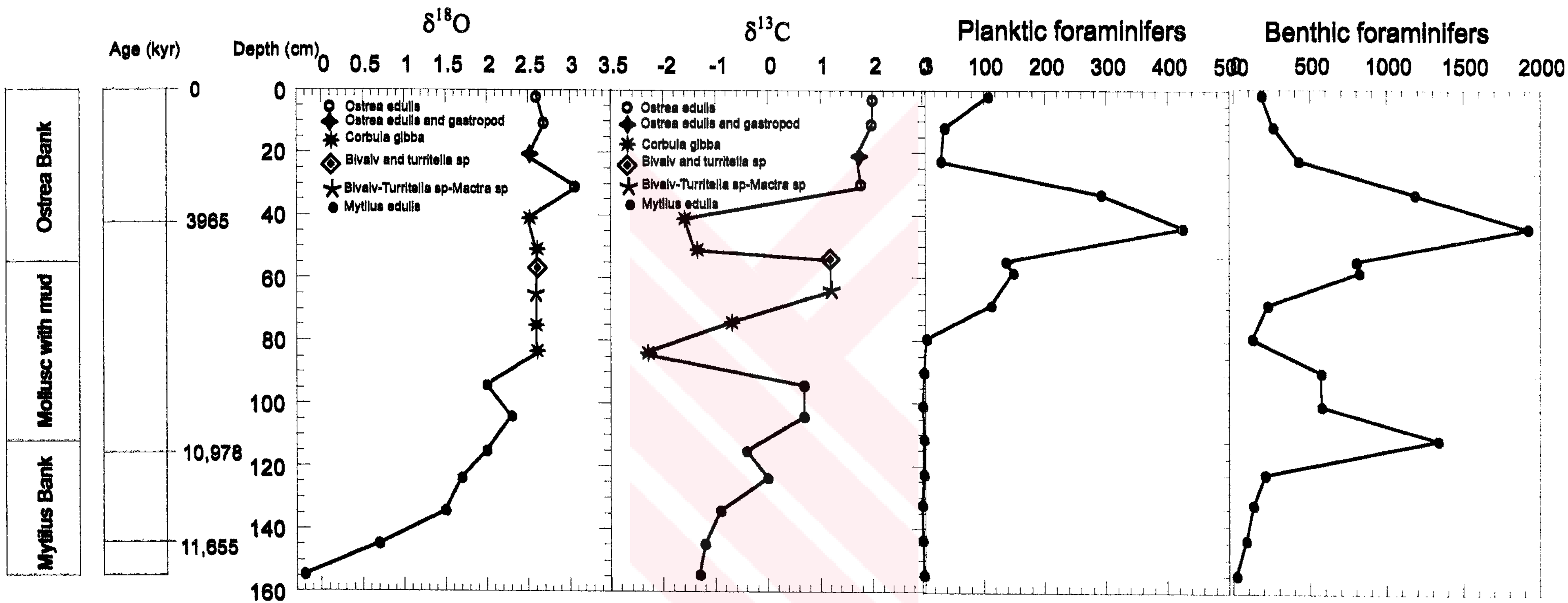


Fig3.9. The $\delta^{18}O$ and $\delta^{13}C$ isotopic data of marine molluscs and distribution of planktic and benthic foraminifres in core C1.

Between 94,5 cm and 155 cm depths, the $\delta^{13}C$ values of Mytilus edulis range between –1.30 ‰ and + 0.70 ‰. Some benthic foraminifers increase in this interval such as *Ammonia parkinsonia*, *Elphidium crispum* and *Cassidulina carinata*. We obtained an age of 10,978 kyr from *Mytilus* shells at the base of the core.

The heavy $\delta^{18}O$ values of mollusc shells in core C1 indicate that the sediments in this core was deposited in a fully marine environment with a significant increase in salinity from about 12 kyr BP to 10 kyr BP. Mediterranean mollusc and foraminiferal distributions support this conclusion. The $\delta^{18}O$ values increase toward to the top of the core. The increase in $\delta^{18}O$ explains flooding of the Marmara Sea by Mediterranean waters, which began at ca 12,000 kyr. The $\delta^{13}C$ curve show pronounced fluctuations along the core. These fluctuations are perhaps mainly related to interspecies variations and vital effects (Berger and Wefer, 1991) (Table 3.5).

3.4.2. Oxygen and Carbon Isotope Analyses of Mollusc Shells in Core C 17

Oxygen and carbon isotopic data for marine and fresh-water mollusc shells in Core C17 are given in Table 3.6. and shown graphically in Fig.3.10. Marine shells (*Pelecypoda* and *Corbula gibba*) analysed show a range of $\delta^{18}O$ values between 1.80 ‰ and 3.50 ‰, in 1-57 cm interval. Below this depth the lacustrine mollusc shells have relatively low $\delta^{18}O$ values in the range $\delta^{18}O$ of -5.80 ‰ to –2.25 ‰ (Fig.3.10). At 62 cm depth of the core the $\delta^{18}O$ values start increasing sharply, where the first appearence of Mediterranean euryhaline molluscs occur in this core. Thus, the observed high $\delta^{18}O$ values in the upper. 62 cm of the core are the result of the Mediterranean transgression. There is a low $\delta^{18}O$ value at 51-52 cm, which suggests a brief return to the lacustrine conditions perhaps during the Younger Dryas.

Moreover, when $\delta^{18}O$ isotope data is compared with distribution of both planktic and benthic foraminifers, it is observed that numbers of planktic and benthic foraminifers decrease to zero below 61 (Fig.3.10). However, between 470,5 cm and 483 cm depths (Unit 3), they appear again, with the benthic foraminifer species *Brizalina spathulata*, *Cassidulina carinata* and *Elphidium crispum*. $\delta^{18}O$ values of Dreissena rostriformis shells in Unit 2 and 3 ranges between –3.70 ‰ and –2.40 ‰.

Table 3.6. Oxygen and Carbon isotopes data from marine and fresh-water mollusc shells in core C 17.

Depth(cm)	Samples	$\delta^{13}C$ PDB	$\delta^{18}O$ PDB
1	Pelecypod	-0.20	2.40
7	Corbula gibba	-1.40	3.10
15	Corbula gibba	-1.90	1.80
22	Corbula gibba	-0.90	3.50
29	Corbula gibba	-2.20	2.80
35	Corbula gibba	-2.00	2.90
39	Corbula gibba	-1.60	3.40
44	Corbula gibba	-1.30	3.30
51	Dreissena rostriformis	2.70	-5.40
57	Corbula gibba	-1.10	3.40
61	Dreissena rostriformis	2.90	-5.60
66	Dreissena rostriformis	2.80	-5.80
71	Dreissena rostriformis	2.20	-5.30
79	Dreissena rostriformis	1.30	-4.70
87	Dreissena rostriformis	2.00	-5.50
93	Dreissena rostriformis	2.10	-5.30
101	Dreissena rostriformis	0.50	-5.00
110	Dreissena rostriformis	1.80	-4.90
116	Dreissena rostriformis	2.30	-5.60
127	Dreissena rostriformis	2.70	-5.60
135	Dreissena rostriformis	1.80	-5.50
145	Dreissena rostriformis	1.90	-5.10
155	Dreissena rostriformis	1.95	-5.10
165	Dreissena rostriformis	2.60	-5.70
175	Dreissena rostriformis	3.20	-5.70
185	Dreissena rostriformis	2.00	-4.50
195	Dreissena rostriformis	2.50	-5.50
205	Dreissena rostriformis	2.40	-5.50
215	Dreissena rostriformis	2.60	-5.40
225	Dreissena rostriformis	1.50	-4.50
235	Dreissena rostriformis	2.80	-5.00
245	Dreissena rostriformis	2.50	-4.80
255	Dreissena rostriformis	2.10	-4.90
265	Dreissena rostriformis	1.70	-4.20
275	Dreissena rostriformis	2.20	-4.80
285	Dreissena rostriformis	2.10	-4.85
291	Dreissena rostriformis	2.00	-4.50
301	Dreissena rostriformis	1.00	-4.60
311	Dreissena rostriformis	1.80	-4.80
321	Dreissena rostriformis	2.10	-4.50
331	Dreissena rostriformis	1.90	-4.10
341	Dreissena rostriformis	1.45	-4.10
351	Dreissena rostriformis	1.00	-4.00
361	Dreissena rostriformis	0.70	-4.10
371	Dreissena rostriformis	0.60	-4.20
381	Dreissena rostriformis	0.55	-4.10
391	Dreissena rostriformis	0.60	-4.10
401	Dreissena rostriformis	1.00	-4.10
413,5	Dreissena rostriformis	0.60	-3.80
425	Dreissena rostriformis	0.40	-3.25
435	Dreissena rostriformis	0.10	-3.10
445	Dreissena rostriformis	0.20	-2.90
457	Dreissena rostriformis	0.40	-2.80
462,5	Dreissena rostriformis	1.10	-2.25
470.5	Dreissena rostriformis	1.00	-3.70
477	Dreissena rostriformis	0.40	-3.10
483	Dreissena rostriformis	0.90	-2.40

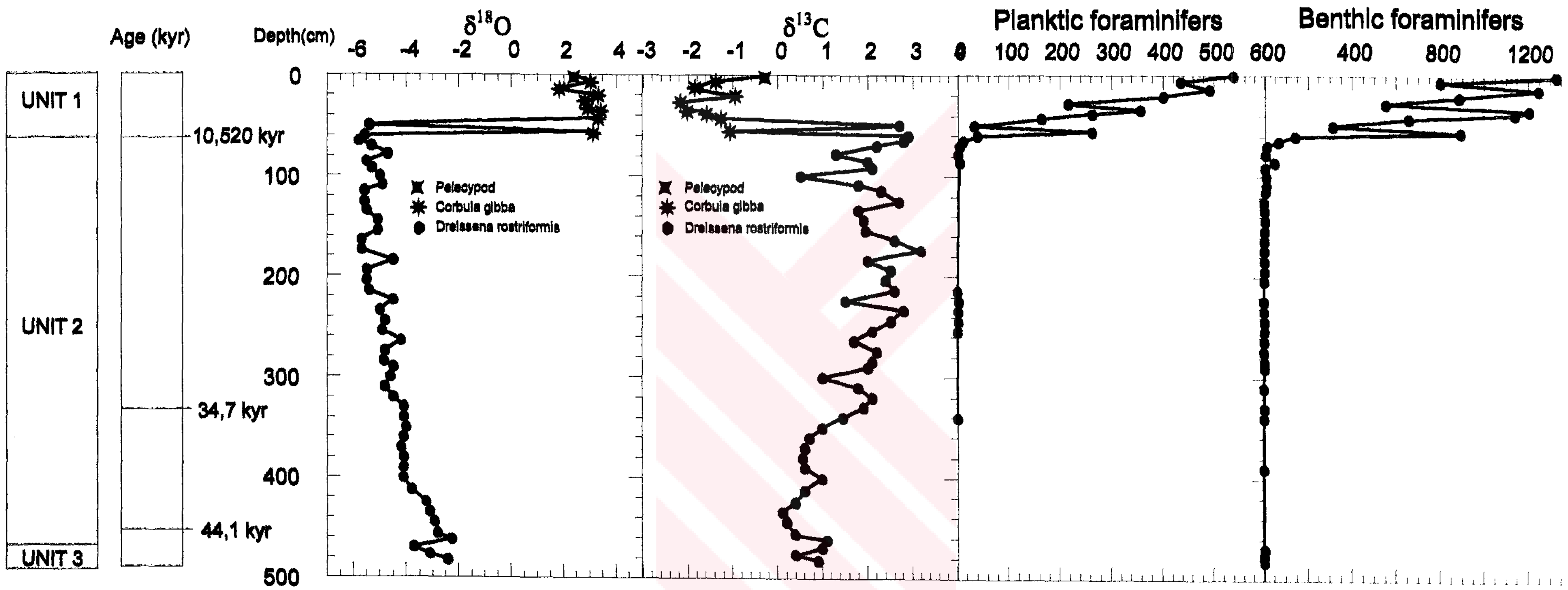


Fig.3.10. The $\delta^{18}O$ and $\delta^{13}O$ isotopic data of marine and lacustrine molluscs and distribution of planktic and benthic foraminifers in core C17.

The slight increase in $\delta^{18}O$, and the presence of gypsum and benthic foraminifera indicate incursion of marine waters into the Marmara Sea during early part of oxygen isotopic stage 3 (based on a ^{14}C age 44,1 kyr at this level). The more negative values in Unit 2 shells reflect lacustrine conditions during the deposition of this unit. In comparison with the ocean, continental waters are relatively deficient oxygen-18 and isotopically more variable.

The analysed marine and fresh-water shells have different ranges of carbon isotopic composition: the marine shells range between –2.20 ‰ and –0.20 ‰ (Unit 1) and the lacustrine shells between 0.10 ‰ and 3.20 ‰ (Unit 2), (Table 3.6; Fig.3.10). At 57 cm depth, the $\delta^{13}C$ values of *Corbula* shells decrease abruptly. At 51, $\delta^{13}C$ of *Dreissena rostriformis* shell has a high value $\delta^{13}C$ of 2.70 ‰. In the marine unit (Unit 1) the $\delta^{13}C$ values are low (-2.20 to –0.2 ‰).

Oppo and Fairbanks (1989) offered hypothesis which could explain decrease in $\delta^{13}C$ of mollusc shells. They propose that an enhanced upwelling rate caused the $\delta^{13}C$ minimum by transporting more ^{12}C-enriched deeper water to the surface. Mediterranean water inundated Marmara Sea at ca 12,000 yr BP, resulting in an early upwelling of the ^{12}C-enriched deep water to the surface and later establishment of water column stratification. At 57 cm a positive $\delta^{18}O$ value is assocated with a decrease in $\delta^{13}C$ at 10,5 kyr BP. Unit 2 have high $\delta^{13}C$ values of mollusc shells (0.2-3.2 ‰). The $\delta^{13}C$ values decrease at the base of Unit 2 to 0.1-0.4 ‰ and increase again to >1‰ in Unit 3.

3.5. Geochemical Analyses

3.5.1. Mg/Ca and Sr/Ca Ratios of Marine Mollusc Shells in Core C 1

The element composition of mollusc shells has been shown to be related to environmental parameters (Dodd, 1965; Lorens and Bender, 1980; Bourgoin, 1990; Pitts and Wallace, 1994; Klein et al., 1996a,b; Shen et al., 1996; Ingram, 1998; Putten et al., 1999; Schrag, 1999; Mıtsuguchi et al.,2001; Watanabe et al., 2001; Anadón et al., 2002 and Henderson, 2002). Marine bivalves secrete their shells nearly in chemical equbilirium with sea water (e.g. Mook and Vogel, 1968; Killingley and Berger, 1979). Hence, owing to their widespread geographic distribution, shallow water marine molluscs are especially well suited for paleoclimatic data (e.g. Krantz et al., 1987; Gossling, 1992; Seed and Suchanek, 1992).

Skeletal Mg/Ca and Sr/Ca ratios of marine shells are given in Table 3.7 and displayed graphically in Fig.3.11. Mg/Ca and Sr/Ca values were determined in different species because no single species existed in all levels of core C1 (Table 3.7). Between 2 cm and 51,5 cm depths, skeletal Mg/Ca mole ratio of *Ostrea edulis* show high values between 0.039 and 0.042. In the same interval, Sr/Ca mole ratio of *Ostrea edulis* indicates low values, ranging from 0.00031 to 0.00039. This is because the calcite shell layer of *Ostrea* easily accommodates Mg with increasing temperature rather than Sr (Fig.3.11).

In 54,7 cm and 64,5 cm depths, skeletal Mg/Ca and Sr/Ca mole ratios of *Corbula gibba* and *Mactra subtruncata* shows smilar pattern (Table.3.7). Between 74,5 cm and 145 cm depths, element composition of mollusc shells are based on *Mytilus edulis*. Skeletal Mg/Ca mole ratio of *Mytilus edulis* is low; but Sr/Ca mole ratio of *Mytilus* is high due to accommodation of Sr ions in the aragonite shell layer of Mytilus. *Mytilus edulis* might provide high resolution records of a large variety of environments.

Table.3.7. Mg/Ca and Sr/Ca ratios of marine mollusc shells in core C 1.

Depth (cm)	Samples	CaCO3 %	MgCO3 %	SrCO3 %	Mg/Ca mole ratio	Sr/Ca mole ratio
2,0	Ostrea edulis	93,5	3,2	0,051	0,04074357	0,000170455
11,5	Ostrea edulis	93	3,2	0,0538	0,040962622	0,00018078
21,5	Ostrea edulis	93,2	3,3	0,0485	0,042152054	0,000157693
31,5	Ostrea edulis	91,6	3,2	0,0489	0,041588688	0,000166826
41,5	Ostrea edulis	90,7	3	0,0474	0,03937628	0,000174201
51,5	Ostrea edulis	91,2	3,2	0,0419	0,041771094	0,000143572
54,7	Corbula gibba	95	0,4	0,106	0,005012531	0,002789474
64,5	Mactra subtruncata	93	0,5	0,107	0,00640041	0,002301075
74,5	Mytilus edulis	93	0,44	0,116	0,00563236	0,0028348
84,5	Mytilus edulis	92,2	0,52	0,107	0,006714182	0,00223177
94,5	Mytilus edulis	93,4	1,2	0,095	0,015295197	0,000847609
104,5	Mytilus edulis	91,6	0,94	0,105	0,012216677	0,001219456
115,0	Mytilus edulis	91	0,42	0,112	0,005494505	0,002930403
124,0	Mytilus edulis	92	1,2	0,102	0,01552795	0,000923913
134,5	Mytilus edulis	94,2	0,82	0,113	0,010362956	0,001462897
145,0	Mytilus edulis	95,1	0,74	0,122	0,009263432	0,001733595

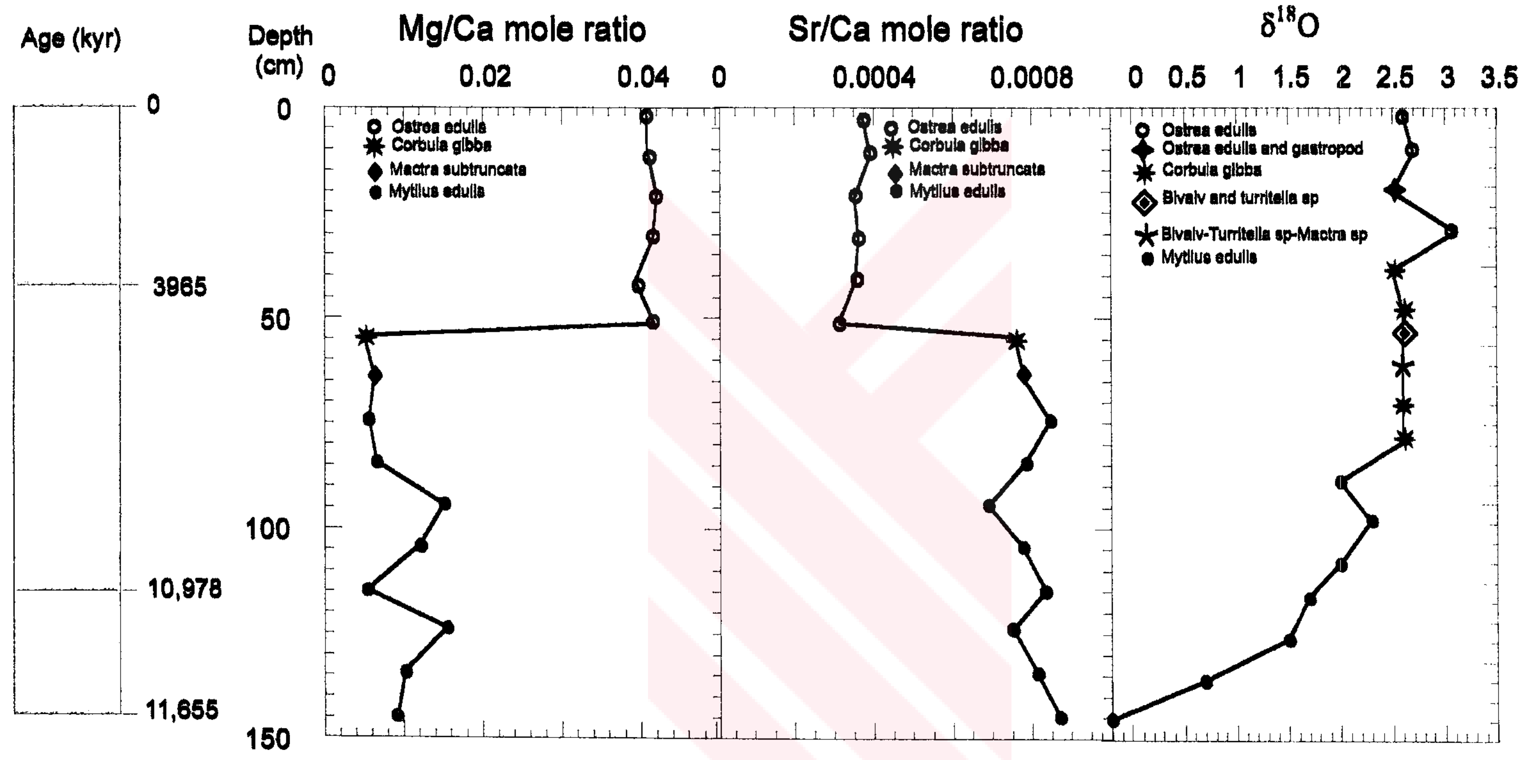


Fig.3.11. Skeletal Mg/Ca and Sr/Ca ratios of marine molluscs and compared with $\delta^{18}O$ curve in core C1.

The use of *Mytilus trossulus* (formerly *Mytilus edulis*) in paleoreconstruction has been illustrated by Klein et al (1996a) who reported that the Mg/Ca variations within the calcite shell layer of this mollusc provide an accurate record of seasonally varying sea surface temperature. Covariation of skeletal Mg/Ca mole ratio in *Mytilus trossulus* (formerly *Mytilus edulis*) and water temperature is higly important and is shown by the following equation by Klein (1996a):

$$T = 2.50_{(\pm 0.36)} \times [\, (\mathrm{Mg/Ca}) \times 1000 \,] - 2.07_{(\pm 2.35)}$$

Where T is estimated temperature (in °C). This equation includes 95 % confidence limits (in parantheses). These limits reflect both the degree of analytical precision and the accuracy with which skeletal Mg/Ca records sea water temperature. This equation developed using *Mytilus* was used in our study for calculating the sea water temperature for all mollusc species because no such equation is available for other bivalves *Corbula gibba* and *Mactra subtruncata* used in this study (Table 3.7; Fig.3.12). The use of the equation for *Mactra subtruncata* and *Corbula gibba* data is justified considering that their Mg/Ca values are conformable with those of *Mytilus*. In core C 1, skeletal Mg/Ca and Sr/Ca peaks show a pronounced fluctuations during Holocene period (Fig.3.7).

As a general trend, Mg/Ca ratio and temperature show a general increasing trend from bottom to the top of the core with two positive and one negative excursions in the lower 80 cm. The negative excursion at about ~ 11 kyr BP could be due to the Younger Dryas cooling episode. However, a ~ 20 °C decrease during this episode appears to be rather high and may be due to an analytical error or more probably to Klein's equation with total *Mytilus* shells, rather than the calcite layer of the shells. The positive excursions may represent the Bölling-Allorod warming and the early Holocene warming events.

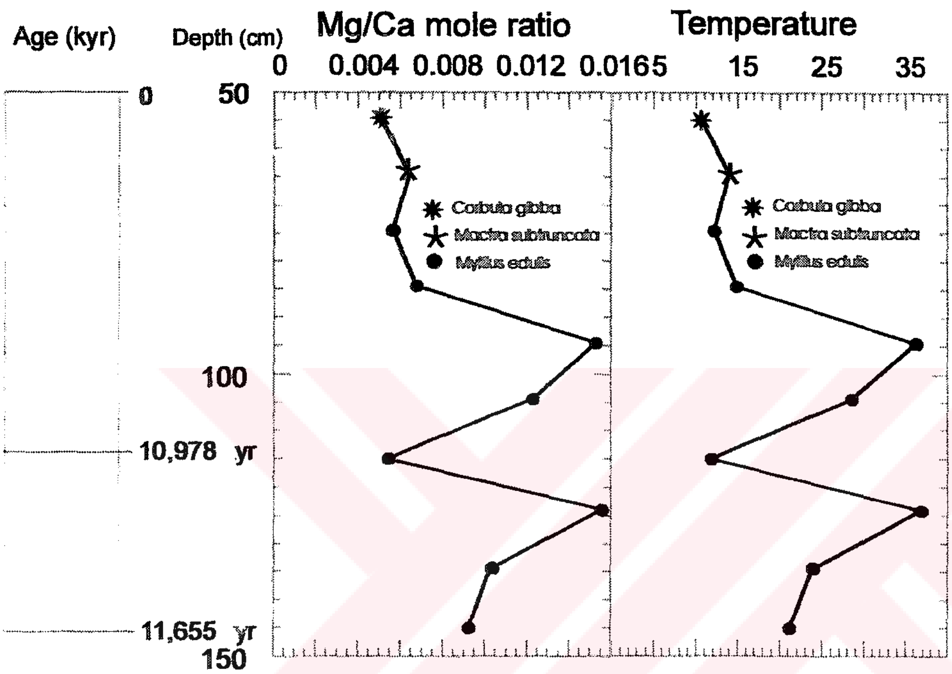


Fig.3.12. Skeletal Mg/Ca mole ratio of marine molluscs compared with estimated temperature in core C 1, using Klein's (1996) equation.

3.5.2. Mg/Ca and Sr/Ca ratios of Mollusc shells in Core C 17

Skeletal Mg/Ca and Sr/Ca ratio of marine and fresh-water shells are presented in Table 3.8 and displayed in Fig 3.13.

Core C 17 includes three units; marine (Unit 1), lacustrine (Unit 2) and brackish-marine (Unit 3) units. Skeletal Mg/Ca and Sr/Ca ratios were analysed in two molluscan species, *Corbula gibba* and *Dreissena rostriformis*. Between 1 cm and 61 cm depths, skeletal Mg/Ca and Sr/Ca ratios of *Corbula gibba* vary between 0.0044 - 0.0052; and 0.00076-0.0090.

Between 61 cm and 483 cm depths, skeletal Mg/Ca and Sr/Ca ratios of *Dreissena rostriformis* range from 0.0025-0.015 and 0.00055-0.0010. Mg/Ca profile shows pronounced fluctuations in the lacustrine Unit 2. In 116 cm-135 cm, 155 cm-195 cm, 255 cm-291 cm depths, Mg/Ca ratio shows positive excursions and between 205 cm-245 cm, 301 cm-361 cm, 401 cm-445 cm negative excursions (Fig.3.13).

Sr/Ca profile indicates a general decreasing trend towards the core top. Only, between 413,5 cm and 483 cm Sr/Ca ratios increase again (Fig.3.13). Fresh-water has a low Sr/Ca. In contrast, in sea water, the higher the temperature the larger percentage of aragonite deposited, which accepts the large strontium atom more readily than calcite in warmer water (Lowenstam, 1954). As a result, skeletal Sr/Ca ratio of fresh-water molluscs having calcitic shells are low in lacustrine levels (Unit 2) of core C17.

However, Sr/Ca in 413,5 and 483 cm depths starts increasing. This situation can be related that the incursion of marine water during deposition of this level (lower part of Unit 2 and Unit 3) (Fig.3.13). Temperature plays only a small role on Sr/Ca ratio in shells (Odum, 1950a; Kulp, Turekian and Boyd, 1952). However, Lowenstam (1954) demonstrated that there is a Sr/Ca variation that is temperature dependent in organisms having ability to vary their aragonite content with temperature.

Table.3.8. Skeletal Mg/Ca and Sr/Ca ratios of marine and lacustrine mollusc shells of core C17.

Depth (cm)	Samples	CaCO3 (%)	MgCO3 (%)	SrCO3 (%)	Mg/Ca mole ratio	Sr/Ca mole ratio
15	Corbula gibba	92,0	0,36	0,116	0,004658	0,00085773
22	Corbula gibba	93,1	0,36	0,113	0,004603	0,00082568
29	Corbula gibba	91,5	0,4	0,122	0,005204	0,00090703
35	Corbula gibba	91,0	0,34	0,121	0,004448	0,00090454
39	Corbula gibba	90,4	0,36	0,111	0,004741	0,00083529
44	Corbula gibba	91,6	0,36	0,112	0,004679	0,00083177
51	Dreissena rostriformis	90,0	0,8	0,115	0,010582	0,00086924
57	Corbula gibba	92,0	0,4	0,104	0,005176	0,000769
61	Dreissena rostriformis	91,0	0,46	0,104	0,006018	0,00077745
66	Dreissena rostriformis	91,0	0,44	0,128	0,005756	0,00095687
71	Dreissena rostriformis	90,0	0,6	0,117	0,007937	0,00088435
79	Dreissena rostriformis	90,8	0,6	0,111	0,007867	0,00083161
87	Dreissena rostriformis	90,0	0,52	0,133	0,006878	0,00100529
93	Dreissena rostriformis	90,0	0,44	0,13	0,00582	0,00098262
101	Dreissena rostriformis	90,2	0,7	0,102	0,009239	0,00076927
110	Dreissena rostriformis	95,0	0,46	0,111	0,005764	0,00079484
116	Dreissena rostriformis	92,0	0,7	0,117	0,009058	0,00086513
127	Dreissena rostriformis	91,4	0,72	0,074	0,009378	0,00055077
135	Dreissena rostriformis	91,8	0,7	0,105	0,009078	0,00077809
145	Dreissena rostriformis	94,2	0,5	0,106	0,006319	0,00076549
155	Dreissena rostriformis	91,0	0,9	0,098	0,011774	0,0007326
165	Dreissena rostriformis	92,0	0,7	0,105	0,009058	0,0007764
175	Dreissena rostriformis	91,8	0,8	0,093	0,010375	0,00068916
185	Dreissena rostriformis	95,0	0,78	0,115	0,009774	0,00082349
195	Dreissena rostriformis	90,0	1,2	0,084	0,015873	0,00063492
205	Dreissena rostriformis	91,5	0,48	0,114	0,006245	0,00084755
215	Dreissena rostriformis	90,4	0,7	0,106	0,009218	0,00079766
225	Dreissena rostriformis	93,0	0,4	0,123	0,00512	0,00089971
235	Dreissena rostriformis	90,2	0,5	0,095	0,006599	0,00071647
245	Dreissena rostriformis	91,0	0,52	0,104	0,006803	0,00077745
255	Dreissena rostriformis	90,2	0,84	0,109	0,011086	0,00082206
265	Dreissena rostriformis	90,4	0,8	0,119	0,010535	0,00089549
275	Dreissena rostriformis	90,6	0,8	0,101	0,010512	0,00075836
285	Dreissena rostriformis	90,6	0,74	0,097	0,009724	0,00072833
291	Dreissena rostriformis	91,0	0,8	0,102	0,010466	0,0007625
301	Dreissena rostriformis	91,4	0,54	0,101	0,007033	0,00075172
311	Dreissena rostriformis	92,0	0,52	0,109	0,006729	0,00080597
321	Dreissena rostriformis	92,6	0,46	0,106	0,005914	0,00077871
331	Dreissena rostriformis	90,4	0,52	0,112	0,006848	0,00084282
341	Dreissena rostriformis	91,4	0,4	0,109	0,00521	0,00081127
351	Dreissena rostriformis	90,0	0,48	0,11	0,006349	0,00083144
361	Dreissena rostriformis	92,4	0,44	0,092	0,005669	0,00067733
371	Dreissena rostriformis	90,0	0,7	0,108	0,009259	0,00081633
381	Dreissena rostriformis	91,4	0,44	0,11	0,005731	0,00081871
391	Dreissena rostriformis	90,0	0,5	0,101	0,006614	0,00076342
401	Dreissena rostriformis	90,0	0,44	0,106	0,00582	0,00080121
413,5	Dreissena rostriformis	94,8	0,2	0,146	0,002512	0,00104768
425	Dreissena rostriformis	95,0	0,2	0,136	0,002506	0,00097386
435	Dreissena rostriformis	91,8	0,26	0,13	0,003372	0,00096335
445	Dreissena rostriformis	92,0	0,5	0,144	0,00647	0,00106477
457	Dreissena rostriformis	91,0	0,3	0,13	0,003925	0,00097182
462,5	Dreissena rostriformis	90,0	0,32	0,135	0,004233	0,00102041
470,5	Dreissena rostriformis	90,0	0,3	0,13	0,003968	0,00098262
477	Dreissena rostriformis	91,4	0,3	0,132	0,003907	0,00098245
483	Dreissena rostriformis	92,0	0,3	0,14	0,003882	0,0010352

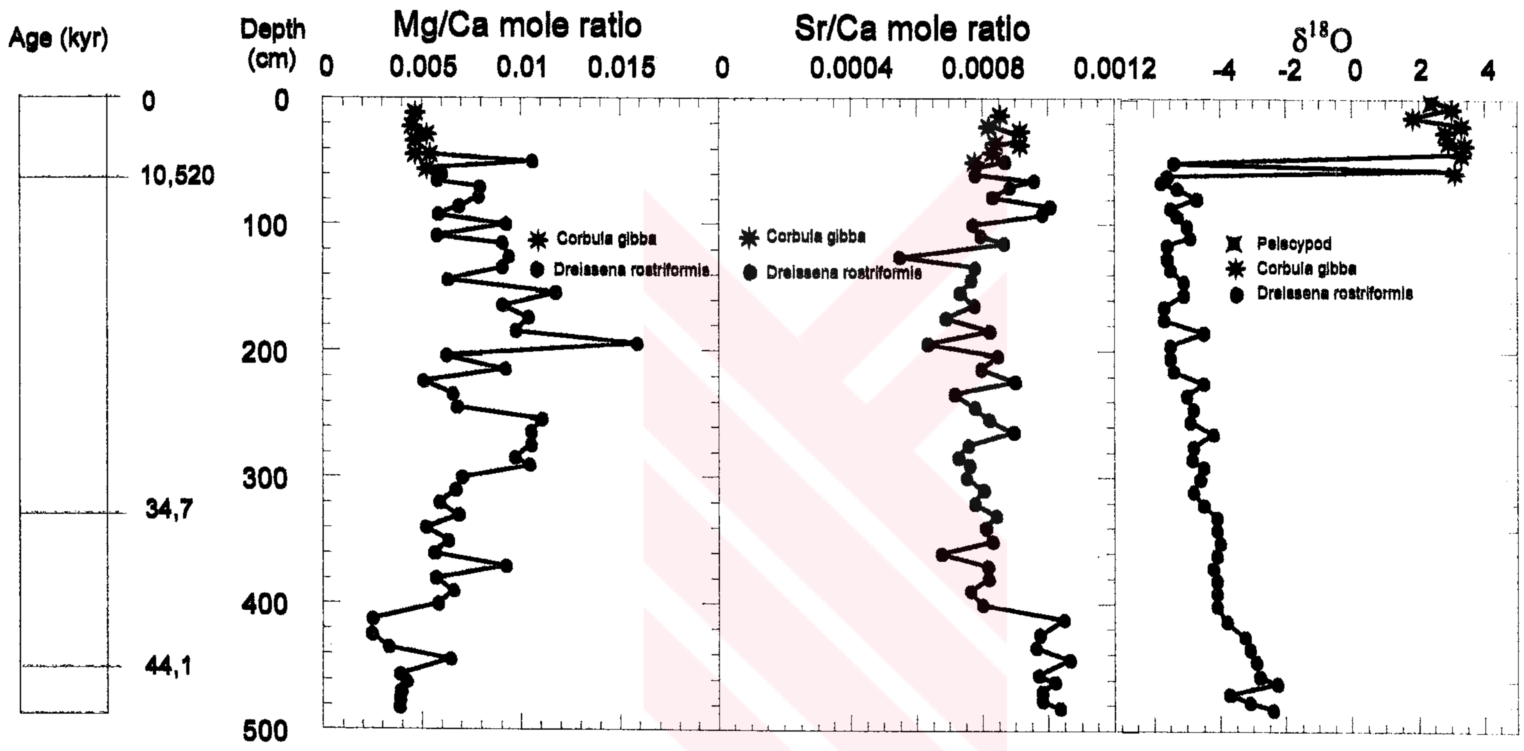


Fig.3.13. Skeletal Mg/Ca and Sr/Ca ratios of marine and lacustrine molluscs and compared with $\delta^{18}O$ curve in core C17

4. CONCLUSIONS

As a result of the studies carried out during this thesis, the following conclusions are reached:

1. Micro and Macro paleontological studies of core C 1 demonstrate that the core C 1 was deposited in a fully marine environment on the northern shelf of the Marmara Sea during Holocene period. Core C 1 sediments are rich in Mediterranean euryhaline marine water molluscs, echinoderms, fish bones, planktic and benthic foraminiferal assemblages. Especially, *Brizalina spathulata*, *Cassidulina carinata*, *Globoratalia sp.*, *Bulimina marginata*, *Elphidium crispum* and *Ammonia parkinsonia* are abundant in different intervals in core C 1. Brackish water forams *Elphidium crispum* and *Ammonia parkinsonia* show low salinity conditions, but well-adjusted to marine environment. Both foraminifers and molluscs display that marine conditions gradually developed over a period of 1500-2000 years after the onset of the marine transgression at about 12 kyr BP.

2. The faunal content of C 17 changes significantly along the core. This core includes three units. The most recent one (Unit 1) was deposited in the last 12 kyr BP. This unit comprises euryhaline Mediterranean molluscs and foraminifers. Unit 2 contains lacustrine molluscs, and was deposited under fresh-brackish water conditions between 12-36 kyr BP. Foraminifers are nearly non-existent in Unit 2, but they are observed between 470,5 cm and 483 cm depth (Unit 3). The foraminifer species in Unit 3 are *Brizalina spathulata*, *Cassidulina carinata* and *Elphidium crispum.* Lacustrine molluscs are of Neouxinian Black Sea affinities, and include mainly *Dreissena rostriformis* and *Micromelania sp*. The faunal content of Unit 2 indicates that the Marmara Sea was a large fresh-brackish water lake during the deposition of this unit between the Last Glacial time and 12,000 yr BP. Over part of this time, the lake may been connected to the Black Sea as indicated by its Neouxinian fauna. Presence of some foraminifers and euryhaline molluscs in Unit 3 strongly suggest a connection of the Marmara Sea with the Aegean Sea.

3. The $\delta^{18}O$ values in core C 1 range between – 0.20 and + 3.10 ‰ (average=+2.14 ‰). The $\delta^{18}O$ values of the mollusc shells show an increasing trend towards to the top of the core starting with the flooding of the Marmara Sea by Mediterranean waters at about 12 kyr. The increase in salinity starting from the base (12 kyr BP) is relatively rapid until about 11.4 kyr and than the increase continues at a slower pace until about 10.8 kyr BP. The $\delta^{13}C$ values of mollusc shell changes between – 2.40 ‰ and + 2.00 ‰ (average=+1.7 ‰). The $\delta^{13}C$ profile shows pronounced fluctuations along the core probably largely depending on the use different species in the analysis.

4. In core C 1, skeletal Mg/Ca of *Ostrea edulis* show high values in the upper part of the core. This values changes between 0.039 and 0.042. Sr/Ca of *Ostrea edulis* has low values, ranging from 0.00031 to 0.00039. Between 74,5 and 145 cm depths, skeletal Mg/Ca of *Mytilus edulis* is low, but Sr/Ca ratio of *Mytilus* is high due to accommodation of Sr into the aragonitic layer of the *Mytilus* shell. Skeletal Mg/Ca and Sr/Ca peaks show pronounced fluctuations.

5. $\delta^{18}O$ isotopic data of C 17 are based on marine and fresh water molluscs. Marine shells that are *pelecypoda* and *Corbula gibba* that indicates a range of $\delta^{18}O$ from 1.80 ‰ to 3.50 ‰ in 1 cm – 57 cm depths. Below this level the lacustrine molluscs shells (*Dreissena rostriformis*) have relatively low $\delta^{18}O$ values in the range of – 5.80 ‰ and – 2.25 ‰. However, between 470,5 cm and 483 cm in Unit 3, $\delta^{18}O$ values starts to increase from -3.70 to – 2.40 ‰. At the same time, some benthic foram species are observed in this interval. Furthermore, gypsum grains were found in this level. These parameters indicates marine incursion during the deposition of Unit 3 (early part of oxygen isotopic stage 3).

6. The $\delta^{13}C$ values of marine shells in Core C17 range between – 2.20 ‰ and – 0.20 ‰ and lacustrine shells between 0.10 ‰ and 3.20 ‰. The $\delta^{13}C$ peak decreases abruptly in 57 cm depth. Decrease in $\delta^{13}C$ of mollusc shells suggests that an enhanced upwelling rate indicated by the $\delta^{13}C$ minimum caused by transporting more ^{12}C-enriched deeper water to the surface. Mediterranean water inundation of the Marmara Sea at ca 12,000 yr BP, might have raised the ^{12}C-enriched deep water to the surface and caused a water column stratification.

7. Between 1 cm and 61 cm depths in core C 17, Mg/Ca and Sr/Ca of *Corbula gibba* varies between 0.0044-0.0052 and 0.00076-0.0090. Between 61 cm and 483 cm, skeletal Mg/Ca and Sr/Ca ratio of *Dreissena rostriformis* ranges between 0.0025-0.015 and 0.00055-0.0010. Skeletal Mg/Ca profile show fluctuations during the lacustrine period of the Sea of Marmara. Sr/Ca profile indicates a general upward decreasing trend. Unit 3 and Unit 1 are characterized by a higher Sr/Ca ratio than in Unit 2, indicating that a marine connection during the deposition of the former units and disconnection from the Mediterranean during the deposition of the latter unit.

8. In core C17, mollusc and foraminifer assemblages indicate that Unit 3 (brackish-marine) is between 470,5 and 483 cm interval. However, Mg/Ca, Sr/Ca and $\delta^{18}O$ values are of mollusc shells indicate that the effect of marine water continues above this interval to about 425 cm below sea floor.

REFERENCES

Aksu, A.E; Yaşar, D.; Mudie, P.J.; Gillespie, H., 1995. Late glacial-Holocene paleoclimatic and paleoceanographic evolution of the Aegean Sea: micropaleontological and stable isotopic evidence. *Marine Micropaleontology* 25, pp 1-28.

Aksu, A.E., Hiscott, R.N. and Yaşar, D., 1999. Oscillating Quaternary water levelsof the Marmara Sea and vigorous out flow into the Aegean Sea from the Marmara Sea-Black Sea drainage Corridor. *Marine Geology* 153:275-302.

Aksu, A.E., Hiscott, R.N., Kaminski, M.A., Mudie, P.J., Gillespie, H., Abrajano, T.,Yaşar, D., 2002. Last glacial-Holocene paleoceanography of the Black Sea and Marmara Sea: stable isotopic, foraminiferal and coccolith evidence. *Marine Geology* 190 pp 119-149.

Alavi, S.N., 1998. Late Holocene deep-sea benthic foraminifera from the Sea of Marmara.*Marine Micropaleontology,* 13, pp 213-237.

Anadón, P., Ghetti, P., Gliozzi, E., 2002. Sr/Ca, Mg/Ca ratios and Sr and stable isotopes of biogenic carbonates from the Late Miocene Velona Basin (Central Apennines, Italy) provide Evidence of unusual non-marine Messinian conditions. *Chemical Geology* 187, pp 213-230.

Craig, H., 1957. Isotopic standards for carbon and oxygen and correction factors for Mass-spectrometric analysis of carbon dioxide. *Geochimica et Cosmochimica Acta.* Vol.12, pp 133-149.

Çağatay, M.N., Görür, N., Algan, O., Eastoe, C., Tchapalyga, A., Ongan, D., Kuhn, T., Kuçcu, I., 2000. Late Glacial-Holocene palaeoceanography of the Sea of Marmara : timing of connections with the Mediterranean and the Black Seas. *Marine Geology* 167, pp 191-206.

Dodd, J.R., 1965. Environmental control of Strontium and Magnesium in Mytilus. *Geochimica et Cosmochimica Acta.* Vol.29, pp. 385-398.

Fairbanks, R.G., 1989. A 17,000-year glacio-eustatic sea level record:influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature* vol.342 pp.637-642.

Görür, N., Çağatay, M.N., Emre, O., Alper, B., Sakınç, M., İslamoğlu, Y., Algan, O., Erkal, T., Keçer, M., Akkök, R., Karlık, G., 2001. Is the abrupt drowning of the Black Sea shelf at 7150 yr BP a myth?. *Marine Geology* 176, pp. 65-73.

Kaminski, M.A., Aksu, A., Box, M., Hiscott, R. N., Filipescu, S., Al – Salameen, M., 2002. Late Glacial to Holocene benthic foraminifera in the Marmara Sea: implications for Black Sea-Mediterranean Sea connections following the last deglaciation. *Marine Geology* 3162, pp.1-37.

Keith, M.L., Anderson, G.M. and Eichler, R., 1964. Carbon and oxygen isotopic composition of mollusc shells from marine and fresh water environments. *Geochimica et Cosmochimica Acta*, vo.28, pp. 1757 to 1786.

Klein, R.T., Lohmann, K.C., Thayer, C.W., 1996. Bivalve skeletons record sea-surface temperature and $\delta^{18}O$ via Mg/Ca and $^{18}O/^{16}O$ ratios. *Geology*. V.24, no.5, p. 415-418.

Lane-Serff, G.F., Rohling, E.L., Bryden, H.L., Charnock, H., 1997. Postglacial connection of the Black Sea to the Mediterranean and its relation to the timing of sapropel formation. *Paleoceanography* 12, 169-174.

Lowenstam, H.A., 1953. Environmental relations of modification compositions of certain carbonate secreting marine inverrebrates. *Acad. Sci. Proc*., v. 40, p. 39-48.

Mitsuguchi, T., Uchida, T., Matsumoto, E., Isdale, P.J. and Kawana, T., 2001. Variations in Mg/Ca, Na/Ca, and Sr/Ca ratios of coral skeletons with chemical treatments: implications for carbonate geochemistry. *Geochimica et Cosmochimica Acta.* V.65, no.17, pp. 2865-2874.

Oppo, D.W., Fairbanks, R.G.,1989. Carbon isotope composition of tropical surface water during the past 22000 years. *Paleoceanography*, 4(4), 333-351.

Park, R. and Epstein, S., 1960. Carbon isotope fractionation during photosynthesis. *Geochimica et Cosmochimica Acta*. V.21, pp.110-126.

Putten, E.V., Dehairs, F., Keppens, E. And Baeyens, W., 2000. High resolution distribution of trace elemnts in the calcite shell layer of modern *Mytilus edulis*: environmental and biological controls. *Geochimica et Ccosmochimica Acta*. Vol.64, no.6, pp. 997-1011.

Schrag, D.P., 1999. Rapid analysis of high-precision Sr/Ca ratios in corals and other marine carbonates. *Paleoceanography*. V.14, No.2, pp 97-102.

Sperling, M., Schmiedl, G., Hemleben, C., Emeis, K.C., Erlenkeuser, H., Grootes, P.M., 2003. Black Sea impact on the formation of eastern sapropel S1? Evidence Mediterranean from the Marmara Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology*2957. pp. 1-3.

Stanley, D.J. and Blanpied, C., 1980. Late Quaternary water exchange between the eastern Mediterranean and The Black Sea. *Nature*. Vol.283, pp.337-347.

Thunell, R.C. and Williams, D.F., 1989. Glacial-Holocene salinity changes in the Mediterranean Sea: hydrographic and depositional effects. *Nature* vol.338, pp.493-496.

Thunell, R.C. and Sautter, L.R., 1992. Planktonic foraminiferal faunal and stable isotopic indices of upwelling: a sediment trap study in the San Pedro Basin, southern California Bight. *Geological Society Special Publications* No.64, pp. 77-91.

Tolun, T., Çağatay, M.N., Carrigan, W.J., Eastoe, C.J., Balkis, N., Algan, O., 1999. Organic geochemistry and origin of Holocene sapropelic sediments from Sea of Marmara and Black Sea, *19th international Meeting on Organic Geochemistry*, 6-10 September 1999, İstanbul, Abstracts, Part 1, pp. 41-42.

Turekian, K., 1955. Paleoecological significance of the strontium-calcium ratio in fossils and sediments. *Bulletin of the Geological Society of America*. Vol.66, pp.155-158.

Ünlüata, Ü., Özsoy, E., 1986. Oceanography of Turkish Straits, Health of Turkish Straits. In: Oxygen deficiency of Sea of Marmara, METU – *Institute of Marine Sciences Report*, Erdemli-İçel, Turkey, 78 pp.

Ünlüata, Ü., Oğuz, T., Latif, M.A., Özsoy, E., 1990. On the physical oceanography of the Turkish Straits. In: Pratt, L.J. (Ed.). *The Physical Oceanography of Seç Straits*, NATO/ASI Series Kluwer, Dordrecht, pp. 25-60.

Watanabe, T., Winter, A., Oba, T., 2001. Seasonal changes in sea surface temperature and salinity during the Little Ice age in the Caribbean Sea deduced from Mg/Ca and $^{18}O/^{16}O$ ratios in corals. *Marine Geology* 173 pp. 21-35.

Wefer, G. And Berger, W.H., 1991. Isotope paleontology. Growth and composition of extant calcareous species. *Marine Geology* 100, pp.207-248.

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