GEOCHEMISTRY OF SEDIMENT CORES
FROM THE SEA OF MARMARA, EASTERN TROUGH.

By

ATEF A. MOUSSA* AND MOUSTAFA ERGIN

*National Institute of Oceanography and Fisheries, Kayet Bey, Alexandria, Egypt.

ABSTRACT

The major and trace elements were studied in two sediment cores taken from the Eastern Marmara Trough. Both cores are extremely homogenized, having a structurless appearance except for bioturbation marks. They comprised essentially of fine materials; 1-2 % sand, up to 70 % silt and up to 40 % clay.

The calcium carbonate content is about 15-18 %, and the organic matter is about 2-3 %. Since the sediments are practically free of sands, most of the carbonates is attributed to coccolithophores, which are shown to be abundant.

The concentrations and interrelationships of major elements indicate a terrigenous source in the first place and biogenous one in the second place. Yet, a hydrogenous source (authigenic) is also identified from trace elements associations concentrations.

Post-depositional mobilization of elements and early diagenetic reactions are indicated.

INTRODUCTION

The sea of Maramara is an almost enclosed basin forming the unique link between the Mediterranean and the Black Sea via the narrow straits of Dardanelles in the southwest and the Bosphorus in the northeast.

This basin lies along an seismically active zone (Crampin and Evans, 1986). However, tectonic displacement has shown to be of no importance in the Pleistocene geology of this region (Gunnerson and Ozturgut, 1974). Stanley and Blanpied (1980) suggested that the Pleistocene-Holocene sedimentary history of the basin has been shaped largely in response to eustatic fluctuations rather than teconics.

Generally, very few geological investigations have been conducted in the Sea of Marmara. In the present work emphasis is placed on the geochemistry of sediments, although attention is also given to sedimentological aspects.

The preliminary results of this study have been submitted in an abstract form to The Fourth Meeting of The European Union of Geosciences, Strasbourg 1987 (Ergin and Moussa, 1987).

PHYSICAL OCEANOGRAPHY :

Detailed informations on different aspects of physical oceanography of the Sea of Marmara and the Turkish straits are given in a series of annual reports prepared by the academic staff members of the Institute of Marine Sciences of the Middle East Technical University in Turkey.

In summary, an estuarine system of water exchange between the Sea of Marmara and the Black Sea have been established due to the difference in water level and salinity between the two water bodies. A fresh-water top current of salinity 18 flows southwards through the Bosphorus and a saline northward current of 36 average salinity flows into the Black Sea (Scholten, 1974; IMS METU, 1986 a). According to these sources current velocities as great as 4 Km and more were measured for the southward fresh-water current near the southern exit of the Bosphorus.

BATHYMETRY :

The conspicuous bathymetric feature in the sea of Marmara (Fig. 1) is an east-west trending trough separating a northern narrow continental shelf (2-13 km from the southern broad one (33 km).

The northern shelf can be divided into a shallow inner part extending from about 0.5 to 5 Km from the shore to 20-30 m depth, and an outer part extending from 3.5 to 10 Km to 100 m depth (DAMOC/WHO/UNDP/SF/TUR 20, 1971). On the other hand, the southern shelf extends from the shores in the form of a board terrace until the shelf break at 115 m depth (Carter et al., 1972).

The east-west trending trough which is called The Marmara Trough is divided into three small depressions by low sills having 720 m average depth. The maximum recorded depths in these depressions are 1097, 1389 and 1238 m from west to east respectively.

In addition, a submarine canyon can be traced from the Bosphorus into the Sea of Marmara to a depth of about 70 m (Gunnerson and Ozturgat, 1974). This canyon is presumably a relict feature which have been formed when the entire flow was to the south. In general, the isobath distribution in the northeastern part of the sea shows great slopes in the north-northeast up to 7-16 degrees and gradual gentler slopes in the west-southwest (DAMOC/WHO/UNDP/SF/TUR 20, 1971).Seismic reflection profiles made in the northeastern part of the sea (DAMOC/WHO/UNDP/SF/TUR 20, 1971), show the canyon slopes (Fig. 2).
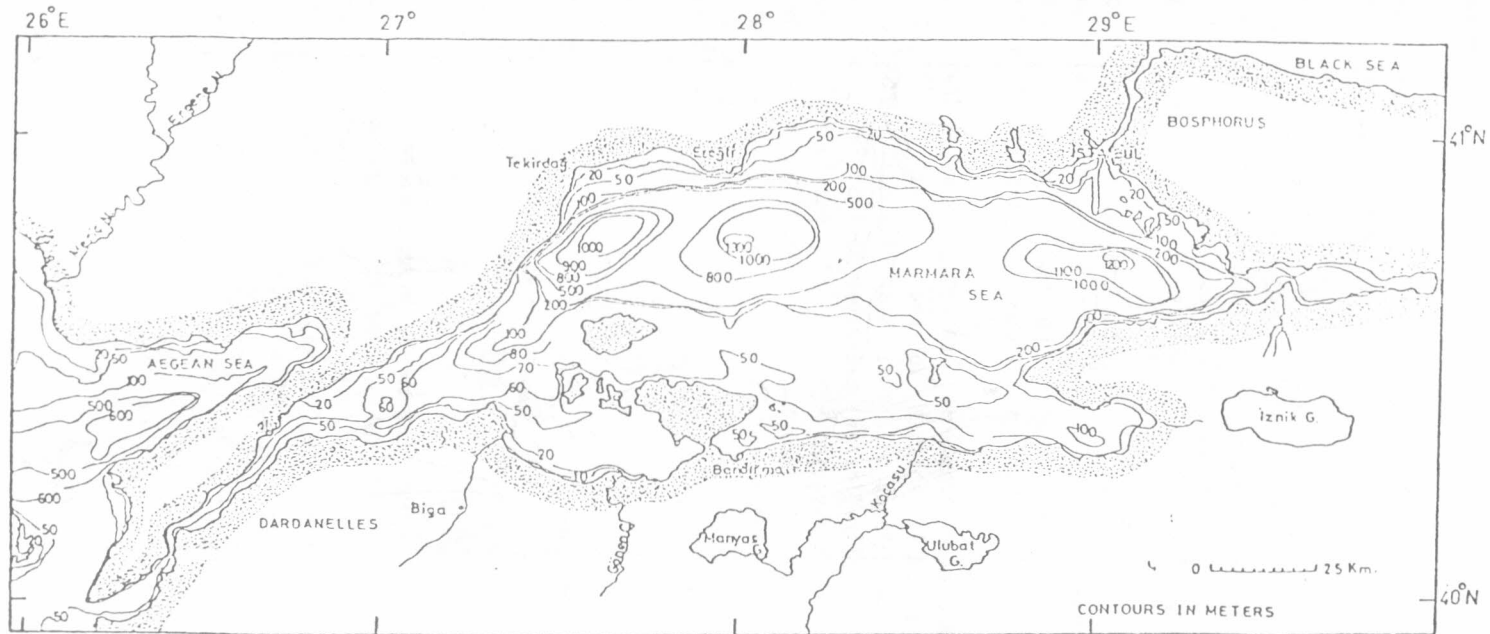
Figure 1: Bathymetry of the Sea of Marmara.

Sediments from Sea of Marmara.

...AL SETTING :

...e land geology around the Sea of Marmara coasts is very complicated ...pecially in the south (Fig. 3).

...e northern coast of the sea is bordered by Tertiary marine sediments of ...e Thracian Peneplain (Brinkmann, 1976). These sediments are unconformably ...erlying Precambrian to Lower Paleozoic basement rocks (Rigassi, 1971). Their ...ting show gradation from Eocene limestone near the Dardanelles to Oligocene ...sch deposits, evaporites and alluvial deposits northwards (Ilhan, 1976).

...e geology of the southern coast on the other hand is dominated by Tertiary ...sch deposits and metamorphic rocks. Plutonic massives are found in the ...nsulas and far inland. Neogene - Eocene volcanic rock outcrops are widely ...tributed in the south between Erdemit and Dardanelles.

...ese different types of rocks and sediments are drained by many rivers ...ch finally flow into the Sea of Marmara (Fig. 4). The total annual ...charge of water from all these rivers is about 7400 x 10^6 m^3/y (Table 1) ...ded with 7.85 x 10^5 tons of sediments (Water Quality and Annual Observations, ...5). Almost 85 % of the total water discharge and 95 % of the sediment input ...e through Simav River alone. Also, the small ephemeral streams draining the ...ly sloping coastal areas can deliver sometimes important amounts of ...ments flowing intense rainfall or melting of snow. Additional supply of ...e suspended sediments is expecting from the inflowing waters through the ...phorus and the Dardanelles. The river discharge into the Black Sea is ...endous. The Sea receives annually about 374 Km^3 of water loaded with 150 x ...^{8} tons of solid materials (Strakhov, 1954). Whereas, the yield from the ...ers flowing into the northern part of the Aegean Sea is comparatively low. ...e water discharge theirin was estimated as 16.5 x 10^9 m^3/y with a sediment ...d of 5-6 x 10^6 tons/y (Water Quality and Annual Observations, 1985; Lykousis ...al., 1981).

...eanwhile, the downward flux of the organic suspended sediments in the Sea of ...mara was estimated as 10 x 10^5 tons/y (IMS, METU, v,c, 1986). The authors of ...se volumes used this figure to calculate a sedimentation rate of 17 cm/1000 ... However, taking into account the influx of inorganic sediments from rivers ...s rate become tentatively 30-50 cm/1000 y. Comparably, an average rate of ...mentation of about 30 cm/1000y can be obtained from the radiocarbon dated ...res collected in the "Eastern Marmara Basin" and described by Stanley and ...pied (1980).
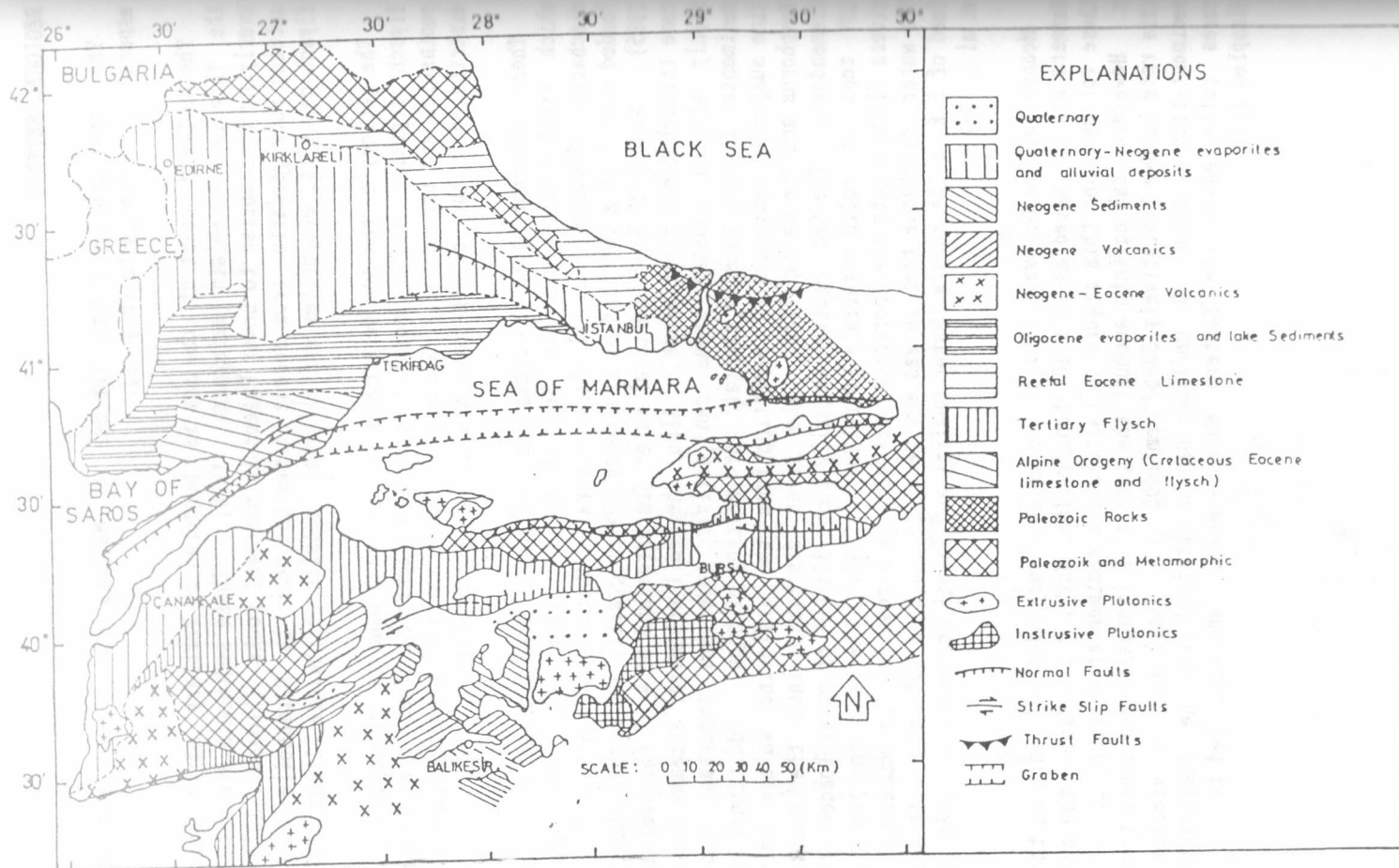
Figure 3: Geology of Marmara Sea Coasts.

EXPLANATIONS

- Quaternary
- Quaternary-Neogene evaporites and alluvial deposits
- Neogene Sediments
- Neogene Volcanics
- Neogene-Eocene Volcanics
- Oligocene evaporites and lake Sediments
- Reefal Eocene Limestone
- Tertiary Flysch
- Alpine Orogeny (Cretaceous Eocene limestone and flysch)
- Paleozoic Rocks
- Paleozoik and Metamorphic
- Extrusive Plutonics
- Instrusive Plutonics
- Normal Faults
- Strike Slip Faults
- Thrust Faults
- Graben

SCALE: 0 10 20 30 40 50 (Km)

BLACK SEA

SEA OF MARMARA

BAY OF SAROS

BULGARIA

GREECE

EDIRNE

KIRKLARELI
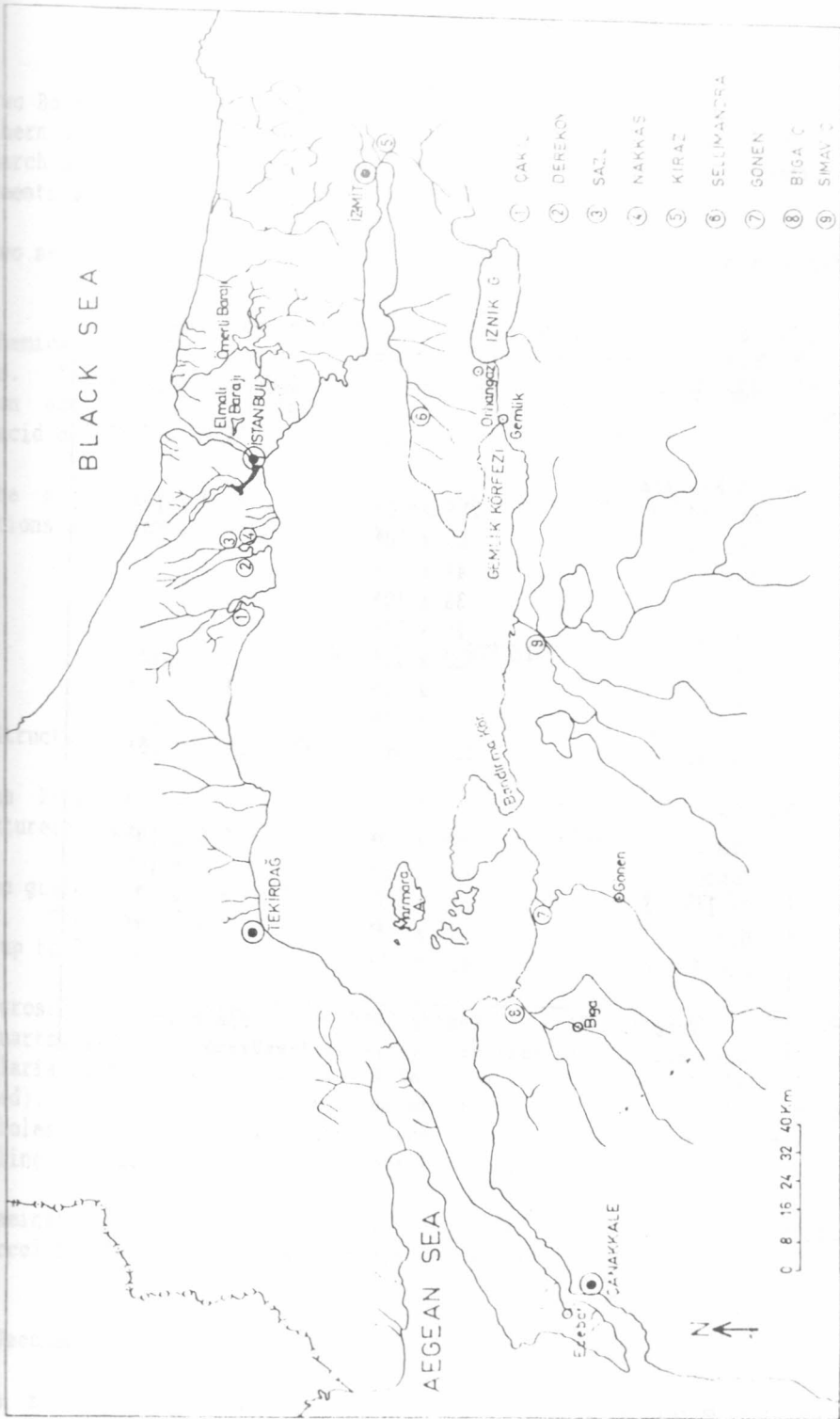
TEKIRDAG

ISTANBUL

CANAKKALE

BURSA

BALIKESIR

124

Figure 4: Marmara Sea Rivers.

Table (1): Annual river discharge into the sea of Marmara.

Name of River	Water (m^3/y)	Sediments (ton/y)
North Marmara :		
Kirazdere	259 x 10^6	8.3 x 10^3
Sarisu	50 x 10^6	3,8 x 10^3
Sazli	44 x 10^6	2.6 x 10^3
Karasu	38 x 10^6	3.4 x 10^3
Nakkas	28 x 10^6	1.4 x 10^3
Derekoy	22 x 10^6	1.6 x 10^3
Cakil	16 x 10^6	1.1 x 10^3
Golden Horn	100 x 10^6	4.0 x 10^3
Sub-Total	557 x 10^6	26.2 x 10^3
Soth Marmara :		
Simav	6200 x 10^6	750 x 10^3
Gonen	100 x 10^6	3.8 x 10^3
Sellimandira	76 x 10^6	4.3 x 10^3
Biga	44 x 10^6	1.8 x 10^3
Sub-Total	6430 x 10^6	760 x 10^3
Total	6987 x 10^6	736.2 x 10^3

MATERIAL AND METHODS

Two Boomerang sediment cores of about one meter length were taken from the northern part of the Eastern Marmara Basin (Fig. 5) onboard the Turkish Research ship "Bllim". Visual examination of samples on deck showed that the sediments are composing of H_2S-odorless, uniform dark greenish-gray mud.

Two sediment cores were subjected to X-ray radiography, smear examination by SEM.

Chemical analyses of sediments were made at two-centimeter intervals of the cores. The element analysis was done by plasma mass spectrometry; the organic carbon and carbonate contents were determined using Perkin-Elmer CHN analyzer and acid decomposition treatment respectively.

The percentages of sand, silt and clay were determined and the sand fractions were examined microscopically.

RESULTS AND DISCUSSION

I- Structure and Sediment Composition

The X-ray radiography showed complete homogenety of sediments with a structureless appearance except for bioturbation marks.

The grain size analysis indicate that the sediments are composing of clayey silts. The sand fraction in the cores is only 1-2 %, clay forms up to 40 % and silt up to 70 %.

Microscopic examination of the sand fractions showed that they are composing of quartz, clayey aggregates, shell fragments, Molluscs, Foraminifers, Radiolaria and sponge spicules, micas (white, yellow, greenish and dark colored), feldspars, heavy minerals (Epidote, garnet, pyroxene, amphiboles....etc.), metamorphic rock fragments, organic remains and infillings, fecal pellets, and pyrite infillings.

Examination of fine fraction (silt and clay) by SEM indicated the presence of Coccolithophores (no photomicrographs were taken).

II- Geochemistry :

The mean concentration values of elements for each 10-cm interval were computed from the original data. For better understanding the upper interval was divided into surficial (0-2 cm) layer and 2-10 cm layer (Table 2).

Figure 5: Sampling locations.

Table (2): Element concentrations in core no. M1

a) Major elements (W %)

Interval (cm)	CaCO3	Organic matter	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
0-02	15.25	3.09	6.80	4.10	1.88	4.50	2.70	1.94	0.39	0.067	0.55
2-10	15.75	2.60	6.40	4.05	1.87	4.60	2.63	1.93	0.38	0.062	0.35
10-20	17.61	2.28	6.52	4.08	1.92	4.86	2.46	2.03	0.38	0.058	0.25
20-30	17.56	2.82	6.92	4.14	1.97	5.02	2.36	2.04	0.38	0.057	0.24
30-40	16.78	2.61	6.78	4.10	1.98	5.22	2.24	2.02	0.38	0.056	0.24
50-60	18.06	2.15	6.60	4.14	1.97	5.10	2.10	2.00	0.39	0.056	0.26
60-70	17.83	2.12	6.48	4.12	1.97	5.08	2.06	2.00	0.39	0.056	0.20
70-80	17.70	2.45	6.78	4.10	1.99	5.22	2.02	2.02	0.38	0.055	0.24
80-90	17.81	2.39	6.88	4.16	2.01	5.24	2.03	1.99	0.39	0.055	0.22
90-92	17.50	2.37	7.05	4.15	2.05	5.45	2.00	2.00	0.37	0.056	0.35
mean	17.20	2.45	6.70	4.12	1.97	5.06	2.21	2.00	0.39	0.057	0.27

Table 2 (contin): Element concentrations in core no. M1

b) Trace Elements (ppm)

	V	Cr	CO	Ni	Cu	Zn	Pb	Li	Rb	Sr	Ba	La	Be
0-02	119	124	25	88	48	104	51	53	101	194	310	28	2.1
2-10	116	116	23	87	45	99	51	52	97	183	295	26	2.1
10-20	115	115	24	89	41	91	46	54	103	188	296	26	2.2
20-30	118	115	24	92	41	88	40	57	96	200	304	26	2.1
30-40	116	115	24	91	38	88	37	56	101	199	276	26	2.1
40-50	121	114	25	91	40	86	38	56	95	186	284	26	2.1
50-60	119	115	24	90	40	87	39	56	98	195	294	26	2.1
60-70	120	116	25	91	41	87	38	57	95	188	324	26	2.1
70-80	121	117	25	95	41	86	37	56	98	191	350	26	2.1
80-90	118	121	25	99	41	86	37	57	95	194	246	26	2.1
90-92	121	121	26	107	48	87	44	59	108	210	330	28	2.2
mean	119	117	25	93	42	89	41	56	99	194	310	26	2.1

Table 2 (contin.) Element concentrations in core no. M4

a) Major elements (W %)

Interval (cm)	CaCO3	Organic matter	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
0-02	17.92	3.11	5.9	4.2	1.91	4.6	2.5	1.98	0.40	0.064	0.50
2-10	16.80	2.62	6.7	4.2	1.89	4.6	2.4	1.99	0.39	0.060	0.29
10-20	16.10	2.26	6.56	4.16	1.91	4.62	2.36	2.04	0.39	0.061	0.21
20-30	16.80	2.19	6.64	4.08	1.92	5.00	2.26	2.03	0.39	0.057	0.23
30-40	18.10	2.24	6.78	4.16	1.96	5.16	2.18	2.00	0.38	0.057	0.24
40-50	18.30	1.96	6.78	4.10	1.96	5.14	2.16	2.02	0.38	0.56	0.18
50-60	15.90	2.00	6.78	4.12	1.91	5.02	2.06	1.97	0.40	0.057	0.24
60-70	15.60	1.92	6.78	4.18	1.91	2.94	2.08	1.97	0.40	0.057	0.19
70-80	16.10	2.77	6.76	4.12	1.94	5.08	2.01	2.01	0.39	0.057	0.24
80-90	16.30	3.20	6.62	4.08	1.89	5.02	1.94	1.95	0.39	0.55	0.20
mean	16.70	2.35	6.72	4.13	1.92	4.95	2.17	2.00	0.39	0.058	0.23

Table 2 (contin.) Element concentrations in core no. M4

b) Trace Elements (ppm)

	V	Cr	CO	Ni	Cu	Zn	Pb	Li	Rb	Sr	Ba	La	Be
0-02	120	131	25	90	48	111	59	58	115	192	300	27	2.1
2-10	118	114	24	86	43	98	49	56	93	185	300	26	2.1
10-20	118	110	24	87	44	100	42	56	98	187	300	26	2.1
20-30	116	112	24	87	39	87	38	55	98	194	306	25	2.1
30-40	116	114	24	90	39	89	39	56	97	197	292	26	2.1
40-50	177	113	24	88	38	87	33	56	92	198	284	26	2.1
50-60	122	111	25	86	39	87	35	55	91	194	292	25	2.1
60-70	121	114	24	87	40	85	35	55	94	190	310	26	2.1
70-80	119	112	25	88	40	86	39	56	97	190	300	26	2.1
80-90	117	112	24	89	40	84	36	54	93	186	320	25	2.1
90-92	118	113	24	88	40	90	34	55	95	196	300	26	2.1
mean													

The vertical distribution of elements along the core is shown graphically in Figure (6). The elements which are not represented graphically are those having almost straight line distribution pattern from top to bottom (Sea table 2). Since the ranges and distribution patterns are almost similar in the two cores the discussion and interpretation of data concern both.

The overall data indicate that the sediments have a chemical composition closely similar to that of standard shale (Table 3). For comparison, chemical data of some other related sediment types and distinctive element ratios are also given in the table. The interrelationships between the elements are expressed in terms of the correlation coefficient matrix (Table 4).

Calcium carbonate and Organic matter

The calcium carbonate content fluctuates within relatively narrow limits (15.6-18.3 %) being 17 % in average. The concentration profiles of CaCO$_3$ suggest some carbonate dissolution in the upper layer.

The organic matter content on the other hand varies between 1.92 and 3.2 % around the average value of 2.4 %.

These data are not conformable to earlier studies for core sediments from the neighborhood by Stanley and Blanpied (1980). Their data show inversed picture where the carbonates rang up to 3 % only and the organic matter up to 19 %. The disagreement between their results and ours can probably be explained in terms of site location and possible variations in subenvironment conditions in such geologically active basins (Sea Maldonado et al., 1981).

The main contributor to the carbonate fraction seems to be the Coccoliths of the clay fraction followed by the sand fraction components (Foramineferas, Bivalves, etc.).

On the other hand, the relative enrichment in organic matter is obviously due to co-settlement of clay particles and light organics under quite deep sea condition. The generated amount of particulate organic matter in the Sea of Marmara is 8 x 10^5 tons/y, almost half of this figure sinks to the bottom (IMS - ETU, C, 1986). Better preservation of organic matter in low redox - potential environments and the rapid burial due to the high rate of sedimentation resulted in the high content of organic matter in sediments (Calvert, 1976).

Al, Mg, Ca, Na and K

The aluminium content of sediments is high indicating terrigenous source predominated by aluminosilicates such as clay minerals and feldspars.
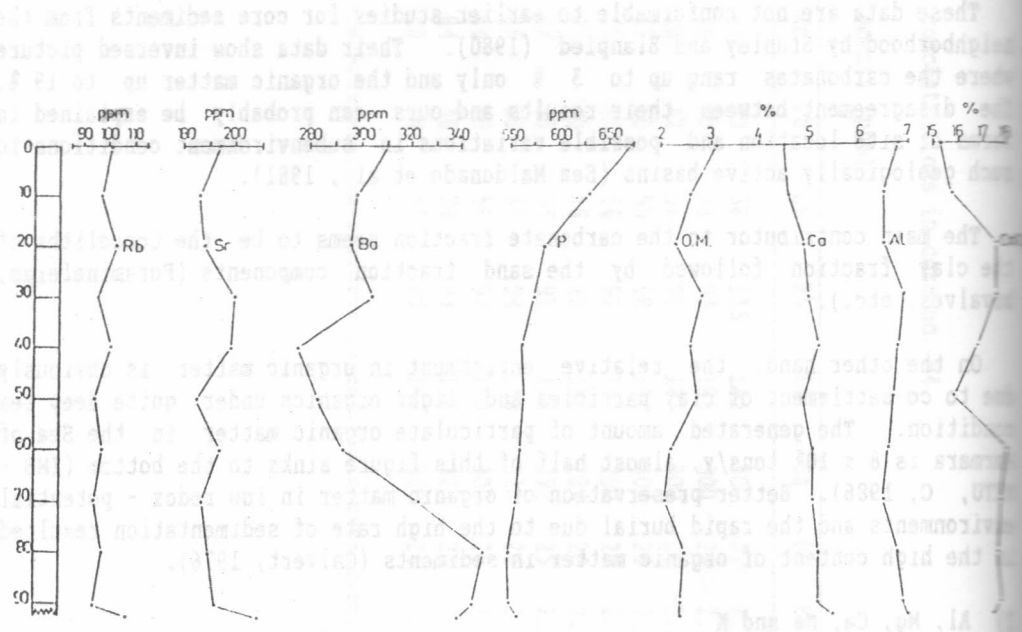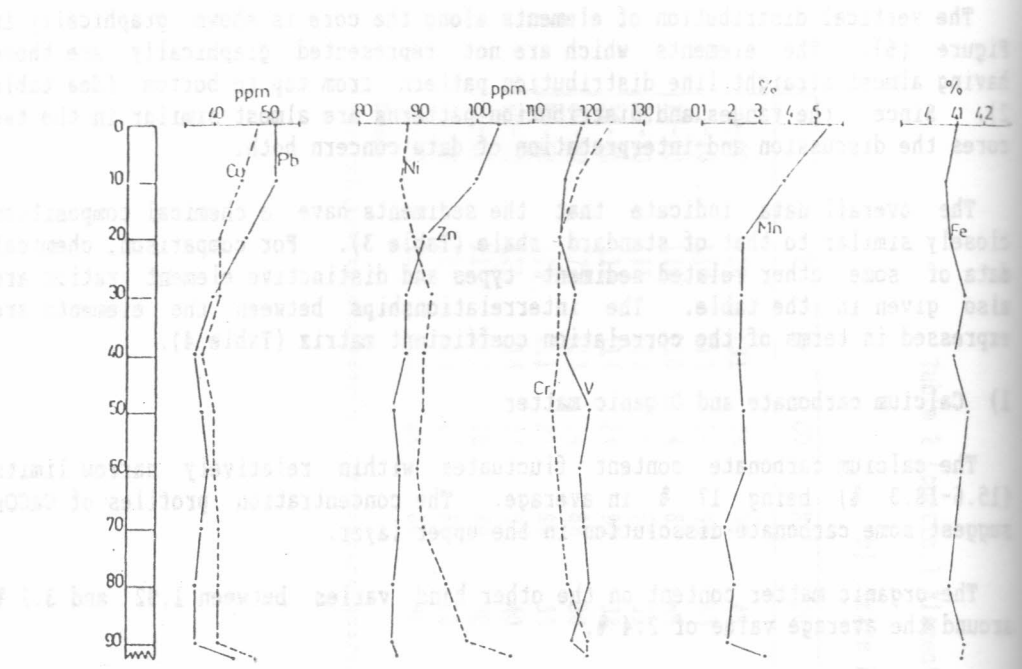
Figure 6: Vertical distribution of elements along core No. Ml.
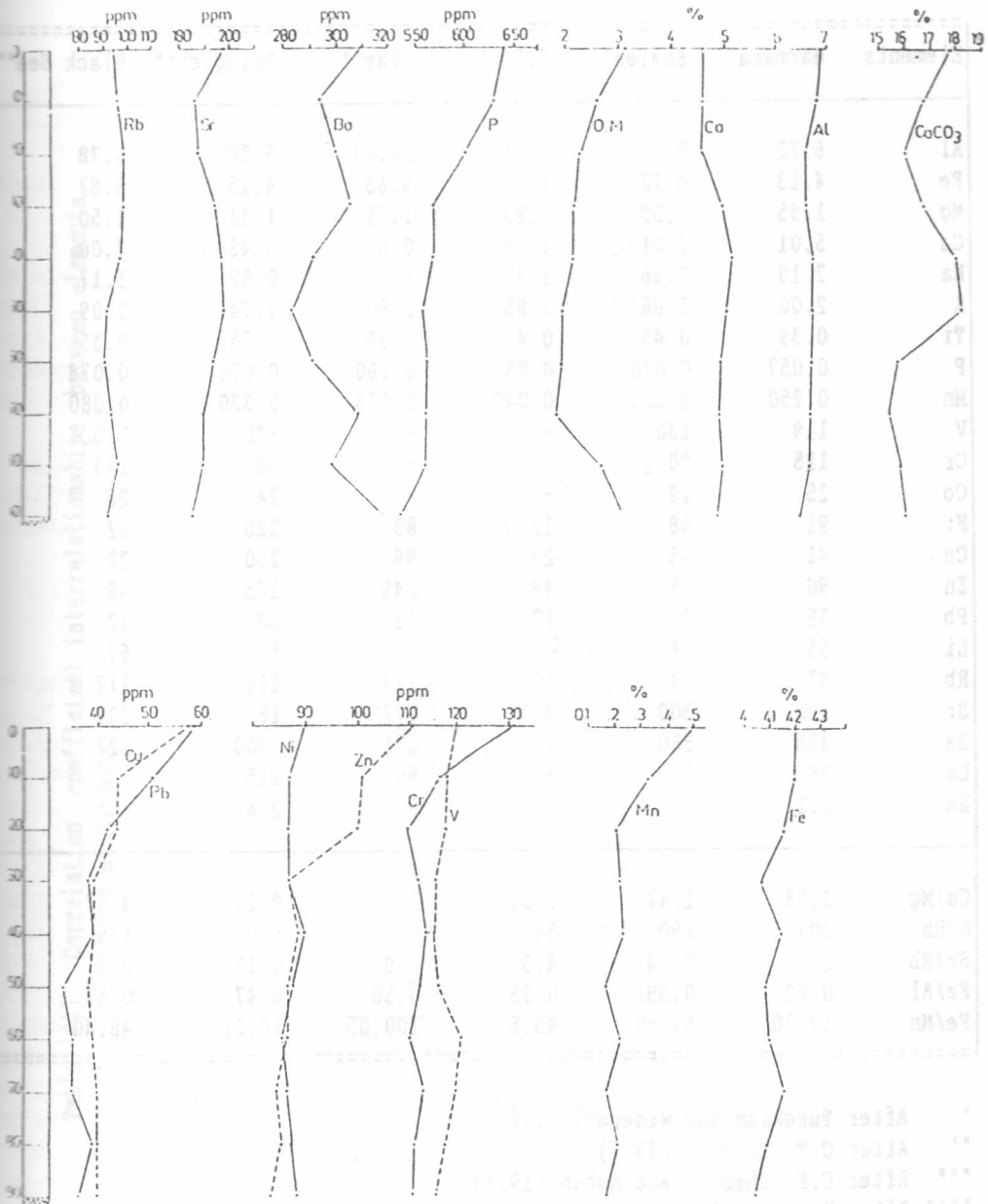
Sediments from Sea of Marmara.

Figure 6 (contin): Vertical distribution of elements along core No. M4.

Table (3): Average element concentrations and distinctive ratios in the
sediments of the Sea Marmara and comparable types.

Elements	Marmara	Shales*	Silt**	Clay**	Pelagic***	Black Sea****
Al	6.72	8.00	5.86	10.12	6.50	6.78
Fe	4.13	4.72	1.77	6.63	4.15	3.87
Mg	1.95	1.50	0.83	1.91	1.31	1.50
Ca	5.01	2.21	1.29	0.64	0.43	7.00
Na	2.19	0.96	1.84	-	0.82	1.17
K	2.00	2.66	1.85	2.90	1.74	2.09
Ti	0.39	0.46	0.43	0.59	0.35	0.35
P	0.057	0.070	0.052	0.160	0.070	0.074
Mn	0.250	0.085	0.040	0.073	0.320	0.080
V	119	130	-	-	120	225
Cr	115	90	-	-	90	143
Co	25	19	-	-	74	26
Ni	91	68	22	83	225	82
Cu	41	45	20	96	250	38
Zn	90	95	49	245	165	98
Pb	38	20	17	53	80	12
Li	56	66	-	-	57	67
Rb	97	140	65	173	110	117
Sr	195	300	280	177	18	337
Ba	305	580	769	671	2300	327
La	26	92	34	66	115	-
Be	2.1	3	-	-	2.6	-
Ca/Mg	2.58	1.47	1.31	0.28	0.28	4.67
R/Rb	207	190	343	658	190	179
Sr/Rb	2	2.14	4.3	1.0	0.16	2.9
Fe/Al	0.62	0.59	0.23	0.50	0.47	0.57
Fe/Mn	17.30	55.50	43.6	100.85	14.22	48.40

*   After Turekian and Wedepohl (1961)
**   After C.F. Calvert (1976)
*** After C.F. Chester and Aston (1976)
**** After Hirst (1974)

Table (4)): Correlation coefficient interrelationships between elements of Sea of Marmara.

	Mn	V	Cr	Co	Ni	Cu	Zn	Pb	Li	Rb	Sr	Ba	La	Be	Co$_3$	Om	Al	Fe	Mg	Ca	Na	K	Ti	P
Mn	1																							
V	0.03	1																						
Cr	0.54	0.08	1																					
Co	0.19	0.70	0.43	1																				
Ni	0.26	0.29	0.76	0.71	1																			
Cu	0.71	0.15	0.54	0.36	0.47	1																		
Zn	0.54	-0.39	0.05	-0.36	0.21	0.55	1																	
Pb	0.82	-0.31	0.39	-0.11	0.01	0.74	0.81	1																
Li	0.30	0.39	0.19	0.60	0.70		-0.57	-0.50	1															
Rb	0.50	-0.16	0.44	0.27	0.59	0.54	0.13	0.46	0.3	1														
Sr	0.10	0.08	0.32	0.32	0.64	0.09	-0.35	-0.22	0.69	0.46	1													
Ba	-0.06	0.38	0.52	0.51	0.61	0.34	-0.28	-0.1	0.33	0.12	0.07	1												
La	0.46	0.22	0.65	0.50	0.75	0.66	0.09	0.33	0.51	0.71	0.54	0.21	1											
Be	0.33	0.06	0.37	0.34	0.51	0.48	0.00	0.37	0.20	0.77	0.36	0.13	0.6	1										
Co$_3$	-0.15	-0.22	0.38	0.04	0.42	-0.11	-0.22	-0.12	0.44	0.23	0.48	0.24	0.3	0.23	1									
Om	0.24	0.20	0.07	-0.01	0.1	0.15	0.04	0.25	-0.19	0.06	-0.21	0.06	-0.07	-0.08	-0.25	1								
Al	0.05	0.34	0.36	0.44	0.62	0.10	-0.35	-0.23	0.54	0.18	0.74	0.23	0.34	0.22	0.21	0.05	1							
Fe	-0.01	0.48	0.16	0.16	0.18	0.21	0.13	0.04	0.23	-0.06	0.08	0.02	0.34	-0.11	-0.01	-0.16	0.43	1						
Mg	-0.05	0.30	0.54	0.62	0.85	0.08	-0.50	-0.31	0.88	0.45	0.73	0.40	0.64	0.3	0.62	-0.11	0.62	0.21	1					
Ca	-0.24	0.26	0.31	0.84	0.70	-0.23	-0.80	-0.58	0.78	0.26	0.74	0.38	0.34	0.22	0.53	-0.11	0.61	-0.04	0.85	1				
Na	0.48	-0.57	0.02	-0.56	-0.39	0.28	0.80	0.74	-0.59	0.16	-0.27	-0.46	-0.03	0.08	-0.15	0.05	-0.39	-0.15	-0.50	-0.74	1			
K	-0.35	-0.17	-0.19	-0.06	0.11	-0.17	-0.05	-0.15	0.47	0.35	0.33	0.07	0.15	0.18	0.47	-0.18	0.17	0.08	0.40	0.21	0.07	1		
Ti	-0.28	0.56	0.37	0.14	-0.33	-0.21	-0.18	-0.31	-0.11	-0.53	-0.43	-0.07	-0.40	-0.35	-0.59	-0.16	-0.18	0.40	-0.31	-0.23	-0.33	-0.33	1	
P	0.57	-0.29	-0.02	-0.38	-0.43	0.51	0.96	0.81	-0.68	0.04	-0.41	-0.34	0.01	-0.39	-0.39	0.04	-0.35	0.12	-0.64	-0.86	0.82	-0.19	0.05	1

The calcium and magnesium content on the other hand may represent terrigenous (Plagioclase feldspar, clay minerals, amphibole, etc.) as well as biogenic and chemogenic fractions. Both elements are moderately correlated with $CaCO_3$ and Al.

Sodium is negatively correlated with the lithogenous elements and the calcium as well. Meanwhile, it shows positive correlation with Mn, Zn, P and Pb, suggesting its association with other phases (hydrogenous phase for example). Potassium does not show significant correlation with any of the elements. However, its weak correlation ($\tilde{}$ 0.4) with $CaCO_3$, Mg and Li probably indicate its uptake by marine organisms.

The variability in concentrations of the above mentioned five elements along the core is almost negligible. However, sodium shows slight steady decrease downcore apparently resulting from the upward diffusion of interstitial water due to compaction and the diagenesis of sodium bearing hydrogenous phases as well. Calcium also shows some decrease in the upper 20 cm of sediments, which could be a result of carbonate dissolution at the surface.

However, as a general rule, such slight variations in the concentrations of some of the major elements can be attributed also to minor changes in mineralogy or grain size of sediments.

3) **Ba and Sr.**

Barium shows a wide range of variability along the core length relative to strontium. Both elements are known to be originally derived in the feldspar structure. Plagioclase feldspars are commonly strontium bearing, whereas potash feldspare are barium bearing (Rankama and Sahama, 1950). However, part of the dissolved Ba and Sr is again being subjected to redeposition in the marine environment in association with carbonates or manganese oxides (Arrhenius, 1963). Barium can also precipitates by silicous organisms (Revelle et al., 1955). Strontium on the other hand is specially incorporated in the carbonate phase (Wedepohl, 1971).

In general, the data show moderate to strong correlation of Sr with carbonate, aluminium, calcium and magnesium suggesting both lithogenous and biogenious sources for Sr. Contrarily, barium does not show significant correlations with any of the studied elements which may indicate that it could be associated with silicous organisms or present as a separate phase. Arrhenius and Bonatti (1965) suggested that barium can be removed from sea water by organisms and released as barite granules incorporated into sediments as the organic remains become oxidized.

Therefore, it is expected that strontium concentrations will increase in intervals containing excess plagioclase feldspar and carbonate shells. Whereas, barium will be enriched in intervals containing silicous organic remains, high content of potash feldspar and probably incorporated barite granules.

Li, Rb, Be and La.

The concentrations of these four elements in the core intervals are almost uniform suggesting their initial association in phases that have reached their ultimate stability and which are difficult to show transformations by diagenetic reactions at such depths of burial. Rankama and Sahama (1950) suggested that during weathering processes these elements become enriched predominantly in hydrolyzate sediments i.e. clays and shales. They mentioned that due to the similarity of ionic radii of Rb and K rubidium is always present in K-bearing sediments such as potash feldspar, biotite and lepidolite micas. However, the data show that rubidium is partly correlated with lithogenous elements and partly with hydrogenous phases. Lithium on the other hand show negative correlation with hydrogenous elements and is significantly positively correlated with Mg, Ca, Sr, and to a less extent with Al, K and $CaCO_3$. This may suggest that part of the lithium is associated with magnesium in clay minerals, micas, amphiboles and pyroxenes and part of it is enriched through uptake by calcareous organisms. Beryllium seems to be more closely following rubidium.

Although lanthanium is one of the rare-earth elements it is present in the Marmara sediments in amount comparable to other trace elements. Its concentration however is only one third of its original concentration in shales. This means that the greater part of lanthanium goes into solution during the processes of chemical weathering. Generally, the data indicate the association of La with the lithogenous as well as the hydrogenous elements.

Fe and Mn

The iron concentration is almost uniform all along the cores in values consistent with its concentration in standard shales. Meanwhile, manganese is present in values three times greater than in shales being significantly enriched in the upper surface layer of sediments.

The Fe/Al ratio is almost the same as in shales indicating that iron is principally derived from land-either in iron-bearing minerals or most probably as ferric hydroxides commonly associated with clays.

On the other hand, the Fe/Mn ratio is 18.5 in Marmara sediments comparing to 55.5 in shales suggesting a dominating manganese source other than the terrestrial one which is obviously chemical precipitation from sea water. Chester and Messiha-Hana (1970) found that 70 % of manganese in marine sediments is present in the hydrogenous rather than the lithogenous phase. According to Goldberg and Arrhenius (1958) manganese can be specifically removed from the bottom water through catalytic oxidation of manganese ions by colloidal ferric hydroxide at the sediment-water interface. Oxidation of manganese ions can be also autocatalytic (Stumm and Morgan, 1981) or can be influenced by inorganic ions such as HCO_3^- or SO_2^{2} (Hem, 1964). Besides, it was found that the Mediterranean bottom-water layer in the Sea of Marmara is saturated with respect to manganese. Values up to 450 ug/l were measured in the Bosphorus bottom water (Skopintzef, 1975; c.f. IMS-METU, C, 1986). Such high

manganese concentrations may favor the formation of colloidal manganese hydroxides if any change in the physico-chemical conditions of water occur, for example the removal of CO_2 (Rankama and Sahama, 1950).

Meanwhile, post-depositional diagenetic processes related to redox conditions in the sediment-interstitial water system result in upward diffusion of manganese. In anoxic sediments manganese and iron are mobilized; iron is fixed within the sediment as sulfide, whereas, manganese migrates to the upper sediment layer to be precipitated in the oxidized zone. However, Lynn and Bonatti (1965) and Li et al (1969) suggested that part of the manganese will be fixed in the reduced layer in the form of manganoan carbonates.

As subsequently shown, these highly reactive manganese oxide/hydroxide afford the most favorable conditions for adsorption of several element ions such as Zn, Pb, Cu, Cr, Ni, P, Na, etc.

6) Phosphorous

Although the concentration of phosphorous in the sediments is close comparable to that in shale, the data do show that much of it is related to authigenic precipitation. It shows a moderate to strong correlation with In, Pb, Na, Mn and Cu, while, in the meantime it shows negative correlation with lithogenic components (Al, Mg, Ca, Li, etc.) and with biogenic components (organic matter and $CaCO_3$) as well. Association of phosphorous with manganese phases in deep sediments has been previously shown by Arrhenius (1952).

The vertical distribution of phosphorous along the cores shows upward enrichment resulting probably from diagenesis. In the reduced layer of sediments phosphate is released to the interstitial water (Stumm and Leckie 1971) and under oxic conditions at the sediment-water interface it becomes adsorbed on clay minerals (Berner, 1974) or on metal hydroxides.

7) Ti and V

The distribution of these two elements along the cores is almost constant. They seem to be introduced into the Sea of Marmara in the same mineral phase more likely being incorporated in the heavy mineral structure. The data do not show any correlation between these elements and the clay components. Meanwhile titanium and vanadium are positively correlated with each other as well as with iron which may confirm that heavy minerals are the main host.

Zn and Cu

These elements are slightly enriched in the upper 10-30 cm of sediments relative to lower core intervals. The data suggest that both zinc and copper are probably associated with a hydrogenous manganese phase. where a strong positive correlation between them and Mn, Pb, P and sodium is found. In the meantime, Zn and Cu are either negatively correlated or not correlated at all with lithogenic components. Lynn and Bonatti (1965) suggested that the

increased copper and zinc concentrations in the oxic sediments are a consequence of manganese oxide dissolution in the subsurface resulting in their liberation and subsequent precipitation in the surface layer.

9) Cr, Ni and Co

The variability in concentrations of these elements along the whole length of both cores is negligible. The three elements are positively correlated with each other, and in the meantime they are positively correlated with alkaline, alkaline earth elements and aluminium. This indicates that they are primarily derived from land, more likely associated with clay minerals. However, the positive correlation between chromium and manganese suggest that chromium is partly associated with the precipitated manganese oxide phase. Also the positive correlation between nikel and carbonates could possibly indicate nikel uptake by calcareous organisms.

10) Lead

Lead like manganese shows increased values relative to its concentration in shales and average crustal rocks. Its enrichment in the upper oxic layer confirm its association with Manganese.

The data show a strong positive correlation of lead with manganese, zinc, phosphorous, copper and sodium, i.e. elements showing indications of hydrogenous precipitation. Meanwhile, lead is negatively correlated with most of the lithogenic and biogenic elements. Like manganese, lead is highly enriched in the Bosphorus bottom water layer. The factor of enrichment was estimated as 460 (DAMOC/WHO/UNDP/SF/TUR 20, 1971). The rapid change in the physico-chemical characteristics of the Mediterranean water upon entering the Sea of Marmara will result in the precipitation of the dissolved lead ions.

Finally, it is of importance to note that the enrichment of lead and also of other elements due to anthropogenic contamination is not taken into consideration herein because the vertical profiles of concentrations do not suggest such case.

CONCLUSIONS

1. The sediments are extremely homogenized probably due bioturbation and resultant sediment mixing. Their are no major sedimentological, chemical or paleontological differences along the core intervals.

2. The chemical composition of sediments indicate the preponderance of aluminosilicates.

3. The geochemistry of sediments is significantly influenced by hydrogenous precipitation and postdepositional diagenetic reactions.

4. As a general conclusion, the sedimentary characteristics in the deep parts of the "Northeastern Marmara Basin" indicate the prime influence of terrigenous sedimentation that has been modified by deep-sea conditions, biogenic activity and low redox potential.

ACKNOWLEDGMENTS

REFERENCES

Arrhenius, G., 1952. Sediment cores from the East Pacific. Reps. Swed. Deep-Sea Expedition, 5, Goteberg.

Arrhenius, G., 1963. Pelagic sediments. In: The Sea, M.N. Hill (ed), Interscience, New York, 3: 655-727.

Arrhenius, G. and Bonatti, E., 1965. Neptunism and volcanism in the ocean. In: Progress of Oceanography, M. Sears (ed), Pergamon Press, New York, 3: 7-21.

Berner, R.A., 1974. Kinetic models for the early diagenesis of nitrogen, sulfur, phosphorous and silicon in anoxic marine sediments. In: The Sea, E.D. Goldberg (ed), Jhon Willy and Sons, New York, 5: 427-450.

Brinkmann, R., 1976. Geology of Turkey. Elsevier, Amesterdam, 158 p.

Calvert, S.E., 1976. The mineralogy and geochemistry of near shore sediments. In: J.P. Riley and R. Chester (eds.), Chemical Oceanography, Academic Press, New York, 6: 187-280.

Carter, T.G., Flanagan, J.P., Jones, C.R., Marchant, F.L., et al., 1972. A new bathymetric chart and physiography of the Mediterranean Sea. In: The Mediterranean Sea, a Natural Sedimentation Laboratory, D.J. Stanley (ed), Dowden, Hutchinson and Ross Inc., Pennsylvania, 1-23.

Chester, R. and Aston, S.R., 1976. The geochemistry of deep-sea sediments. In: J.P. Riley and R. Chester (eds.), Chemical Oceanography, Academic Press, New York, 6: 281-390.

Sediments from Sea of Marmara.

Chester, R. and Messiha-Hanna, R.G., 1970. Trace element partition patterns in north Atlantic deep-sea sediments, Geochim. Cosmochim. Acta, 34: 1121-1128.

Crampin, S. and Evans, R., 1986. Neotectonics of the Marmara Sea region of Turkey, Jour. Geol. Soc., London, 143: 343-348.

DAMOC/WHO/UNDP/SF/TUR-20, 1971. Master plan and feasibility report for water supply and sewage for the Istanbul region, vol. III, part II, ministry of energy and natural resources, Turkey.

Ergin, M and Moussa, A.A., 1987. Geochemistry of two sediment cores from the Sea of Marmara, Abstracts of the Fourth Meeting of the European Union of Geosciences, TERRA CONGINTA, vol. 7.

Goldberg, E.D. and Arrhenius, G.O., 1958. Chemistry of pacific pelagic sediments, Geochim. Cosmochim. Acta, 13: 153-212.

Gunnerson, C.G. and Ozturgut, E., 1974. The Bosphorus. In: The Black Sea - Gealogy, Chemistry and Biology, E.T. Degens and D.A. Ross (eds.), Mem. Am. Assoc. Petrol. Geol. 20, Tulsa, Oklahoma, 99-114.

Hem, J.D., 1964. Deposition and solution of manganese oxides U.S. Geol. Surv. Water Supply Pap., 1667-B, 42.

Hirst, D.M., 1974. Geochemistry of sediments from eleven Black Sea cores. In: The Black Sea - Geology, Chemistry and Biology, E.T. Degens and D.A. Ross (eds.), Mem. Am. Assoc. Petrol. Geol. 20, Tulsa, Oklahoma, 430-455.

Ilhanm E., 1976. Geology of Turkey, MIddle East Technical University, Faculty of Engineering Rep. no. 51, Ankara, 239 p. (In Turkish).

IMS-METU, 1986 a. Institute of Marine Sciences, Middle East Technical University Annual REport: Oceanography of the Turkish Straits, Vol. I, Physical Oceanography, 136 p.

IMS-METU, 1986 b. Institute of Marine Sciences, Middle East Technical University Annual Report: Oceanography of the Turkish Straits, Vol. II, Health of the Turkish Straits: Oxygen deficiency of the Sea of Marmara, 78 p.

IMS-METU, 1986 c. Institute of Marine Sciences, Middle East Technical University Annual Report: Oceanography of the Turkish Straits, Vol. III, Health of the Turkish Straits: Chemical and environmental aspects of the Sea of Marmara, 86 p.

Li, Y.H., Bischoff, J. and Mathieu, G., 1969. The migration of manganese in the Arctic basin sediments, Earth Planet. Sci. Lett., 7: 265-270.

Lykousis, V., Collins, M.B. and Ferentions, G., 1981. Modern sedimentation in the N.W. Aegean Sea, Marine Geol, 43: 111-130.

Lynn, D.C. and Bonatti, E., 1965. Mobility of manganese in diagenesis of deep-sea sediments. Marine Geol. 3: 457-474.

Maldonado, A., Kelling, G. and Anastasakis, G., 1981. Late Quaternary sedimentation in a zone of continental plate convergence - The Central Hellenic Trench System. Marine Geol. 43: 83-110.

Rankama, K. and Sahama, Th. G., 1950. Geochemistry. University of Chicago press, Chicago, 911 p.

Revelle, R., Bramlette, M., Arrhenius, G. and Goldberg, E.D., 1955. Pelagic sediments of the Pacific. Spec. Paper, Geol. Soc. Am., 62: 221-236.

Rigassi, D., 1971. Petroleum geology of Turkey, In: Geology and history of Turkey. A.S. Cambell (ed), The Petroleum Exploration Society of Libya, Tripoli, 453-482.

Scholten, R., 1974. Role of Bosphorus in Black Sea Chemistry and Sedimentations. In: The Black Sea - Geology, Chemistry and Biology, E.T. Degens and D.A. Ross (eds.), Mem. Am. Assoc. Petrol. Geol., Tulsa, Oklahoma, 20: 115-126.

Stanley, D.J. and Blanpied, C., 1980. Late Quaternary water exchange between the Eastern Mediterranean and the Black Sea, Nature, vol. 285, no. 5766, 537-541.

Strakhov, N.M., 1954. Formation of sediments in the Black Sea, In: Formation of sediments in modern reservoirs, D.S. Belyankin (Ed), Akad. Nauk. SSSR, Moscow, 81-136.

Stumm, W. and Leckie, J.O., 1971. Phosphate exchange with sediments; its role in the productivity of surface waters, Adv. in Water Poll. Res., vol. 2, Pergamon Press, New York, III: 26/1-26/16.

Stumm, W. and Morgan, J.J., 1981. Aquatic chemistry. Wiley Interscience, New York, 583 p.

Turekian, K.K. and Wedephol, K.H., 1961. Distribution of the elements in some major units of the earth's crust. Bull. Geol. Soc. Am., 27: 175-192.

Water Quality and Annual Observations (1979-1982), 1985. Ministry for energy and natural resources, general directorate for water affairs, department of drinking water and sewage, Ankara (In Turkish).

Wedepohl, K.H., 1971. Environmental influences on the chemical composition of shales and clays. In: Physics and chemistry of the earth, L.H. Ahrens, F. Press, S.K. Runcorn and H.C. Urey (eds.), Pergamon Press, New York, 8: 305-333.