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# Source and depositional controls on heavy metal distribution in marine sediments of the Gulf of İskenderun, Eastern Mediterranean

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**Abstract**

The concentrations of major (Al, Mg, Fe, and Mn) and trace (Zn, Cr, Ni, Co, Cu, and Pb) elements as well as carbonate, organic carbon, and grain size distributions have been determined in surface sediments collected at 73 stations from the Gulf of İskenderun.

The shelf sediments of the Gulf of İskenderun are largely muds but sediments with higher contents of sand and gravel also occur due to the presence of high biogenic $CaCO_3$ contents (up to 80%) in the samples.

The abundance and regional distributions of elements in the surface sediments of the Gulf are largely controlled by differences in grain size and in the level of dilution by skeletal/shell remains, and by the variation in composition of source materials. Mg, Ni, Cr, Co, and to a lesser extent Zn and Pb, are significantly enriched relative to their average crustal abundances. These metal enrichments are found especially in the eastern part along the SW–NE-trending areas of the Gulf and are mostly consistent with the chemical and mineralogical compositions of the major basic and ultrabasic source rocks present on the adjacent coast and hinterland. There is strong evidence that suggest that aluminosilicates, Fe and Mn compounds (possibly oxyhydroxides), and organic matter act as the most effective carriers for transfer of available metals (Zn, Cr, Ni, Co, and Cu) to the sediments.

## 1. Introduction

The Gulf of İskenderun is situated in the easternmost part of the Mediterranean Sea off southern Turkey (Fig. 1). The Gulf of İskenderun serves as an ideal natural laboratory to study the combined effects of various terrain sources on the sediment chemistry. To the south and east, the Gulf is bordered by narrow coastal plains usually flanked by a high topographic relief with abundant ophiolitic (i.e., basic and ultrabasic rocks) series and associated mineral deposits of Cretaceous to Quaternary age. In contrast, large fluvial plains flanked by Neogene calcareous rocks (mainly Miocene limestones and marls poor in heavy metals) occur in the north and west of the Gulf.

The very limited knowledge on marine sediment geochemistry of the Gulf of İskenderun (Ergin et al., 1988; Kapur et al., 1989) prompted the present study with as main purpose the investiga-

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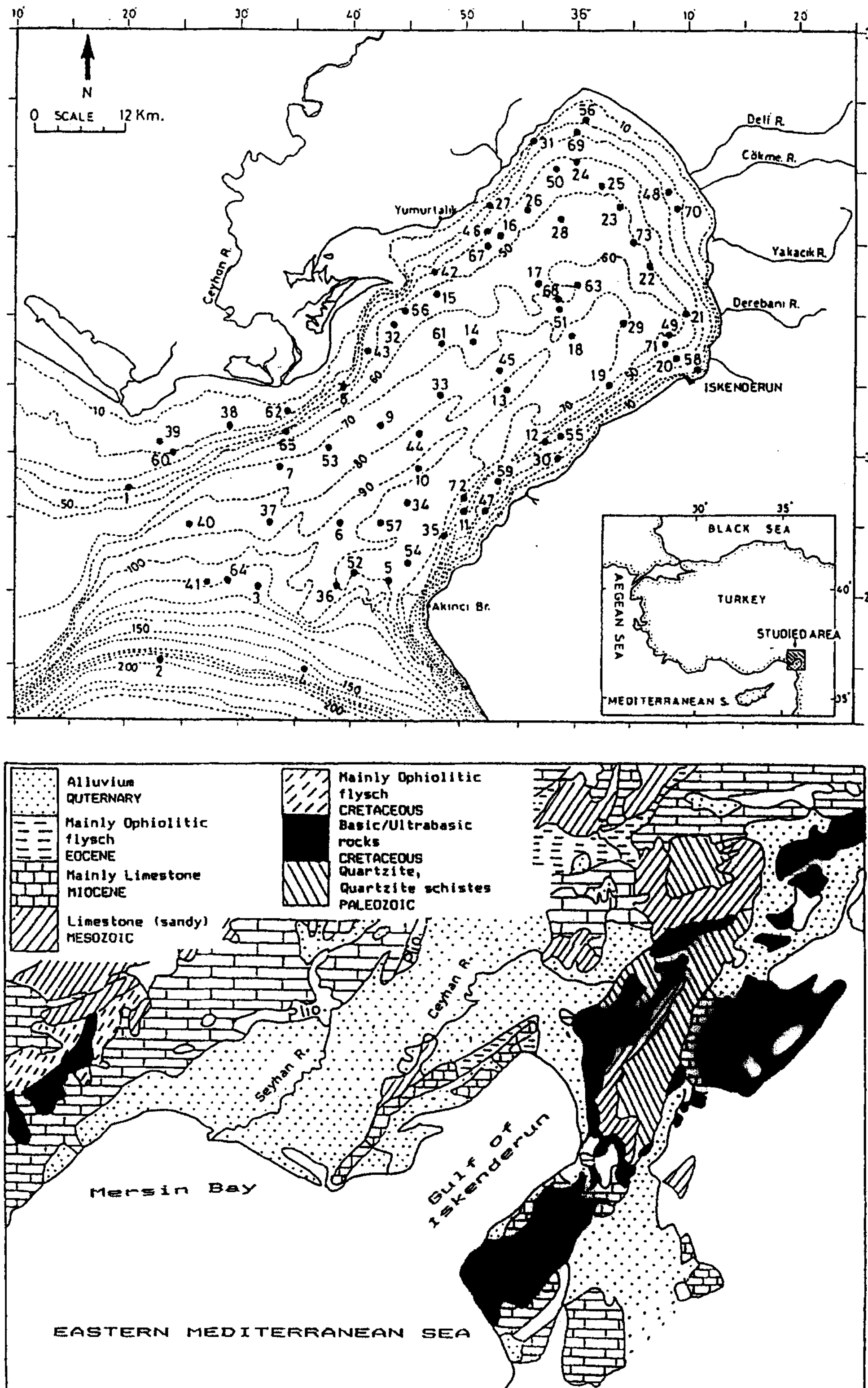


Fig. 1. Map showing the bathymetry, sampling stations and surrounding-land geology of the study area, Gulf of İskenderun. Geology is slightly modified from the Geological Map of Turkey (1989).

tion of the major geochemical characteristics of bottom sediments in respect to the geological specifics of the surrounding land. Particular emphasis here is placed on the dispersal and provenance of major (Al, Mg, Fe, Mn) and minor (Zn, Cr, Ni, Co, Cu, and Pb) elements, as well as grain size, organic carbon content, and carbonate distribution in the sediment. The results presented here show that the elemental distribution in marine sediments can be used as guidance in finding the source rocks, providing a useful tool for geochemical exploration of mineral deposits.

## 2. Geology, hydrography and potential sources of heavy metals to the Gulf of İskenderun

The geological evolution of the Gulf of İskenderun is related to Neogene convergence and strike-slip displacements along the East Anatolian and Dead Sea Fault complexes (e.g., Şengör et al., 1985; Kelling et al., 1987). During the Plio-Quaternary period, this orogenic depocentre was filled with very thick sedimentary sequences from the prograding deltas (Tolun and Pamir, 1975).

The important geological formations (Fig. 1) outcropping in the coastal hinterland of the gulf have already been reported in Aslaner (1973) and Tolun and Pamir (1975). Of these formations, the Cretaceous ophiolitic succession (up to 3000 m thick) represented by various basic (mainly gabbro, amphibolite, diabase and basalt) and ultrabasic (mainly dunite, harzburgite, and serpentinite) rocks comprises a potentially important source of some heavy metals (i.e., Cr and Ni).

The Ceyhan River is the main supplier of siliciclastic sediments into the Gulf and has built a prominent delta complex with a large fluvial coastal plain, exhibiting several typical lagoons, marshes, abandoned channels, delta mouths, etc (Bal and Demirkol, 1987). Other rivers and streams entering the gulf are ephemeral and are found on the eastern and southern hinterland. These regions are characterized by narrow coastal plains (i.e., Fig. 1) usually flanked by high topography.

The general circulation current pattern in the Gulf of İskenderun is largely affected by the northwesterly flowing open-sea waters and local winds (Fig. 2; Iyiduvar, 1986). During the summer months, branches of open-sea waters enter in the gulf from the northwest and forms clockwise and anticlockwise gyres (Fig. 2). During this period, as a result of radiative heating of the surface, the water column is strongly stratified. During the winter, open-sea waters enter into the gulf from the south-southwest and move towards the inner gulf along the coast (Fig. 2). Due to northerly and northeasterly winds in winter, the water in the gulf becomes cooler and wind-induced mixing intensifies resulting in a homogenous vertical structure in the water column.

## 3. Material and methods

Seventy-three surface (5–6 cm of the top layer) sediment samples were taken during the 1988–1991 cruises of *R.V. Bilim* and *R.V. Çubuklu* in the Gulf of İskenderun, in water depths ranging from 15 to 190 m (Fig. 1; Table 1). Samples were collected using a Dietz Lafonde grab and the bulk material was immediately placed in plastic bags and frozen onboard ship up until return to the laboratory. In the laboratory, sediment samples were oven-dried at 60°C and representative portions of the samples were separated for grain size analyses. Standard sieve and pipette analysis techniques (Folk, 1980) were used to determine the clay (<0.002 mm), silt (0.002–0.063 mm), sand (0.063–2 mm), and gravel (>2 mm diameter) fractions of the sediments. The term "mud" used here defines a sediment mixture composed of the varying proportions of silt and clay, with neither sand nor gravel. The main lithogenic and biogenic components of the sedi-

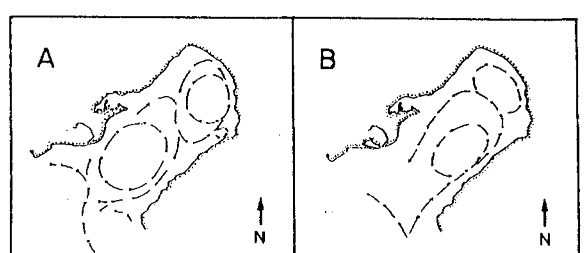


Fig. 2. Surface circulation patterns (A. summer; B. winter) in the Gulf of İskenderun (after Iyiduvar, 1986).

Table 1
Locations of the studied surface sediments and their textures obtained in the Gulf of İskenderun

| Station | Long. | Lat. | Depth (m) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Mud (%) | Texture |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 35.20 | 36.27 | 38 | 1 | 10 | 69 | 20 | 89 | (g)M |
| 2 | 35.23 | 36.15 | 190 | | 1 | 52 | 47 | 99 | M |
| 3 | 35.31 | 36.20 | 117 | 1 | 2 | 55 | 42 | 97 | (g)M |
| 4 | 35.36 | 36.14 | 137 | 1 | 57 | 23 | 19 | 42 | (g)sM |
| 5 | 35.43 | 36.21 | 76 | 2 | 20 | 46 | 32 | 78 | (g)sM |
| 6 | 35.39 | 36.25 | 86 | | 1 | 51 | 48 | 99 | M |
| 7 | 35.33 | 36.29 | 64 | | 1 | 61 | 38 | 99 | M |
| 8 | 35.39 | 36.34 | 41 | | 1 | 72 | 27 | 99 | Z |
| 9 | 35.42 | 36.32 | 78 | 1 | 1 | 53 | 45 | 98 | (g)M |
| 10 | 35.46 | 36.29 | 83 | 1 | 1 | 63 | 35 | 98 | (g)M |
| 11 | 35.50 | 36.26 | 65 | 12 | 13 | 37 | 38 | 75 | gM |
| 12 | 35.57 | 36.31 | 50 | 36 | 20 | 28 | 16 | 44 | mG |
| 13 | 35.53 | 36.35 | 76 | 1 | 2 | 45 | 52 | 97 | (g)M |
| 14 | 35.50 | 36.38 | 71 | | 1 | 47 | 52 | 99 | M |
| 15 | 35.47 | 36.41 | 55 | | 1 | 57 | 42 | 99 | M |
| 16 | 35.53 | 36.45 | 49 | | 1 | 55 | 44 | 99 | M |
| 17 | 35.56 | 36.42 | 58 | 3 | 53 | 20 | 24 | 44 | (g)mS |
| 18 | 35.59 | 36.38 | 7 | 1 | 1 | 45 | 53 | 98 | (g)M |
| 19 | 36.03 | 36.35 | 58 | 1 | 1 | 59 | 39 | 98 | (g)M |
| 20 | 36.09 | 36.37 | 44 | | 2 | 64 | 33 | 97 | M |
| 21 | 36.09 | 36.40 | 55 | 1 | 1 | 51 | 47 | 98 | (g)M |
| 22 | 36.06 | 36.43 | 55 | 1 | 6 | 55 | 38 | 92 | (g)M |
| 23 | 36.03 | 36.47 | 53 | 33 | 37 | 14 | 16 | 30 | msG |
| 24 | 36.00 | 36.50 | 45 | | 1 | 56 | 43 | 99 | M |
| 25 | 36.02 | 36.49 | 51 | 1 | 1 | 63 | 35 | 98 | (g)M |
| 26 | 35.55 | 36.47 | 48 | 1 | 1 | 60 | 38 | 98 | (g)M |
| 27 | 35.52 | 36.47 | 28 | 1 | 12 | 65 | 22 | 87 | (g)sM |
| 28 | 35.58 | 36.46 | 56 | 1 | 2 | 74 | 23 | 97 | (g)M |
| 29 | 36.04 | 36.39 | 68 | 1 | 1 | 49 | 49 | 98 | (g)M |
| 30 | 35.58 | 36.29 | 25 | 3 | 55 | 34 | 8 | 42 | (g)mS |
| 31 | 35.56 | 36.51 | 61 | 6 | 46 | 33 | 15 | 48 | gM |
| 32 | 35.43 | 36.39 | 56 | | 1 | 62 | 37 | 99 | M |
| 33 | 35.47 | 36.34 | 76 | | 1 | 55 | 44 | 99 | M |
| 34 | 35.45 | 36.26 | 83 | 1 | 1 | 51 | 47 | 98 | (g)M |
| 35 | 35.48 | 36.23 | 57 | 5 | 29 | 48 | 18 | 66 | (g)sM |
| 36 | 35.38 | 36.20 | 96 | 1 | 4 | 57 | 38 | 95 | (g)M |
| 37 | 35.32 | 36.25 | 88 | 1 | 1 | 54 | 44 | 98 | (g)M |
| 38 | 35.29 | 36.32 | 16 | 1 | 48 | 47 | 4 | 51 | (g)sM |
| 39 | 35.23 | 36.30 | 19 | 1 | 24 | 70 | 5 | 75 | (g)sM |
| 40 | 35.26 | 36.25 | 90 | 7 | 5 | 52 | 36 | 88 | gM |
| 41 | 35.27 | 36.20 | 115 | | 1 | 55 | 44 | 98 | M |
| 42 | 35.47 | 36.43 | 45 | | 1 | 64 | 35 | 99 | M |
| 43 | 35.41 | 36.37 | 46 | | 1 | 51 | 48 | 99 | M |
| 44 | 35.46 | 36.31 | 77 | | 1 | 55 | 44 | 99 | M |
| 45 | 35.53 | 36.36 | 77 | 1 | 1 | 47 | 51 | 98 | (g)M |
| 46 | 35.52 | 36.46 | 35 | | 1 | 65 | 34 | 99 | M |
| 47 | 35.52 | 36.26 | 35 | 31 | 43 | 17 | 9 | 26 | msG |
| 48 | 36.08 | 36.48 | 18 | 36 | 33 | 24 | 7 | 30 | msG |
| 49 | 36.10 | 36.38 | 58 | 1 | 1 | 52 | 47 | 99 | (g)M |
| 50 | 35.58 | 36.50 | 44 | | 1 | 58 | 41 | 99 | M |
| 51 | 35.58 | 36.40 | 65 | 4 | 14 | 31 | 51 | 82 | (g)sM |
| 52 | 35.40 | 36.21 | 80 | 1 | 1 | 41 | 57 | 98 | (g)M |
| 53 | 35.37 | 36.30 | 71 | | 1 | 56 | 43 | 99 | M |

Table 1 (*continued*)

| Station | Long. | Lat. | Depth (m) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Mud (%) | Texture |
|---|---|---|---|---|---|---|---|---|---|
| 54 | 35.45 | 36.22 | 80 | 2 | 4 | 57 | 37 | 94 | (g)M |
| 55 | 35.58 | 36.31 | 38 | 12 | 31 | 39 | 18 | 57 | gM |
| 56 | 36.01 | 36.53 | 18 | 2 | 16 | 68 | 14 | 82 | (g)sM |
| 57 | 35.42 | 36.25 | 80 | 1 | 14 | 47 | 38 | 85 | (g)sM |
| 58 | 36.11 | 36.36 | 20 | 1 | 11 | 65 | 23 | 88 | (g)sM |
| 59 | 35.53 | 36.28 | 65 | 2 | 10 | 48 | 40 | 88 | (g)sM |
| 60 | 35.24 | 36.30 | 25 | 1 | 17 | 64 | 18 | 82 | (g)sM |
| 61 | 35.48 | 36.38 | 65 | 1 | 1 | 50 | 48 | 98 | (g)M |
| 62 | 35.34 | 36.33 | 15 | | 11 | 69 | 20 | 89 | sZ |
| 63 | 36.00 | 36.42 | 70 | 1 | 80 | 10 | 10 | 20 | (g)mS |
| 64 | 35.29 | 36.21 | 94 | 1 | 2 | 54 | 43 | 97 | (g)M |
| 65 | 35.34 | 36.31 | 38 | | 1 | 60 | 39 | 99 | M |
| 66 | 35.44 | 36.40 | 51 | | 1 | 61 | 38 | 99 | M |
| 67 | 35.52 | 36.44 | 44 | | 1 | 53 | 46 | 99 | M |
| 68 | 35.58 | 36.41 | 59 | 1 | 12 | 36 | 51 | 87 | (g)sM |
| 69 | 36.00 | 36.52 | 17 | 1 | 2 | 71 | 27 | 98 | (g)M |
| 70 | 36.09 | 36.47 | 22 | 12 | 29 | 41 | 18 | 59 | gM |
| 71 | 36.08 | 36.38 | 54 | | 1 | 52 | 47 | 99 | M |
| 72 | 35.50 | 36.26 | 69 | 1 | 4 | 49 | 46 | 95 | (g)M |
| 73 | 36.05 | 36.45 | 51 | 1 | 3 | 54 | 42 | 96 | (g)M |

M = mud; Z = silt; (g)M = slightly gravelly mud; msg = muddy sandy gravel; (g)sm: slightly gravelly sandy mud; (g) ms = slightly gravelly muddy sand; mG = muddy gravel.

ment samples were identified by standard microscopic examination techniques. A representative split of each bulk (whole) sediment sample was ground for chemical analyses to a fine powder using an agate mortar. Total carbonate contents were determined volumetrically in a modified Scheibler-apparatus through the release of $CO_2$ and the results are expressed as $\%CaCO_3$. Total organic carbon contents were determined using the wet-combustion method of Gaudette et al. (1974). The analytical absolute precision for total carbonate and total organic carbon determinations were, $\pm 0.5\%$ and $\pm 0.2\%$ respectively. Total concentrations of Al, Mg, Fe, Mn, Ni, Zn, Cr, Co, Cu, and Pb were measured by flame atomic absorption spectrometer (Varian Techtron AA6 Model) after complete digestion of 0.3 g of the dry and ground bulk samples in a $HF–HNO_3–HClO_4$ mixture. Final solutions were made up in 1 *M* HCl acid. In the case of Al and Mg, an acetylene/nitrous oxide flame was used while other metals were analyzed using an acetylene/air flame. The accuracy of the analytical method was tested against standard material CRM 142 (light sandy soil from the Community Bureau of Reference Materials BCR, Brussels) and the results were satisfactory (0.1–5.0% from the accepted values), except for Co (<%15) and Al (<%19). The analytical relative precision of triplicate analysis were; $\pm 2.8\%$ for Al, and for Mg ($\pm 14.5\%$), Fe ($\pm 7\%$), Mn ($\pm 1.1\%$), Ni ($\pm 3\%$), Cr ($\pm 2.5\%$), Zn ($\pm 1\%$), Co ($\pm 14\%$), Cu ($\pm 4\%$), and for Pb ($\pm 9\%$). The log-transformed correlation coefficients were calculated using a QPRO-Advanced Math Program. Correlation matrix has been used to clarify the relationships between the distribution of the elements and the textural and chemical characteristics of the sediments in the different parts of the gulf. The correlations in this study are considered statistically significant ($r > 0.29$; $n = 73$) at greater than the 99% confidence level (Student's $t$ test; $P < 0.01$).

## 4. Results and discussion

The results obtained from the grain size and chemical analyses are presented in Fig. 3 and Table 1 as well as discussed below.

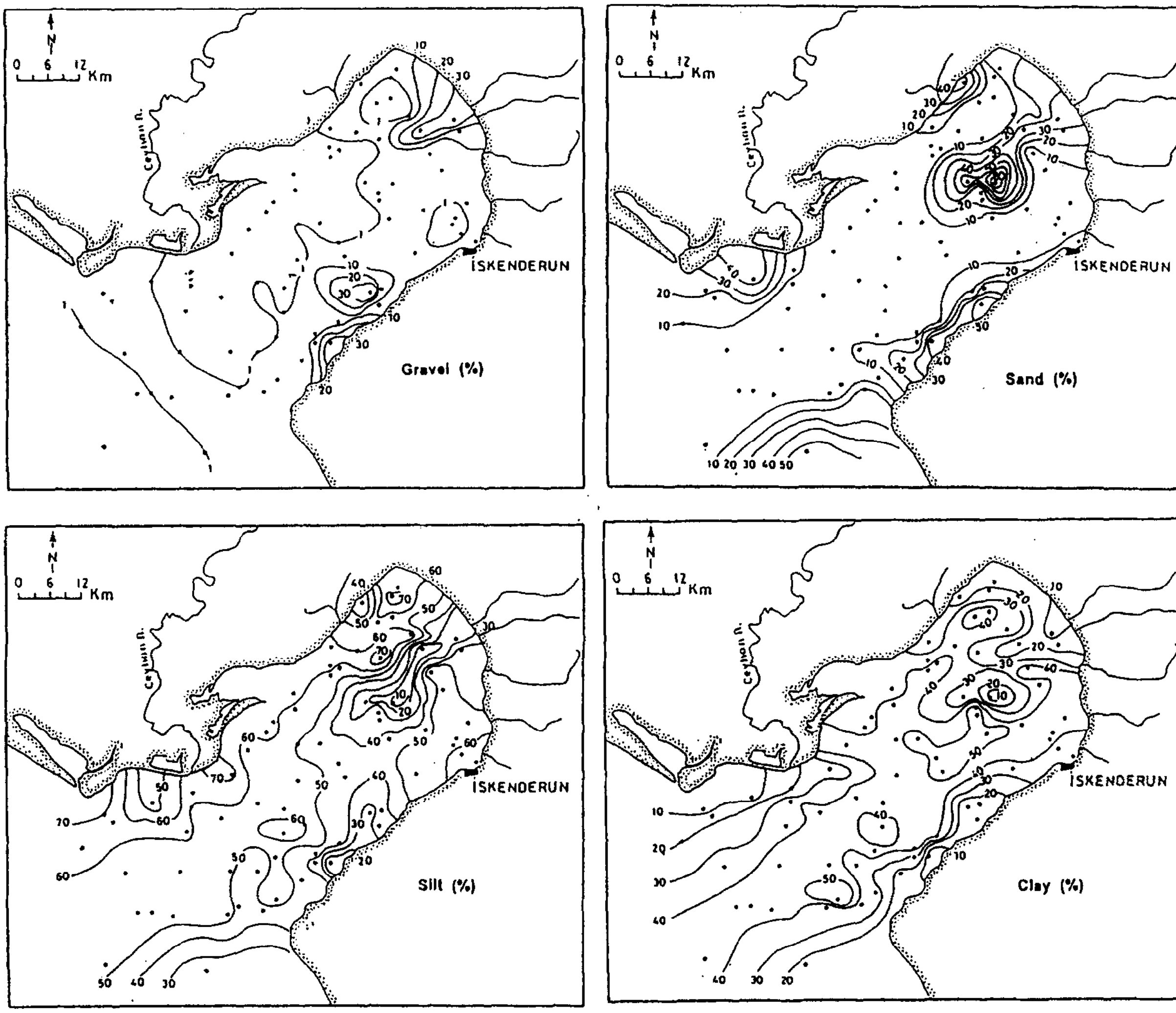


Fig. 3. Grain size distribution in surface sediments of the Gulf of İskenderun.

### 4.1. Grain-size, carbonate and organic carbon distribution

The grain-size distribution and related textural classification of the surface sediments in the Gulf of İskenderun are summarized in Table 1 and illustrated in Fig. 3. As shown, fine-grained sediments referred to as muds, with varying clay (4–71%) and silt (2–74%) fractions, dominate (up to 99% of the bulk sediment) in most parts of the Gulf (Fig. 3; Table 1). Low mud contents (30–75%) are present in patches off the southern, eastern and northwestern coasts where coarser-grained sediments contained higher sand (5–80%) and gravel (12–36%; Table 1; Fig. 3) components due to the presence of benthic organisms. Otherwise, at most stations, sand and gravel fractions in the sediments constituted no more than 2% of the bulk sediment (Fig. 3).

Total carbonate content (expressed as % $CaCO_3$) in surface sediment of the Gulf of İskenderun varies between 19–80% (Table 2; Fig. 4). The majority of sediment samples contain 20–25% $CaCO_3$ (Table 2). The carbonate contents, on the whole, show inverse correlation with the fine-grained (i.e., mud) sediment fractions

Table 2
Chemical analysis of surface sediments in the Gulf of İskenderun

| Station | Fe (%) | Mn (ppm) | Ni (ppm) | Zn (ppm) | Cr (ppm) | Co (ppm) | Cu (ppm) | Pb (ppm) | Mg (%) | Al (%) | $CaCO_3$ (%) | $C_{org}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.94 | 609 | 316 | 75 | 156 | 68 | 20 | 28 | 3.4 | 4.5 | 27.6 | 0.43 |
| 2 | 4.42 | 663 | 283 | 87 | 174 | 6 | 26 | 22 | 3.5 | 4.9 | 28.8 | 0.59 |
| 3 | 4.38 | 591 | 279 | 77 | 170 | 67 | 26 | 50 | 3.6 | 4.7 | 30.7 | 0.61 |
| 4 | 3.20 | 404 | 179 | 52 | 107 | 36 | 15 | 28 | 2.7 | 2.4 | 59.5 | 0.40 |
| 5 | 3.59 | 498 | 571 | 67 | 241 | 52 | 19 | 33 | 5.4 | 4.0 | 41.4 | 0.49 |
| 6 | 4.29 | 613 | 354 | 97 | 196 | 21 | 26 | 33 | 3.9 | 5.4 | 28.4 | 0.56 |
| 7 | 4.56 | 648 | 333 | 104 | 170 | 31 | 32 | 17 | 3.5 | 5.9 | 23.6 | 0.75 |
| 8 | 4.51 | 613 | 338 | 92 | 182 | 6 | 30 | 22 | 3.4 | 5.6 | 24.1 | 0.65 |
| 9 | 4.47 | 661 | 337 | 96 | 179 | 6 | 26 | 28 | 3.8 | 5.6 | 23.6 | 0.73 |
| 10 | 4.42 | 634 | 404 | 97 | 189 | 57 | 29 | 39 | 4.2 | 5.2 | 24.5 | 0.65 |
| 11 | 3.28 | 463 | 446 | 59 | 207 | 36 | 17 | 17 | 4.5 | 3.1 | 40.2 | 0.59 |
| 12 | 3.85 | 637 | 271 | 82 | 200 | 36 | 26 | 44 | 3.5 | 2.2 | 26.7 | 0.57 |
| 13 | 4.56 | 648 | 450 | 90 | 237 | 16 | 28 | 22 | 5.1 | 5.0 | 24.1 | 0.67 |
| 14 | 4.60 | 650 | 425 | 103 | 211 | 6 | 30 | 22 | 4.6 | 5.1 | 23.3 | 0.59 |
| 15 | 4.60 | 665 | 367 | 93 | 204 | 63 | 30 | 38 | 4.4 | 5.4 | 21.5 | 0.68 |
| 16 | 4.47 | 674 | 438 | 97 | 237 | 31 | 30 | 22 | 4.9 | 5.0 | 22.4 | 0.69 |
| 17 | 2.98 | 543 | 271 | 61 | 219 | 41 | 17 | 33 | 3.9 | 3.0 | 34.1 | 0.33 |
| 18 | 4.60 | 648 | 500 | 99 | 252 | 73 | 24 | 28 | 5.1 | 5.2 | 23.3 | 0.68 |
| 19 | 4.25 | 606 | 575 | 82 | 267 | 57 | 20 | 11 | 6.2 | 2.1 | 25.8 | 0.63 |
| 20 | 4.91 | 639 | 604 | 89 | 315 | 93 | 28 | 17 | 5.9 | 4.5 | 20.7 | 0.76 |
| 21 | 4.56 | 615 | 583 | 96 | 259 | 83 | 24 | 16 | 5.7 | 4.2 | 21.5 | 0.78 |
| 22 | 2.67 | 641 | 542 | 81 | 256 | 47 | 20 | 11 | 5.7 | 4.1 | 30.5 | 0.61 |
| 23 | 4.73 | 661 | 188 | 36 | 82 | 68 | 9 | 16 | 2.3 | 1.1 | 79.6 | 0.28 |
| 24 | 4.47 | 646 | 624 | 73 | 341 | 83 | 26 | 33 | 6.8 | 4.3 | 21.5 | 0.77 |
| 25 | 4.82 | 661 | 625 | 78 | 274 | 84 | 28 | 11 | 6.6 | 4.5 | 23.9 | 0.69 |
| 26 | 4.82 | 704 | 517 | 86 | 274 | 67 | 30 | 56 | 5.4 | 5.5 | 21.5 | 0.75 |
| 27 | 2.54 | 376 | 333 | 39 | 119 | 24 | 14 | 39 | 3.6 | 2.2 | 59.6 | 4.45 |
| 28 | 4.86 | 655 | 529 | 83 | 256 | 63 | 24 | 44 | 5.5 | 5.0 | 23.6 | 0.67 |
| 29 | 4.86 | 630 | 583 | 80 | 288 | 99 | 24 | 27 | 5.7 | 5.0 | 23.8 | 0.66 |
| 30 | 3.85 | 550 | 742 | 42 | 315 | 57 | 16 | 33 | 7.8 | 2.1 | 44.5 | 0.44 |
| 31 | 3.28 | 476 | 312 | 64 | 118 | 6 | 19 | 11 | 4.0 | 1.3 | 56.9 | 0.47 |
| 32 | 4.99 | 665 | 383 | 88 | 167 | 36 | 35 | 38 | 3.6 | 6.0 | 21.4 | 0.77 |
| 33 | 4.86 | 672 | 446 | 85 | 196 | 37 | 30 | 39 | 4.4 | 1.8 | 24.1 | 0.64 |
| 34 | 4.78 | 617 | 438 | 82 | 193 | 52 | 26 | 11 | 4.5 | 5.0 | 26.5 | 0.69 |
| 35 | 3.20 | 407 | 500 | 48 | 270 | 42 | 13 | 38 | 5.2 | 2.3 | 49.3 | 0.45 |
| 36 | 4.25 | 559 | 367 | 68 | 174 | 63 | 26 | 44 | 3.8 | 4.5 | 34.1 | 0.52 |
| 37 | 8.68 | 1130 | 596 | 117 | 694 | 94 | 39 | 61 | 6.6 | 9.4 | 24.5 | 0.62 |
| 38 | 3.46 | 602 | 275 | 56 | 200 | 31 | 17 | 11 | 3.3 | 4.1 | 23.4 | 0.32 |
| 39 | 3.55 | 624 | 292 | 53 | 185 | 83 | 14 | 44 | 3.0 | 5.7 | 29.3 | 0.39 |
| 40 | 3.72 | 550 | 342 | 70 | 141 | 57 | 22 | 22 | 3.5 | 5.3 | 34.5 | 0.62 |
| 41 | 4.38 | 620 | 338 | 77 | 167 | 68 | 24 | 38 | 3.7 | 5.7 | 27.6 | 0.58 |
| 42 | 4.78 | 657 | 408 | 78 | 245 | 63 | 29 | 27 | 4.6 | 5.1 | 22.4 | 0.68 |
| 43 | 4.86 | 648 | 367 | 84 | 219 | 83 | 30 | 28 | 3.4 | 5.6 | 20.7 | 0.78 |
| 44 | 4.60 | 667 | 388 | 79 | 259 | 78 | 24 | 16 | 4.3 | 5.4 | 25.0 | 0.67 |
| 45 | 4.56 | 657 | 467 | 77 | 322 | 73 | 25 | 39 | 4.8 | 4.7 | 23.6 | 0.71 |
| 46 | 9.03 | 570 | 388 | 80 | 203 | 47 | 32 | 22 | 4.6 | 5.2 | 24.1 | 0.74 |
| 47 | 1.57 | 281 | 296 | 30 | 70 | 57 | 11 | 22 | 4.3 | 4.0 | 71.9 | 0.52 |
| 48 | 2.58 | 463 | 363 | 50 | 174 | 63 | 12 | 28 | 5.5 | 4.1 | 41.4 | 0.44 |
| 49 | 4.73 | 630 | 596 | 78 | 389 | 57 | 26 | 28 | 5.6 | 4.6 | 22.4 | 0.66 |
| 50 | 4.42 | 665 | 641 | 60 | 359 | 63 | 22 | 17 | 6.1 | 4.0 | 20.7 | 0.79 |
| 51 | 4.03 | 600 | 450 | 74 | 270 | 83 | 22 | 22 | 3.0 | 4.0 | 34.5 | 0.65 |
| 52 | 4.60 | 646 | 425 | 80 | 233 | 78 | 24 | 27 | 4.0 | 5.3 | 25.9 | 0.64 |

Table 2 (*continued*)

| Station | Fe (%) | Mn (ppm) | Ni (ppm) | Zn (ppm) | Cr (ppm) | Co (ppm) | Cu (ppm) | Pb (ppm) | Mg (%) | Al (%) | $CaCO_3$ (%) | $C_{org}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 5.04 | 670 | 416 | 85 | 211 | 83 | 33 | 28 | 3.8 | 5.5 | 18.9 | 0.83 |
| 54 | 4.42 | 584 | 542 | 69 | 348 | 42 | 20 | 11 | 4.8 | 4.8 | 31.3 | 0.69 |
| 55 | 3.02 | 498 | 404 | 51 | 256 | 58 | 15 | 28 | 4.8 | 2.8 | 50.0 | 0.54 |
| 56 | 3.77 | 622 | 654 | 57 | 555 | 78 | 15 | 17 | 7.6 | 4.2 | 25.0 | 0.57 |
| 57 | 3.99 | 585 | 808 | 65 | 237 | 57 | 22 | 11 | 4.1 | 4.0 | 32.1 | 0.59 |
| 58 | 4.34 | 565 | 808 | 115 | 245 | 42 | 26 | 33 | 6.2 | 2.7 | 19.3 | 0.63 |
| 59 | 4.16 | 531 | 537 | 64 | 326 | 78 | 20 | 17 | 4.9 | 3.6 | 35.3 | 0.60 |
| 60 | 3.55 | 611 | 200 | 60 | 278 | 36 | 15 | 11 | 3.3 | 3.9 | 34.5 | 0.53 |
| 61 | 4.82 | 685 | 487 | 82 | 85 | 6 | 24 | 22 | 4.6 | 5.4 | 23.8 | 0.63 |
| 62 | 3.94 | 657 | 362 | 60 | 300 | 72 | 18 | 16 | 3.3 | 4.8 | 23.6 | 0.58 |
| 63 | 2.54 | 537 | 258 | 40 | 278 | 26 | 9 | 16 | 3.8 | 2.6 | 35.9 | 0.33 |
| 64 | 4.25 | 666 | 404 | 76 | 67 | 73 | 21 | 22 | 3.8 | 5.0 | 31.9 | 0.59 |
| 65 | 4.64 | 630 | 333 | 82 | 222 | 78 | 24 | 33 | 3.3 | 4.9 | 24.8 | 0.79 |
| 66 | 4.69 | 648 | 334 | 82 | 219 | 78 | 28 | 10 | 3.6 | 5.8 | 21.5 | 0.63 |
| 67 | 4.42 | 635 | 429 | 71 | 311 | 78 | 22 | 27 | 5.0 | 4.6 | 22.4 | 0.59 |
| 68 | 4.07 | 602 | 500 | 65 | 259 | 89 | 22 | 22 | 4.9 | 3.8 | 30.2 | 0.60 |
| 69 | 4.16 | 628 | 621 | 64 | 666 | 83 | 22 | 17 | 6.3 | 3.8 | 20.2 | 0.82 |
| 70 | 2.58 | 454 | 446 | 48 | 185 | 42 | 13 | 16 | 4.3 | 1.9 | 53.4 | 0.66 |
| 71 | 4.69 | 611 | 563 | 73 | 348 | 83 | 26 | 16 | 5.8 | 4.1 | 22.9 | 0.70 |
| 72 | 4.29 | 556 | 492 | 66 | 96 | 63 | 17 | 27 | 5.4 | 3.8 | 31.9 | 0.50 |
| 73 | 4.25 | 626 | 596 | 64 | 345 | 68 | 20 | 38 | 5.6 | 3.8 | 28.9 | 0.58 |

($r = -0.72$; Table 3). A significant and positive correlation is obtained between $CaCO_3$ and sand ($r = 0.65$) and gravel ($r = 0.59$) contents suggesting the predominance of carbonates in the coarse-grained sediment fractions. Microscopic examinations on sand and gravel fractions revealed that the higher carbonate contents in the sediments appear to have a predominantly biogenic origin, i.e., derived mainly from the calcareous remains of a variety of benthic organisms.

A gradual increase in carbonate content from about 20% in offshore to approximately 70% in nearshore areas is clearly evident particularly along the south-southeastern, eastern, and northeastern areas of the Gulf (Fig. 4). The narrow and carbonate-rich strip along the south-southeastern part of the Gulf tends to broaden towards the west, in the outer Gulf entrance, and follows the distribution of the surface circulation pattern in the Gulf (Fig. 4). On the other hand, higher carbonate content (41–80%) is also found in the eastern–northeastern part of the Gulf (Fig. 4) due to both benthic production on the sea floor and to riverine input of Neogene calcareous rocks from the drainage basin.

The total organic carbon contents in the surface sediments of the Gulf of İskenderun varies between 0.33 and 0.83% (avg. 0.60%; Table 2; Fig. 4). The high $C_{org}$ contents found in sediments from the central part of the Gulf (0.71–0.83%; Fig. 4) roughly correspond to an area of intensive organic matter accumulation due to the presence of anticyclonic surface currents (Fig. 2). Substantial high concentrations of $C_{org}$ are also observed in patches off the northeastern (0.77–0.82%) and eastern (0.76–0.78%) coasts in the inner Gulf (Fig. 4) where a higher terrestrial and anthropogenic input was expected due to the relative proximity of rivers and existing sewage outfalls. Otherwise, the majority of $C_{org}$ contents in the sediments varied between 0.58 and 0.68% and are believed to define the primary production pattern in this Gulf. Comparison showed that these values are also typical for the Mediterranean Sea and reflect the marine production of organic matter in this sea (0.57–0.69; Emelyanov and Shimkus, 1986). The

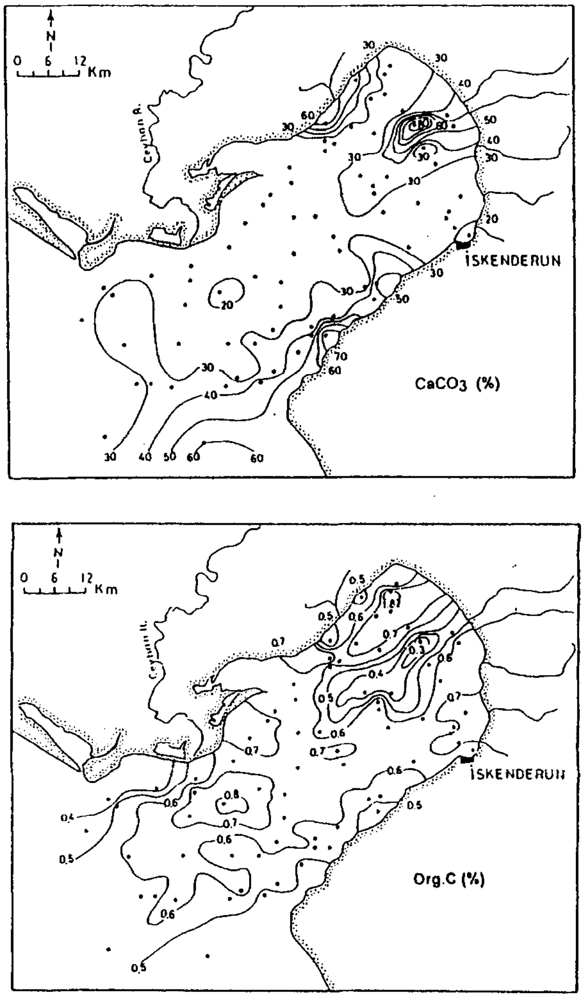


Fig. 4. $CaCO_3$ and $C_{org}$ distributions in surface sediments of the Gulf of İskenderun.

low $C_{org}$ contents (0.28–0.44%; Fig. 4) also reflect variations in the degree of dilution by the coarse-grained biogenic components. This is further indicated by inverse relationships between $C_{org}$ and sand ($r=-0.76$) and gravel ($r=-0.35$), as well as, between $C_{org}$ and $CaCO_3$ ($r=-0.63$) contents (Table 3). The fine-grained (rich in clay) sediments show a reasonably good correlation ($r=0.67$) with the $C_{org}$ contents (Fig. 3), due to their large specific surface areas. Therefore, it appears that the distribution of organic carbon in the Gulf of İskenderun sediments is controlled by a complex interplay of hydrodynamic, biogenic, terrestrial, and anthropogenic factors.

### *4.2. Relative abundances and areal distribution of the elements*

The total bulk concentrations of the studied elements Al, Mg, Fe, Mn, Ni, Cr, Zn, Co, Cu, and Pb in the surface sediments of the Gulf of İskenderun are presented in Table 2. In general, low element concentrations coincide with increases in $CaCO_3$ (predominantly of biogenic origin) contents of the sediments (negative and high "r" values; Table 3). Thus, the coarse-grained carbonate components act as a diluent to most of the measured element concentrations in the sediments. This explains the overall low element concentrations found in the sediments from the south-southeastern, eastern, northern, and northwestern areas of the Gulf. To compensate for the dilution effect by carbonates, the measured total element concentrations in this study are also calculated on a carbonate-free ("non-biogenic") basis (CFB). In addition; as known, Al has commonly been used as a reference element, not only in order to minimize grain-size effects (Bruland et al., 1974; Pratt and Davis, 1992), but also to determine the primary source rocks and the accompanying soils and deposits in aquatic environments (Herron et al., 1977). Therefore, the possible enrichment relative to Al of other elements in the studied Gulf of İskenderun sediments has also been considered here.

#### *4.2.1. Aluminium*

The surface sediments of the Gulf of İskenderun contain from 2.4 to 14.2% Al (on CFB; Fig. 5); however, in most cases, Al ranges from 6–8% (Fig. 5). These values are comparable with the average compositions of crustal rocks (Table 4). The areal distribution pattern of Al shows, with the exception of two values obtained in the two westerly stations (14.2% at st. 47 and 12.5% at st. 37 on CFB), that the Al contents measured along the eastern peripheral areas of the Gulf are found to be generally lower (<6.0% on CFB) than those obtained in the easterly stations (>6.0% on CFB; Fig. 5). This is attributed to the differences in the

Table 3
Correlation coefficient matrix for the chemical and textural parameters of the surface sediments in the Gulf of İskenderun. Based on bulk (natural) data. Significant correlations ($P<0.01$; $r>0.29$; $n=73$) at greater than 99% confidence level are shown in bold type

| | Gravel | Sand | Silt | Clay | Mud | $CaCO_3$ | $C_{org}$ | Fe | Mn | Ni | Zn | Cr | Co | Cu | Pb | Mg | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1.00 | | | | | | | | | | | | | | | | |
| Sand | **0.40** | 1.00 | | | | | | | | | | | | | | | |
| Silt | −0.54 | −0.62 | 1.00 | | | | | | | | | | | | | | |
| Clay | −0.46 | −0.74 | 0.08 | 1.00 | | | | | | | | | | | | | |
| Mud | −0.68 | −0.93 | **0.74** | **0.72** | 1.00 | | | | | | | | | | | | |
| $CaCO_3$ | **0.59** | **0.65** | −0.52 | −0.54 | −0.72 | 1.00 | | | | | | | | | | | |
| $C_{org}$ | −0.35 | −0.76 | **0.38** | **0.67** | **0.71** | −0.63 | 1.00 | | | | | | | | | | |
| Fe | −0.35 | −0.56 | **0.39** | **0.46** | **0.58** | −0.63 | **0.49** | 1.00 | | | | | | | | | |
| Mn | −0.34 | −0.52 | **0.34** | **0.44** | **0.53** | −0.63 | **0.39** | **0.72** | 1.00 | | | | | | | | |
| Ni | −0.27 | −0.30 | 0.17 | 0.29 | **0.31** | −0.33 | **0.39** | 0.21 | 0.19 | 1.00 | | | | | | | |
| Zn | −0.42 | −0.49 | **0.46** | **0.58** | **0.71** | −0.72 | **0.61** | **0.62** | **0.66** | 0.20 | 1.00 | | | | | | |
| Cr | −0.28 | −0.22 | 0.01 | **0.32** | 0.21 | −0.40 | 0.29 | **0.35** | **0.51** | **0.60** | 0.13 | 1.00 | | | | | |
| Co | −0.05 | −0.24 | 0.07 | 0.20 | 0.19 | −0.20 | 0.25 | 0.23 | 0.26 | **0.34** | −0.04 | **0.41** | 1.00 | | | | |
| Cu | −0.43 | −0.71 | **0.46** | **0.60** | **0.73** | −0.70 | **0.71** | **0.74** | **0.66** | 0.16 | **0.87** | 0.15 | 0.06 | 1.00 | | | |
| Pb | −0.01 | −0.12 | 0.15 | 0.01 | 0.11 | −0.08 | 0.02 | 0.23 | 0.24 | 0.05 | 0.20 | 0.04 | 0.12 | 0.28 | 1.00 | | |
| Mg | −0.14 | −0.16 | 0.07 | 0.15 | 0.15 | −0.26 | 0.28 | 0.17 | 0.17 | **0.83** | 0.10 | **0.66** | **0.30** | **0.84** | 0.02 | 1.00 | |
| Al | −0.38 | −0.59 | **0.46** | **0.43** | **0.61** | −0.60 | **0.47** | **0.58** | **0.65** | 0.01 | **0.61** | 0.25 | 0.22 | **0.66** | 0.25 | −550.02 | 1.00 |

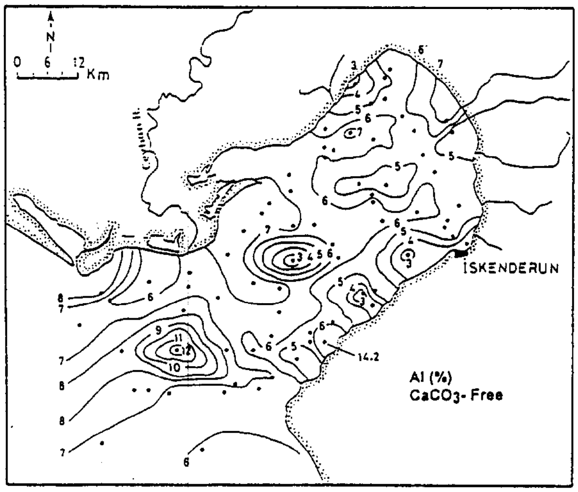


Fig. 5. Al contents (carbonate-free data) of the surface sediments in the Gulf of İskenderun.

lithogenic source areas on the coast and hinterland. For example, the sediments with lower Al contents receive significant input from the ophiolite-associated rocks or their weathering products which are widespread on the eastern coasts and are relatively low in Al. By contrast, the higher Al contents (6–8% on CFB; Fig. 5) generally occur in sediments which have received substantial input from the Holocene alluvial soils through run-off by the Ceyhan River and from the nearby Gölovasì clayey deposits (Kapur et al., 1989). The ophiolitic source rocks which have been drained by the northwesterly Ceyhan River are approximately 100 km away from the mouth of this river.

#### 4.2.2. *Magnesium, chromium, nickel, and cobalt*

The concentrations of Mg (4.2–15.3% on CFB), Cr (212–919 ppm on CFB), Ni (305–1337 ppm on CFB) and Co (30–150 ppm on CFB; Fig. 6) measured in surface sediments of the Gulf of İskenderun are noticably high when compared with the relative abundances of these elements in average crustal rocks (Table 4), even given our possible underestimation of Co by 15>. However, the levels of Mg, Cr, Ni, and Co concentrations obtained in this study broadly conform to an intermediate compositions between ultrabasic and basic rocks occurring on the south- to north-eastern coasts of the Gulf (Table 4). This is further indicated by noteworthy zonations of the Mg, Cr, Ni, and Co concentration values within the Gulf (Fig. 6). Here, with the exception of two stations, the majority of the concentrations of Mg (5.9–10.3% on CFB), Cr (258–568 ppm on CFB), Ni (370–1190 ppm on CFB) and Co (61–203 ppm on CFB) obtained in sediments from the eastern part of the Gulf was considerably higher than those found in the western part (4.2–6.1% Mg; 212–424 ppm Cr; 305–593 ppm Ni;40–128 ppm Co) of the Gulf (Fig. 6). The enrichment of Mg, Cr, Ni and Co in the eastern part (especially along the SW–NE-trending peripheral areas) of the Gulf is also evident from the presence of higher element to Al ratios (Mg/Al > 1; Cr/Al > 50; Ni/Al > 100; Co/Al > 15; Fig. 6), values comparable to those found in the ultrabasic–basic rocks (Table 4) on the adjacent land. Thus, the overall high Mg, Cr, Ni and Co contents appear to be confined to the eastern peripheral areas of the Gulf where there is important terrigenous input from the basic–ultrabasic rock sources close to the coast. By contrast, the generally lower concentrations of Mg, Cr, Ni and Co obtained in the western part of the Gulf (Fig. 6) rather reflect long distances (approx. 100 km) between the easterly ophiolitic source rocks and westerly marine depositional sites. Nevertheless, the fluvial input (i.e., suspended solids) of the northerly Ceyhan River contained relatively high Cr (275 ppm), Ni (338 ppm) and Co (40 ppm) compared to their crustal abundances (Table 4; Fig. 7).

Regional comparisons showed similar Mg, Cr, Ni and Co enrichments in the surface sediments in other parts of the Mediterranean (Shaw and Bush, 1978; Emelyanov and Shimkus, 1986; Bodur and Ergin, 1988), Aegean (e.g., Ergin et al., 1993), and Black Seas (Yücesoy and Ergin, 1992), as a result of the seaward dispersal of detrital minerals from nearby ultrabasic rocks. Mg, Cr, and Ni are commonly known to be guide elements of most ultrabasic–basic rocks or their ferromagnesian minerals such as olivine, pyroxene, chromite (Rose et al., 1979; Mason and Moore, 1982).

#### 4.2.3. *Iron and manganese*

Most of the total concentrations of Fe (3.8–7.9% on CFB) and Mn (700–1104 ppm on CFB) fall in

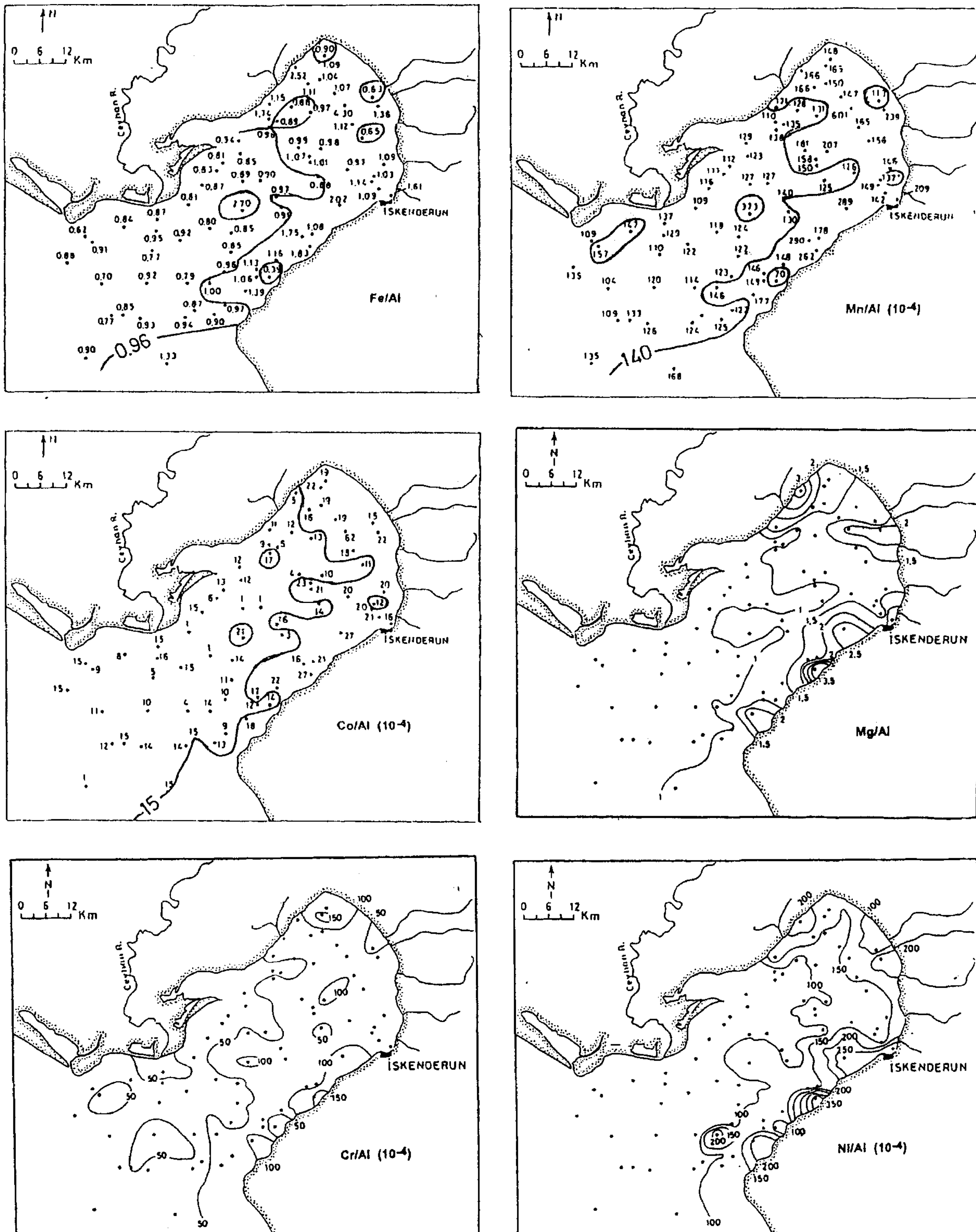


Fig. 6. Fe, Mn, Co, Mg, Cr, and Ni contents and their ratios to Al in the surface sediments of the Gulf of İskenderun. Note the overall increased Fe, Mn, Co, Mg, Cr, and Ni contents in the eastern part of the Gulf.

Table 4
Comparison of metal concentrations obtained in the surficial Gulf of İskenderun sediments with those found in other adjacent regions and some average rocks

| | Al(%) | Mg(%) | Fe(%) | Mn(ppm) | Ni(ppm) | Cr(ppm) | Zn(ppm) | Co(ppm) | Cu(ppm) | Pb(ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) This study[a] | 1.1–9.4 | 2.3–7.8 | 1.5–9.0 | 281–1130 | 179–808 | 70–694 | 30–117 | 6–99 | 9–39 | 10–61 |
| This study[b] | **2.4–14.2** | **4.2–15.3** | **3.8–23.2** | **700–3240** | **305–1337** | **212–919** | **62–176** | **8–333** | **14–52** | **13–97** |
| This study[c] | 5.4–8.1* | 4.2–6.1* | 4.5–7.9* | 751–978* | 305–593* | 212–424* | 73–155* | 40–177 | 20–45* | 14–81* |
| This study[d] | 2.2–7.0$^{+}$ | 5.9–10.3$^{+}$ | 3.8–7.6$^{+}$ | 700–1000$^{+}$ | 370–1190$^{+}$ | 258–568 + | 76–178 + | 41–130$^{+}$ | 14–44$^{+}$ | 14–97$^{+}$ |
| (2) Mersin Bay | **7.5** | 3.2 | **5.3** | **1103** | **326** | **551** | **107** | n.d. | **42** | n.d. |
| (3) Eastern Aegean Shelf | n.d. | n.d. | 0.5–5.7 | 103–2625 | 11–406 | 9–312 | 19–162 | 2–41 | 3–77 | n.d. |
| (4) Marmara Sea Shelf | n.d. | n.d. | **1.7–5.1** | **307–2059** | **42–173** | **89–186** | **50–169** | **13–33** | **14–04** | **31–306** |
| (5) Golden Horn Estuary | n.d. | n.d. | 2.6–3.8 | 333–565 | 98–167 | 242–485 | 450–8750 | 17–31 | 333–3900 | 124–702 |
| (6) Southern Black Sea Shelf | n.d. | n.d. | 0.2–4.9 | 112–1064 | 11–202 | 13–224 | 24–138 | <1–20 | 15–82 | 12–66 |
| (7) Crustal average | 8.1 | 2. | 5.0 | 950 | 75 | 100 | 70 | 25 | 55 | 13 |
| (8) Shales | 8.0 | 2.1 | 4.7 | 850 | 68 | 90 | 90 | 9 | 45 | 20 |
| (9) Ultrabasic rocks | 0.4–1.6 | 18.9–23.7 | 5.0–7.6 | 700–2600 | 1700–2900 | 500–7000 | n.a. | 75–101 | 46–62 | n.a. |
| (10) Basic | 1.1–9.1 | 2.3–19.3 | 1.5–8.5 | 500–4900 | 200–3200 | 400–3000 | n.a. | 25–112 | 39–87 | n.a. |
| (11) Ceyhan River | n.d. | n.d. | 3.2–5.9 | 285–2159 | 115–1066 | 124–683 | 121–318 | 25–95 | 40–84 | 2–110 |

Numbers in bold indicate $CaCO_3$ free values. Sources: (1) This study[a] (all samples); This study[b] ($CaCO_3$-free data for all samples); This study[c] (western samples); This Study[d] (eastern samples); (2) Shaw and Bush (1978); (3) Ergin et al. (1993); (4) Bodur and Ergin (1994); (5) Ergin et al. (1991); (6) Yücesoy and Ergin (1992); (7) Mason and Moore (1982); (8) Turekian and Wedepohl (1961); (9, 10) Analysis of rocks surrounding the Gulf of İskenderun (Aslaner, 1973). Values from two stations (*), ($^{+}$) are excluded; (11) Clay sediment, Sevim (1991).

n.a. = not available.

n.d. = not determined.

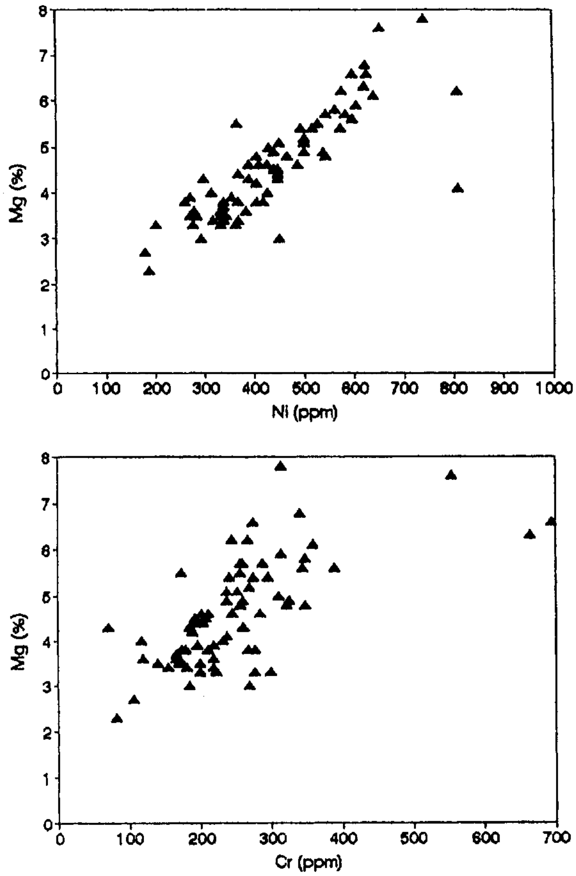


Fig. 7. Relationships among the Mg, Cr, and Ni contents of the surface sediments of the Gulf of İskenderun.

the range of the average composition of crustal rocks (Table 4). The maximum concentrations of Fe (23.2% on CFB) and Mn (3240 ppm on CFB) are found in the northeastern part of the Gulf (St.23), a region which seems to receive waste materials from the iron and steel works on the nearby coast. This is confirmed by the microscopic studies of the coarse grain fractions of sediment samples. High Fe/Al (270) and Mn/Al (373) ratios found in the central part of the gulf (St. 33; Fig. 6) possibly indicate that intense redox chemistry may occur in these sediments. As shown (Fig. 6), Fe/Al and Mn/Al ratios suggest some zonal peculiarities. For example, Fe/Al and Mn/Al ratios obtained in sediments especially from the southern, eastern, and northeastern peripheries of the Gulf (Fig. 6), are generally greater than 0.96 and 140 ($10^{-4}$), respectively. The enrichment of these sediments in Fe and Mn relative to Al must largely be caused by their proximity to the ultrabasic–basic source rocks (Fig. 1) which contain higher Fe (up to 9%) and Mn (up to 4900 ppm; Table 4).

#### *4.2.4. Zinc and lead*

The larger part of the total concentrations measurements of Zn (62–176 ppm on CFB) and Pb (13–97 ppm) of the Gulf of İskenderun surface sediments was considerably high when compared to those found in average crustal rocks (Table 4). Furthermore, Zn appears to be enriched relative to Al in sediments from the eastern part of the Gulf where Zn/Al ratios are usually greater than 19 (Fig. 8). Thus, it can be inferred that the ultrabasic–basic source rocks on the eastern coasts of the Gulf seem to play a considerable role in the relative abundance of Zn in the Gulf sediments. Higher Zn contents (121–318 ppm; Table 4) are also known from the fluvial fine sediments of the Ceyhan River (Sevim, 1991), suggesting an influence from the weathering products of ultrabasic–basic source rocks (Fig. 1). Sediment with the highest Zn (143–178 ppm on CFB) content measured in the east-northeastern part of the Gulf (St.23) are most likely due to the contamination effect from the nearby iron and steel complexes.

It is not clear whether the presence of generally higher Pb/Al ratios, especially in the southern part of the Gulf (Fig. 8), can be linked to the presence of ultrabasic–basic rocks or/and associated mineral deposits on the adjacent land, because no data on Pb content of the surrounding major source rocks are available. The other higher Pb contents are measured in sediments from the northeastern part of Gulf, close to the discharge areas of industrial and domestic effluents. The overall high Pb contents (2–110 ppm; Table 4) of fluvial sediments of the Ceyhan River, on the other hand, could be, in part, due to anthropogenic activities.

#### *4.2.5. Copper*

The Cu contents of surface sediments in the Gulf of İskenderun varied between 14 and 52 ppm (on CFB), where most sediments in the area contained 30–45 ppm Cu. These values are roughly similar to those found in average crustal rocks

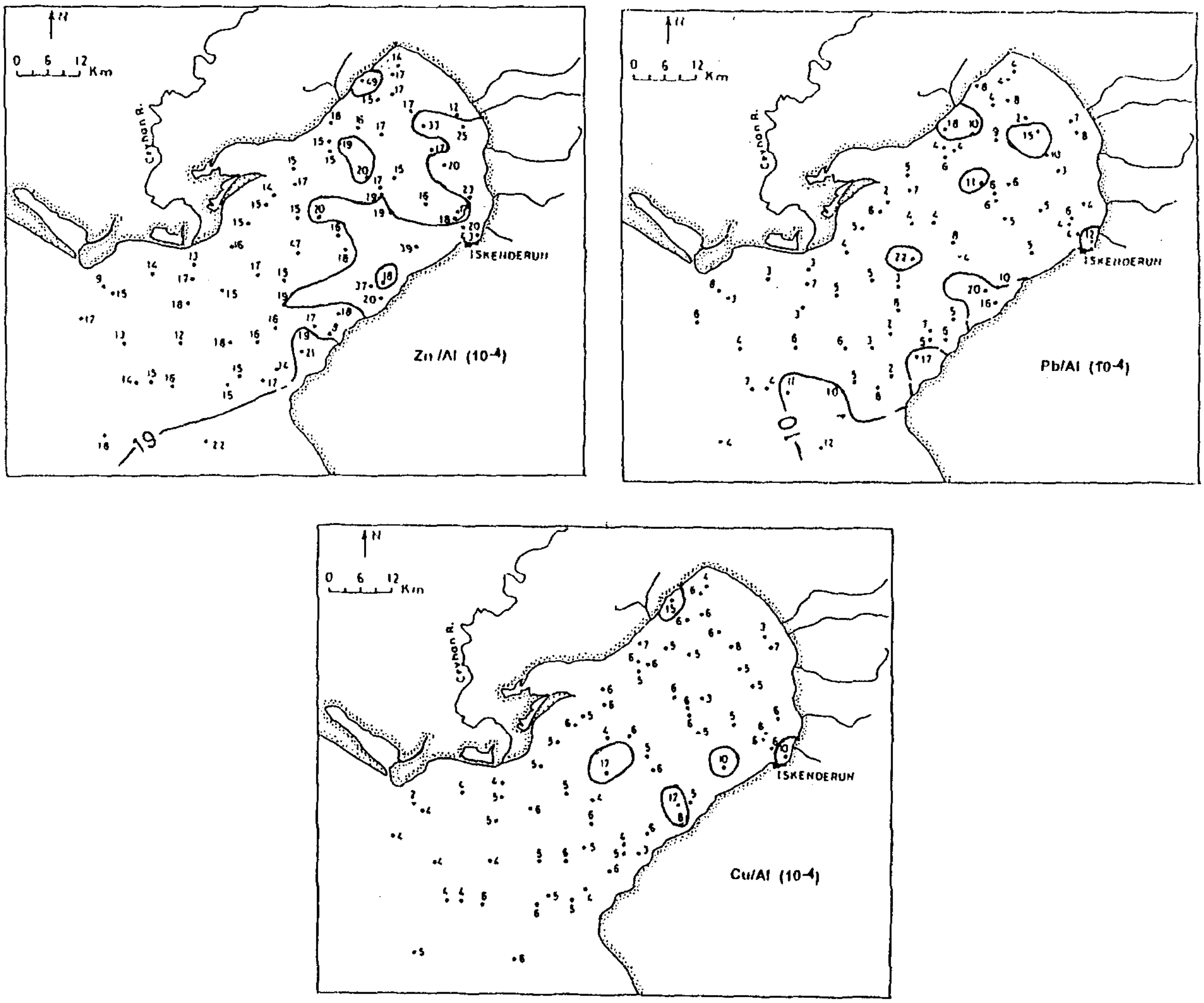


Fig. 8. Zn, Pb, and Cu contents and their ratios to Al in the surface sediments of the Gulf of İskenderun.

(Table 4). The ultrabasic and basic rocks in the surrounding regions, as well as the fluvial sediments of the Ceyhan River (Sevim, 1991) however, contain, on average, notably higher Cu levels (39–87 ppm; Table 4); however, the studied sediments do not show any significant regional trend in the distribution of Cu within the Gulf (Fig. 8).

### *4.3. Relationships between the geochemical and textural characteristics of the sediments*

The general element distribution pattern reflects their close relationship to sediment texture with high concentrations preferentially occurring in fine-grained sediments. For example, the significant increases in the concentrations of Cu, Zn, Fe, and Mn is indicated by decreasing grain-size toward clay or mud (Table 3). This observation is found to be in good agreement with the findings from a number of investigations (e.g., Brannon et al., 1977; Oakley et al., 1981; Cauwet, 1987) that the finer-grained (mainly clay and silt) sediments show relatively high metal content due to the large specific surface area and thus strong adsorptive properties of the fine-sized particles. On the other hand, significant correlation of Al with increasing clay ($r = 0.43$) and silt ($r = 0.46$) or mud ($r = 0.61$; Table 3) content in sediments reflects that aluminosilicates such as clay minerals, micas, feldspars are the main form of Al in these sediments.

The correlation between $C_{org}$ and Cu, Zn, Fe, Al, Mn, and Ni contents ($r=0.71$–$0.39$; Table 3) imply either a primary association or a secondary relationship to grain size (i.e., complexation, adsorption on clay minerals) in which the organic carbon content increases with increasing mud content in the sediments (e.g., Stumm and Morgan, 1981; Loring, 1984; Calvert et al., 1985).

### 4.4. *Correlation between the elements*

The distribution of Mg, Cr, Ni, Co, Fe, and Mn in the Gulf sediments seem to be generally related to each other ($r=0.34$–$0.83$; $P>0.99$; Table 3; Fig. 7) which attest to a similarity in their geochemical source, i.e., the weathering products from the nearby basic and ultrabasic rocks (Fig. 1). The significant correlation between Mg and Cu ($r=0.84$; Table 3) can be interpreted as reflecting interferences or competitions between $Cu^{2+}$ and $Mg^{2+}$ during the adsorption/replacement processes in clays, as has also been observed by O'Connor and Kester (1975).

Significant correlation of Fe with Mn ($r=0.72$) and Cu ($r=0.74$), and of Mn with Zn ($r=0.66$) and Cr ($r=0.51$; Table 3) suggest important associations between the oxide–oxyhydroxides of Fe–Mn and other elements (Tessier et al., 1979; Wallace et al., 1988; Pruysers et al., 1991). On the other hand, the covariance of Al with Cu, Mn, Zn and Fe ($r=0.66$–$0.58$; Table 3) found in the İskenderun Gulf sediments can be interpreted in terms of common detrital and non-detrital associations of this element mainly with the fine-grained aluminosilicates (i.e., clay minerals; Brannon et al., 1977; Oakley et al., 1981). The significant correlation of Cu with Zn ($r=0.87$) is probably primarily due to uptake by microorganisms since these elements also behave as micronutrients for plankton growth (e.g., Pratt and Davis, 1992; Calvert and Pedersen, 1993).

## 5. Conclusions

Mud with locally high biogenic sand and gravel contents is the major sediment type of the sea floor of the Gulf of Iskenderun. A biogenic carbonate belt extends from the western to southwestern to northeastern peripheral areas of the gulf. This indicates the possible influence of prevailing currents (i.e., calm, nutrient-rich and clear offshore waters) on benthic carbonate production (benthic algae) in this part of the gulf. Organic carbon contents mostly reflect normal marine production and hydrographically-related deposition.

It appears that the source of the Al, Fe, Mn, and partially Cu, in the sediments of the Gulf of Iskenderun is primarily weathering of average crustal rocks. Higher anomalies of Mg, Cr, Ni, Co, and Zn however, occurring in the eastern part of the area, along the SW–NE-trending peripheral areas of the gulf, most likely result from seaward dispersal of detrital minerals from the nearby basic and ultrabasic source rocks.

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