HEAVY METAL ASSOCIATIONS IN RECENT INSHORE SEDIMENTS FROM THE MERSIN BAY, TURKEY

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Summary. A total of 56 surface inshore sediment samples from more or less polluted areas of Pozcu and Karaduvar in the Mersin Bay were analyzed for their grain-size, carbonate, organic-carbon and heavy metal contents. With the exception of *Zn* and *Ni*, concentrations of metals (*Fe*, *Mn*, *Cu*, *Cr*, *Co*, and *Pb*) were widely comparable with the metal levels in average geologically weathered sedimentary rocks. Zinc concentrations showed a possible man-made influence, whereas the nickel contents reflected an ultramafic-ophiolitic origin, most probably derived from the hinterland by the seasonal influx of rivers, streams and also man-made channels in the vicinity of the Bay of Mersin. *Ni*, *Cu*, *Zn*, *Pb*, *Cr* and *Co* contents showed strong positive correlations with the *Fe* and *Mn* contents, indicating coprecipitation and/or incorporation of these metals, largely with the *Fe* and *Mn* phase, or *Fe* and *Mn* oxides/hydroxides, respectively, rather than with clays, organic-carbon and carbonates in muddy-sand-sized sediments from Pozcu and Karaduvar.

Riassunto. Analisi di granulometria, carbonati, carbonio organico e metalli pesanti sono state eseguite su 56 campioni di sedimenti superficiali prelevati vicino alla riva presso le aree più o meno inquinate di Pozcu e Karaduvar nella Baia di Mersin. Con l'eccezione di *Zn* e *Ni*, le concentrazioni dei metalli (*Fe*, *Mn*, *Cu*, *Cr*, *Co* e *Pb*) sono risultate ben correlabili con quelle delle rocce sedimentarie soggette a degrado atmosferico. Le concentrazioni di *Zn* mostrano una possibile influenza antropogenica, mentre quelle di *Ni* riflettono un'origine ultramafica-ofiolitica, derivante molto probabilmente dal retroterra per l'afflusso stagionale di fiumi, torrenti e canali artificiali nei pressi della Baia di Mersin. Le concentrazioni di *Ni*, *Cu*, *Zn*, *Pb*, *Cr* e *Co* mostrano una forte correlazione positiva con quelle di *Fe* e *Mn*, indice di una coprecipitazione e/o incorporazione di questi metalli prevalentemente nelle fasi *Fe* e *Mn* oppure ossidi/idrossidi di *Fe* e *Mn*, piuttosto che nelle argille, nel carbonio organico e nei carbonati dei sedimenti di dimensioni fango-sabbia di Pozcu e Karaduvar.

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1. Introduction

It has been established from numerous investigations that heavy metals from both natural and anthropogenic sources occur in different forms in the marine sediments. Silicates, metallic oxides/hydroxides of iron and manganese, sulfides, organic matter, carbonates, clays, bacteria, etc., constitute the most important sediment components for the complexing or adsorbing of heavy metals. The geology of the surrounding area, the degree of man-made input, and hydrological and chemical conditions will then modify the distribution of heavy metals in the depositional environment.

These aspects attracted special attention in the investigation of sediments of more or less polluted marine coastal regions such as in this case, the Mersin Bay of the northeastern Mediterranean Sea, because no previous intense study of this type is known to the authors in this part of the Mediterranean. Shaw and Bush (1978) studied the mineralogy and geochemistry of the surface sediments of the northeastern Mediterranean (Cilicia Basin) on a large scale. Some authors (Özkan, 1978; Balkas et al., 1982) have also given heavy metal concentrations in sediments from around this area.

This paper deals with the distribution of grain-size, organic-carbon, total carbonate and heavy metals in the modern inshore sediments collected. The objectives were to clarify the origin and the forms of heavy metal associations.

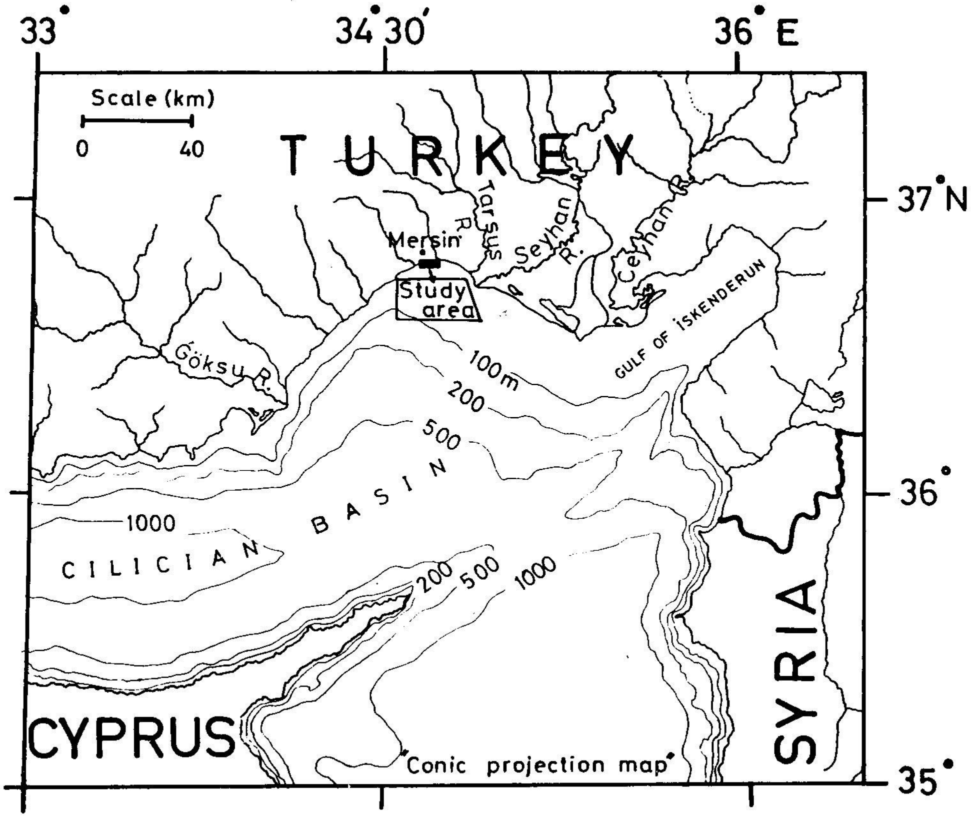


Fig. 1 — Location map of the studied area and its surroundings.

2. Hydrological and Geological Setting

The study area, the inshore area of the Mersin Bay, is situated between the delta of the Göksu River in the west and the Gulf of Iskenderun in the east, extending seaward into the Cilicia Basin (Fig. 1).

Hydrologically, the Mersin Bay, as part of the northeastern Mediterranean Sea, serves as a model for an adjacent sea in a subtropical climate with high salinity and temperature values as compared to the open oceans (IMS-METU, 1986). The Seyhan, Ceyhan, Tarsus and Göksu are the most important rivers along with numerous ephemeral streams supplying sedimentary materials to be deposited inshore the Mersin Bay.

Geologically, the Bay of Mersin and its surrounding coastal plain is part of the Adana Basin. This basin, one of the major Neogene basins of the Taurus orogenic belt, shows various sedimentary facies ranging in age from Burdigalian to Recent (Yalcin and Görür, 1983).

In the Mersin area exposed lithologies are mostly sedimentary rocks. These include limestones (Paleozoic), limestones and flysch (Cretaceous), conglomerates, sandy limestones, marls, sandy marls, sandstones interbedded with clays, limestones (Tertiary), evaporites (Messinian), and alluvium (Quaternary). Metamorphic rocks and serpentinized ophiolitic rocks may also occur in the Taurus Mountains surrounding the study area (Fig. 2). Further data on the recent sedimentation of the southern Turkish coast can be found in works by Evans (1971), Mange-Rajetzky (1979, 1981 and 1983), as well as by Ter-

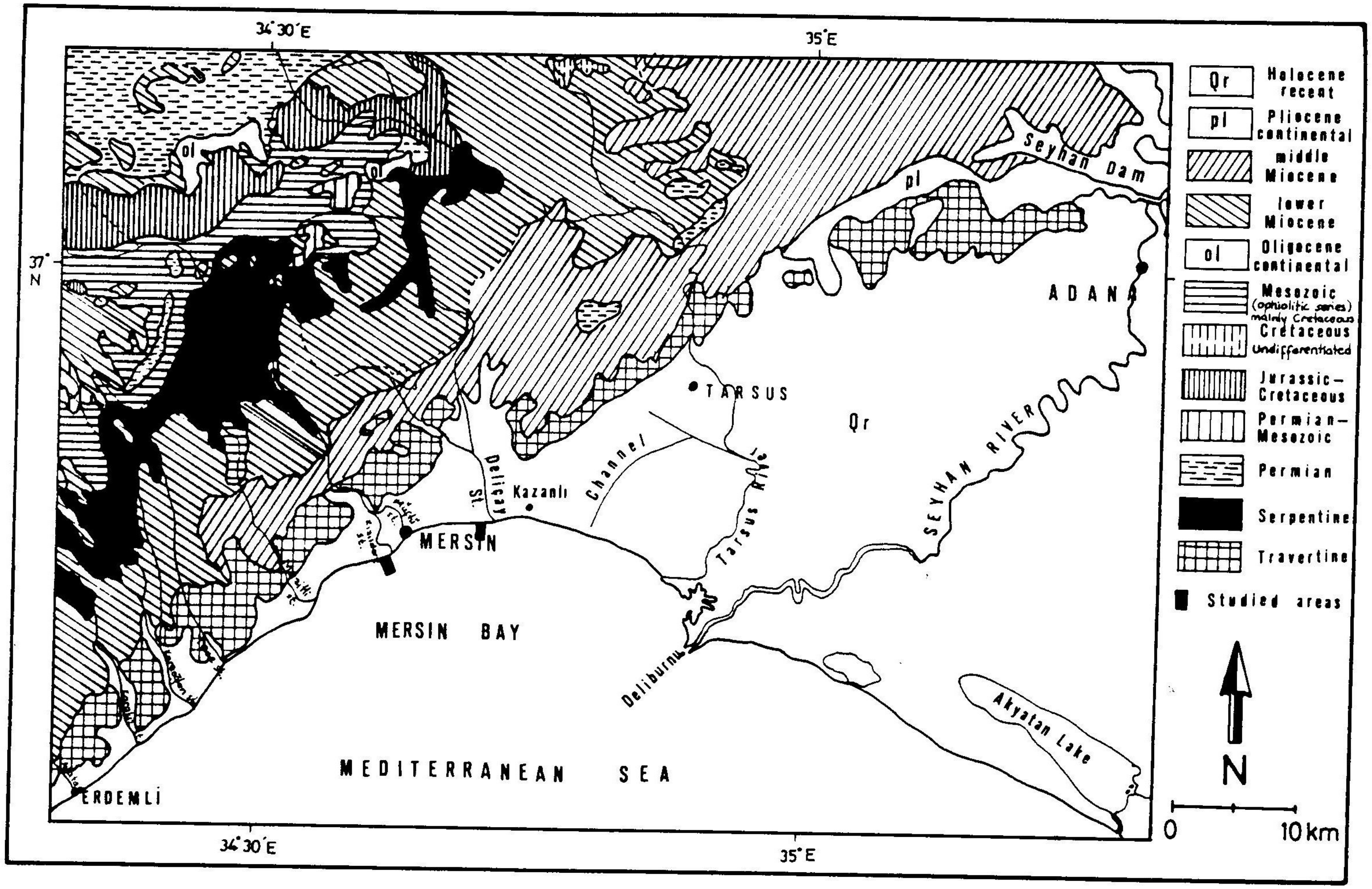


Fig. 2 — General geological map of surrounding coastal land showing studied areas (after Ternek, 1962).

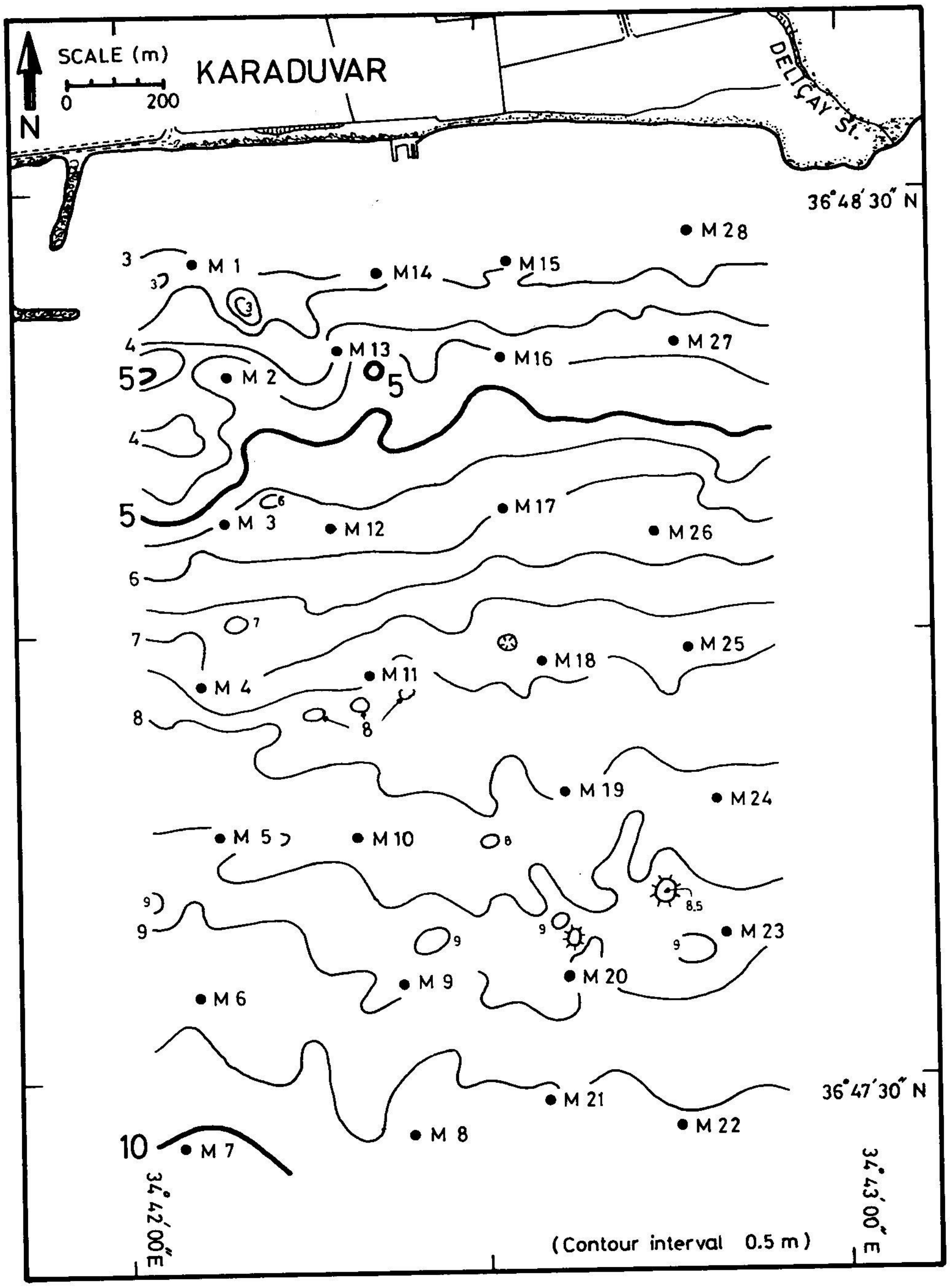
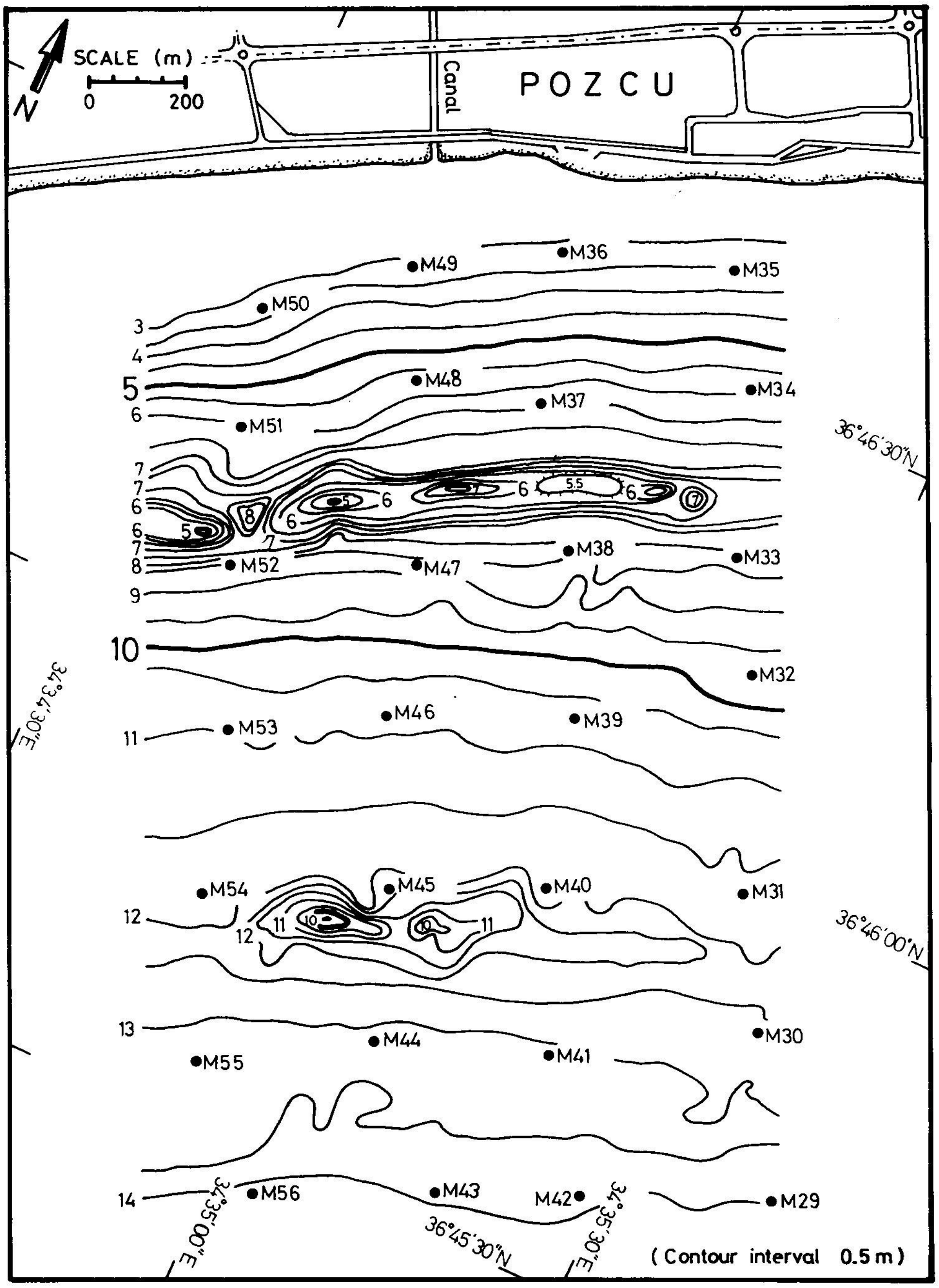


Fig. 3 — Sample locations with bathymetry of studied areas.



SCALE (m)
0
200
N
Canal
POZCU
M49
M36
M35
M50
M48
M34
M37
M51
M52
M47
M38
M33
M32
M53
M46
M39
M54
M45
M40
M31
M44
M41
M30
M55
M56
M43
M42
M29
36°46'30"N
36°46'00"N
36°45'30"N
34°34'30"E
34°35'00"E
34°35'30"E
(Contour interval 0.5 m)

Fig. 3 - (cont.)

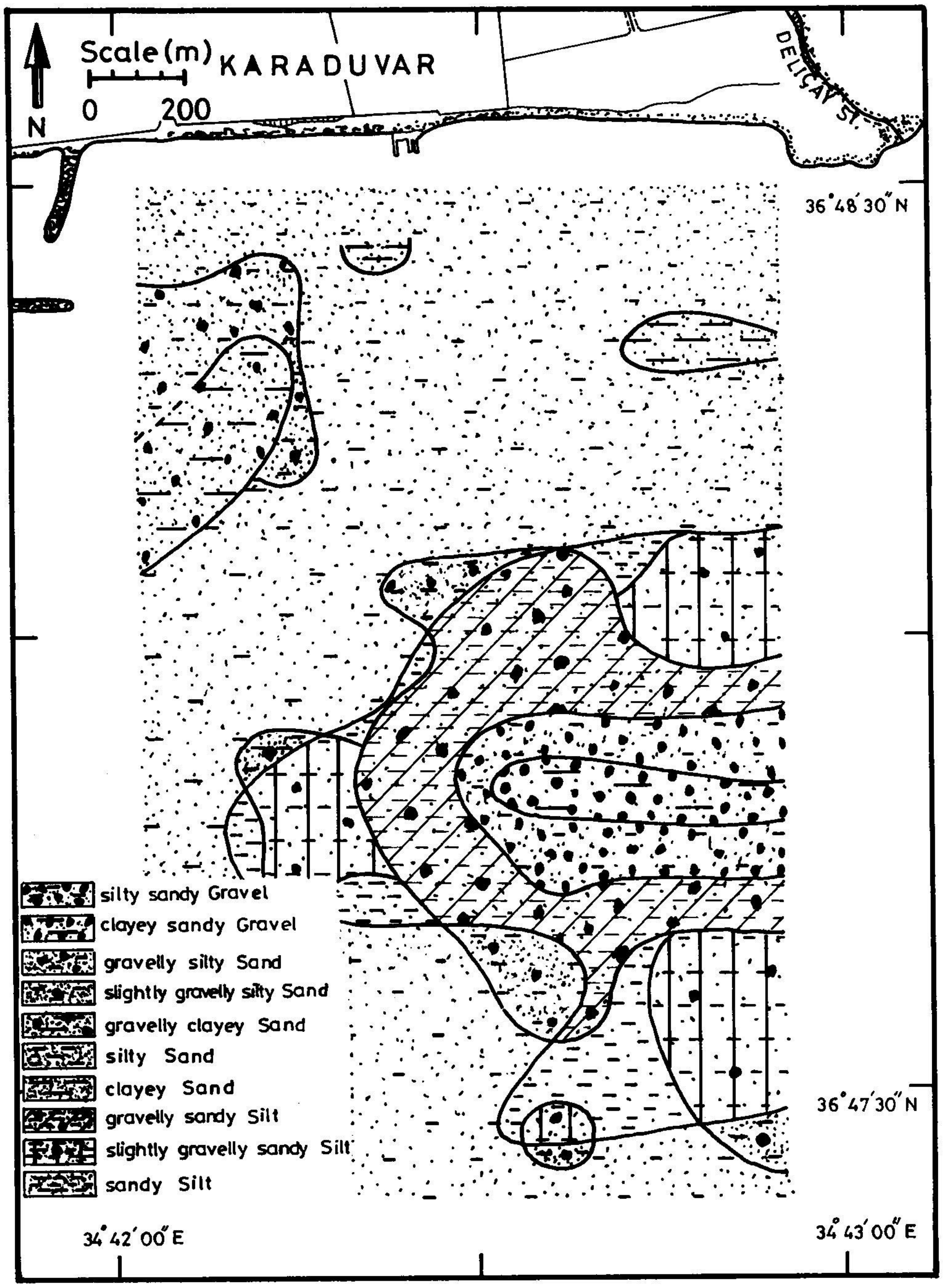
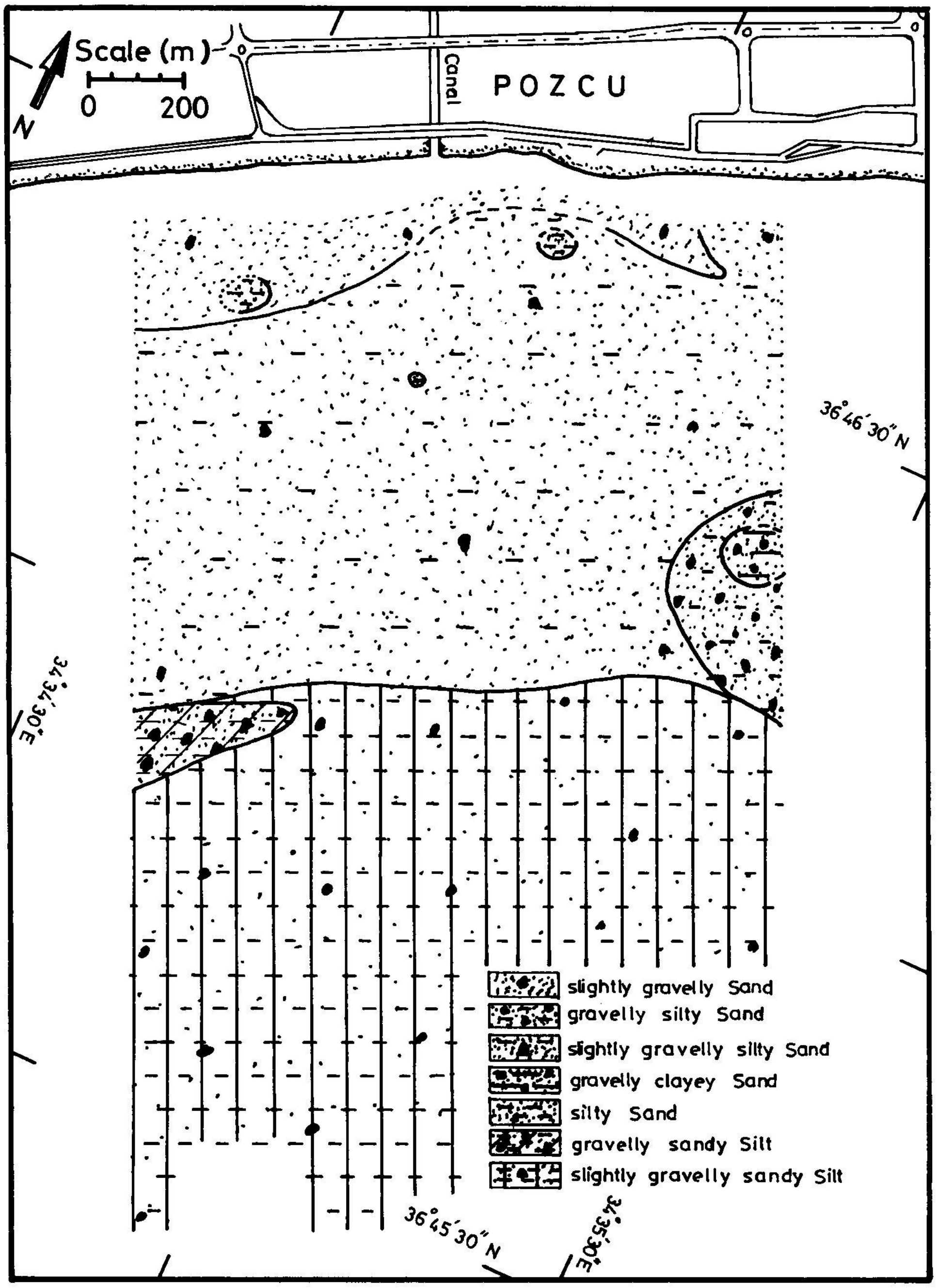


Fig. 4 — Distribution patterns of surface sediments.



Scale (m)
0
200
N
Canal
POZCU
36°46'30"N
34°34'30"E
36°45'30"N
34°35'30"E
slightly gravelly Sand
gravelly silty Sand
slightly gravelly silty Sand
gravelly clayey Sand
silty Sand
gravelly sandy Silt
slightly gravelly sandy Silt

Fig. 4 - (cont.)

Table 1 — Granulometric and geochemical parameters from surface sediments at Karaduvar and Pozcu in the Mersin Bay. Heavy metal concentrations are in μg/g dry wt, except iron in %. The symbol + indicates non-analyzed samples; x = mean, σ = standard deviation.

KARADUVAR

Sample Number	Depth (m)	Gravel %	Sand %	Silt %	Clay %	Mz (φ)	Corg %	$CaCO_3$ %	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb	Sediment Type
M 1	3.1	3.8	76.0	19.1	1.1	3.8	+	+	2.5	406	305	167	46	21	16	10	(g) z vfS
M 2	4.6	14.0	80.2	2.6	3.2	0.2	+	+	+	329	302	145	+	11	9	10	g cl cS
M 3	6.4	0.1	72.3	18.5	9.1	4.1	0.5	42.7	2.4	399	218	119	39	17	14	7	(g) z vfS
M 4	7.8	0.7	52.5	36.0	10.8	4.4	+	+	2.6	381	234	178	42	22	21	10	(g) z vfS
M 5	8.8	—	56.5	32.3	11.2	4.5	+	+	2.6	404	230	122	40	22	19	9	z vfS
M 6	9.6	0.1	63.9	26.2	9.8	4.4	+	+	2.5	397	198	101	42	22	15	10	(g) z vfS
M 7	10.2	0.1	61.7	29.2	9.0	4.3	0.4	19.4	2.4	349	226	76	35	24	18	10	(g) z vfS
M 8	9.9	0.3	61.4	27.3	11.0	4.5	+	+	4.0	611	382	120	50	33	26	15	(g) z vfS
M 9	9.0	0.1	70.1	23.3	6.5	4.0	+	+	2.8	591	300	117	42	23	17	10	(g) z vfS
M10	9.9	1.4	27.8	55.1	15.7	5.5	0.6	35.9	4.2	550	568	149	57	40	47	14	(g) vfs cZ
M11	8.0	—	60.8	30.2	8.9	4.1	+	+	4.0	628	462	146	61	36	31	11	z vfS
M12	6.5	1.8	81.6	11.2	5.4	3.6	+	+	3.1	587	327	66	44	29	17	14	(g) z vfS
M13	4.7	1.0	65.8	25.6	7.6	4.0	+	+	3.4	573	341	106	57	33	25	12	(g) z vfS
M14	4.0	2.4	83.2	9.5	4.9	3.6	0.3	43.9	3.4	655	335	112	56	30	21	14	(g) cl vfS
M15	3.5	0.3	81.1	13.6	5.0	3.7	+	+	3.5	601	315	108	54	32	17	13	(g) z vfS
M16	5.5	1.5	78.3	15.2	5.0	3.8	+	+	1.9	363	187	313	23	32	10	14	(g) z vfS
M17	6.5	0.4	66.7	22.5	10.4	4.4	0.5	26.5	1.6	392	208	136	18	19	17	11	(g) z vfS
M18	8.5	16.8	30.3	42.8	10.1	2.9	+	+	2.6	326	330	192	38	17	34	9	g cZ
M19	8.5	58.6	26.0	8.9	6.5	0.3	+	+	+	+	155	466	+	13	12	11	cl cs G
M20	9.0	6.8	53.6	32.5	7.1	4.1	+	+	2.5	384	294	138	22	24	21	10	g z vfS
M21	9.0	2.5	48.1	39.2	10.2	4.5	0.3	25.9	2.5	334	263	98	19	23	20	8	(g) z vfS
M22	9.0	1.6	50.4	33.9	14.1	5.0	+	+	2.2	362	288	82	18	21	19	10	(g) z vfS
M23	8.5	0.1	35.4	52.7	11.8	5.0	+	+	2.7	360	334	132	23	22	28	9	(g) vfs cZ
M24	8.5	76.4	14.6	5.9	3.1	−1.4	0.2	32.0	2.8	298	285	106	29	37	14	7	cl vfs G
M25	7.5	0.9	34.3	52.6	12.2	5.0	+	+	4.8	610	505	273	77	36	50	14	(g) vfs cZ
M26	6.5	—	51.4	38.3	10.3	4.6	+	+	4.2	684	434	109	73	31	38	14	z vfS
M27	4.5	0.4	64.9	22.5	12.2	4.5	+	+	4.1	698	371	166	59	34	30	15	(g) cl vfS
M28	3.5	0.7	83.0	12.8	3.5	3.5	0.3	30.4	3.5	604	396	225	49	28	30	14	(g) z vfS
x	7.2	6.9	58.3	26.4	8.4	3.7	0.4	32.1	3.0	477	414	152	43	26	23	11	
σ	2.2	17.4	19.0	14.0	3.5	1.5	0.1	7.9	0.8	130	95	81	16	7	10	2	

x	7.2	6.9	58.3	26.4	8.4	3.7	0.4	32.1	3.0	477	414	152	43	26	23	11
σ	2.2	17.4	19.0	14.0	3.5	1.5	0.1	7.9	0.8	130	95	81	16	7	10	2

POZCU

Sample Number	Depth (m)	Gravel %	Sand %	Silt %	Clay %	Mz (φ)	Corg %	$CaCO_3$ %	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb	Sediment Type
M29	13.5	3.5	23.4	51.8	21.3	5.6	0.7	48.2	2.6	403	305	42	32	32	21	13	(g) s cZ
M30	12.5	3.1	25.6	52.9	18.4	5.5	+	+	2.2	414	378	39	35	34	20	16	(g) s cZ
M31	11.7	1.9	28.5	53.4	16.2	5.4	+	+	4.0	499	452	87	43	30	26	17	(g) s cZ
M32	9.8	5.1	49.6	35.6	9.7	3.8	0.3	55.7	2.9	459	393	81	30	29	15	16	g z vfS
M33	8.5	8.0	68.1	15.7	8.2	1.8	+	+	1.1	461	316	161	19	22	13	13	g cl cS
M34	6.3	0.2	77.0	17.4	5.4	3.7	+	+	3.2	496	617	172	43	36	14	12	(g) z vfS
M35	4.0	0.2	90.5	7.0	2.3	3.5	+	+	3.0	584	571	106	38	32	13	11	(g) z vfS
M36	3.3	—	89.1	8.7	2.2	3.5	0.1	46.3	3.1	600	606	185	38	30	14	11	z vfS
M37	6.5	3.7	67.9	19.3	9.1	3.6	+	+	1.5	455	370	+	28	27	12	9	(g) z vfS
M38	8.5	0.4	77.0	16.7	5.9	3.7	+	+	1.5	360	350	+	29	25	8	10	(g) z vfS
M39	11.0	3.7	39.2	45.6	11.5	4.6	+	+	1.9	281	291	51	26	20	11	12	(g) s cZ
M40	13.0	2.0	23.6	52.0	22.4	5.9	0.6	52.2	2.1	264	249	52	28	19	15	11	(g) s mZ
M41	13.5	1.7	22.4	54.5	21.4	5.8	+	+	2.1	427	257	69	27	21	16	13	(g) s cZ
M42	13.5	3.5	14.7	56.6	25.2	6.1	+	+	1.9	388	367	44	29	30	22	11	(g) s mZ
M43	13.5	2.3	23.1	53.2	21.4	5.8	0.7	48.8	1.8	380	306	33	26	31	23	11	(g) s mZ
M44	13.5	3.9	34.0	45.6	16.5	5.0	+	+	1.6	301	224	178	22	17	14	10	(g) s cZ
M45	11.5	0.2	11.3	57.1	31.4	6.9	+	+	1.7	236	223	65	26	15	16	10	(g) s fS
M46	11.5	4.4	41.4	42.0	12.2	4.0	+	+	1.6	258	300	43	24	20	12	10	(g) s cZ
M47	9.5	0.9	66.0	24.5	8.6	3.5	0.5	45.3	2.1	332	342	64	29	21	11	8	(g) s vfS
M48	6.5	—	84.1	12.0	3.9	3.5	+	+	2.2	420	446	55	35	23	12	7	z vfS
M49	3.0	0.2	89.7	7.6	2.5	3.4	+	+	2.8	527	567	126	33	31	13	11	(g) z vfS
M50	3.0	—	91.8	6.1	2.1	3.4	0.2	48.4	3.3	627	572	115	38	32	14	11	z vfS
M51	6.2	0.1	73.5	18.5	7.9	4.0	+	+	3.8	532	753	137	54	40	23	15	(g) z vfS
M52	8.5	0.6	72.5	19.7	7.2	3.8	+	+	2.9	511	542	209	31	31	16	13	(g) z vfS
M53	10.5	5.8	37.8	52.0	4.4	4.1	+	+	3.1	440	453	164	32	30	21	14	g s cZ
M54	11.5	3.2	29.3	49.9	17.6	5.2	0.6	51.4	2.6	380	462	134	27	30	22	14	(g) s cZ
M55	12.5	2.7	26.5	52.5	81.3	5.5	+	+	2.8	411	460	25	37	36	+	14	(g) s cZ
M56	13.5	1.8	18.0	55.7	24.5	6.1	+	+	2.7	348	316	48	40	30	25	+	(g) s mZ
x	9.7	2.3	49.8	35.1	12.8	4.5	0.5	49.5	2.4	421	410	96	32	28	16	12	
σ	3.5	2.0	27.0	18.8	8.2	1.2	0.2	3.2	0.7	102	134	55	7	6	6	2	

G, g, (g) : Gravel, gravelly, slightly gravelly
S, s : Sand, sandy
Z, z : Silt, silty
Cl, cl : Clay, clayey

vc : very coarse
c : coarse
m : medium
f : fine
vf : very fine

Table 2 — Correlation coefficient matrices of heavy metal levels in the studied surface sediments from Karaduvar and Pozcu in the Mersin Bay.

KARADUVAR

Depth	Clay	Corg	$CaCO_3$	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb	
—	0.59	0.34	−0.49	−0.03	−0.34	0.16	−0.10	−0.20	−0.06	0.14	−0.35	Depth
	—	0.87	−0.10	0.34	0.11	0.29	−0.13	0.20	0.14	0.57	0.06	Clay
		—	0.09	0.03	0.05	0.28	0.03	0.14	−0.08	0.46	0.18	Corg
			—	0.44	0.54	0.29	0.16	0.60	0.18	0.12	0.17	$CaCO_3$
				—	0.83	0.76	−0.31	0.92	0.82	0.75	0.50	Fe
					—	0.69	−0.41	0.84	0.67	0.52	0.65	Mn
						—	−0.13	0.69	0.66	0.86	0.52	Ni
							—	−0.22	−0.15	0.04	0.19	Zn
								—	0.71	0.68	0.54	Cr
									—	0.54	0.57	Co
										—	0.44	Cu
											—	Pb

POZCU

Depth	Clay	Corg	$CaCO_3$	Fe	Mn	Ni	Zn	Cr	Co	Cu	Pb	
—	0.85	0.95	0.33	−0.34	−0.73	−0.74	−0.37	−0.39	−0.30	0.30	0.03	Depth
	—	0.92	0.31	−0.30	−0.65	−0.66	−0.37	−0.27	−0.27	0.36	−0.08	Clay
		—	0.06	−0.83	−0.85	−0.88	−0.80	−0.82	−0.23	0.59	−0.03	Corg
			—	0.07	−0.22	−0.24	−0.15	−0.37	−0.03	0.19	0.81	$CaCO_3$
				—	0.64	0.76	0.34	0.86	0.69	0.32	0.32	Fe
					—	0.82	0.38	0.58	0.68	0.06	0.29	Mn
						—	0.40	0.77	0.76	0.03	0.26	Ni
							—	0.19	0.10	0.14	0.19	Zn
								—	0.74	0.25	0.10	Cr
									—	0.25	0.32	Co
										—	0.08	Cu
											—	Pb

nek (1962). A generalized geological map of the study area and its surroundings is shown in Fig. 2.

3. Methods and materials

A total of 56 surface sediments were collected using a "Dietz La Fonde" grab sampler from the region "Karaduvar" and "Pozcu" in the Mersin Bay. Fig. 3 shows the sampling locations of this study.

Grain-size analyses were carried out by wet and dry sieving as well as by the pipette method (Folk, 1974).

The oxidizable amount of organic-carbon contents of some selected surface sediment samples was determined using a chromic acid titration method (Gaudette et al., 1974). The accuracy of this method is $\pm 0.25\%$.

The total carbonate contents in some selected samples of sediments were calculated after complexometric titration of *Ca* and *Mg* with EDTA (Müller, 1967).

For heavy metal concentrations (*Fe, Mn, Ni, Cu, Co, Cr, Zn* and *Pb*), subsamples of sediments were leached by HNO_3-acid and analyzed with flame atomic absorption spectroscopy. The statistical analysis (correlation coefficient matrix) of the data from the chemical and physical tests as well as from standard petrographic techniques completed this study.

4. Results and discussion

The results of physical and chemical analyses obtained in the Karaduvar and Pozcu

Table 3 — Heavy metal levels (in $\mu g/g$ dry wt, except iron in %) in the studied surface sediments from Karaduvar and Pozcu in the Mersin Bay compared with other sediments. Parentheses indicate mean values.

Location	Fe	Mn	Ni	Cu	Zn	Pb	Cr	Co
1. Inshore sediments, Karaduvar, Mersin Bay, This study	1.6-4.8 (3.0)	298-698 (477)	155-568 (314)	9-50 (23)	66-466 (152)	7-15 (11)	18-77 (43)	11-40 (26)
2. Inshore sediments, Pozcu, Mersin Bay, This study	1.1-4.0 (2.4)	236-627 (427)	223-753 (410)	8-26 (16)	25-209 (96)	9-17 (12)	19-54 (32)	15-40 (28)
3. Mersin harbour	3.79	457	266	136	250	144	—	—
4. Inshore sediments, Lamas, Mersin Bay	4.27	757	461	31	65	63	540	—
5. Cilicia Basin	3.61	1325	190	40	76	—	308	—
6. Shales	4.72	850	68	45	95	20	90	19
7. Limestones	0.38	1100	20	4	20	9	11	0.1
8. Sandstones	0.98	⟨90	2	⟨10	16	7	35	0.3
9. Ultramafic-basic ophiolitic rocks	0.01-8.90	500-1200	47-3160	35-55	90-115	5-13	340-3400	24-237

3. and 4. from Özkan (1978); 5. from Shaw and Bush (1978); 6., 7. and 8. from Turekian and Wedepohl (1961); 9. from Capan (1981) and Buket and Ataman (1982).

sediments in the Mersin Bay are shown in Figures 4 to 7 and Table 1 to 3, and are discussed below. A comprehensive data on the grain-size distribution of the studied sediment samples are given elsewere (Bodur, 1987).

4.1. Grain-size distribution

The sediments studied in Karaduvar were composed generally of gravelly-muddy-sand materials. The gravel fractions of the sediments varied from less than 1% to 76% (mean 6.9%). Sand was the dominant fraction ranging from 14% to 83% (mean 58%), whereas silt, with concentrations of between 2 and 55%, and clay (from 1 to 16%) showed lower values in the Karaduvar area. The mean grain size (*Mz*) was around 4ϕ, corresponding to fine sand (Table 1).

The sediments of Pozcu are characterized by much lower gravel contents (less than 1 to 8%). The sand fraction varied between 11 and 92% (mean 50%), followed by silt of between 6 and 57% (mean 35%), and by clay (ranging from 2 to 31%; mean 13%). A mean grain size of 4.5ϕ (coarse silt) was calculated from the Pozcu sediments (Table 1).

Generally speaking, the sediments of Pozcu are composed of much finer grains than those of the Karaduvar area (Fig. 4). This is attributed to the particular hydrodynamic energy conditions in each of the studied areas, with Karaduvar being more wave active than the Pozcu area.

4.2. Total Carbonate

The total carbonate content of the sediments was generally high, ranging from 19 to 44% in Karaduvar and from 45 to 56% in the Pozcu area (Table 1).

Petrographical studies showed that the carbonates of the Pozcu sediments were composed mainly of biogenic calcareous materials primarily of marine origin, whereas the

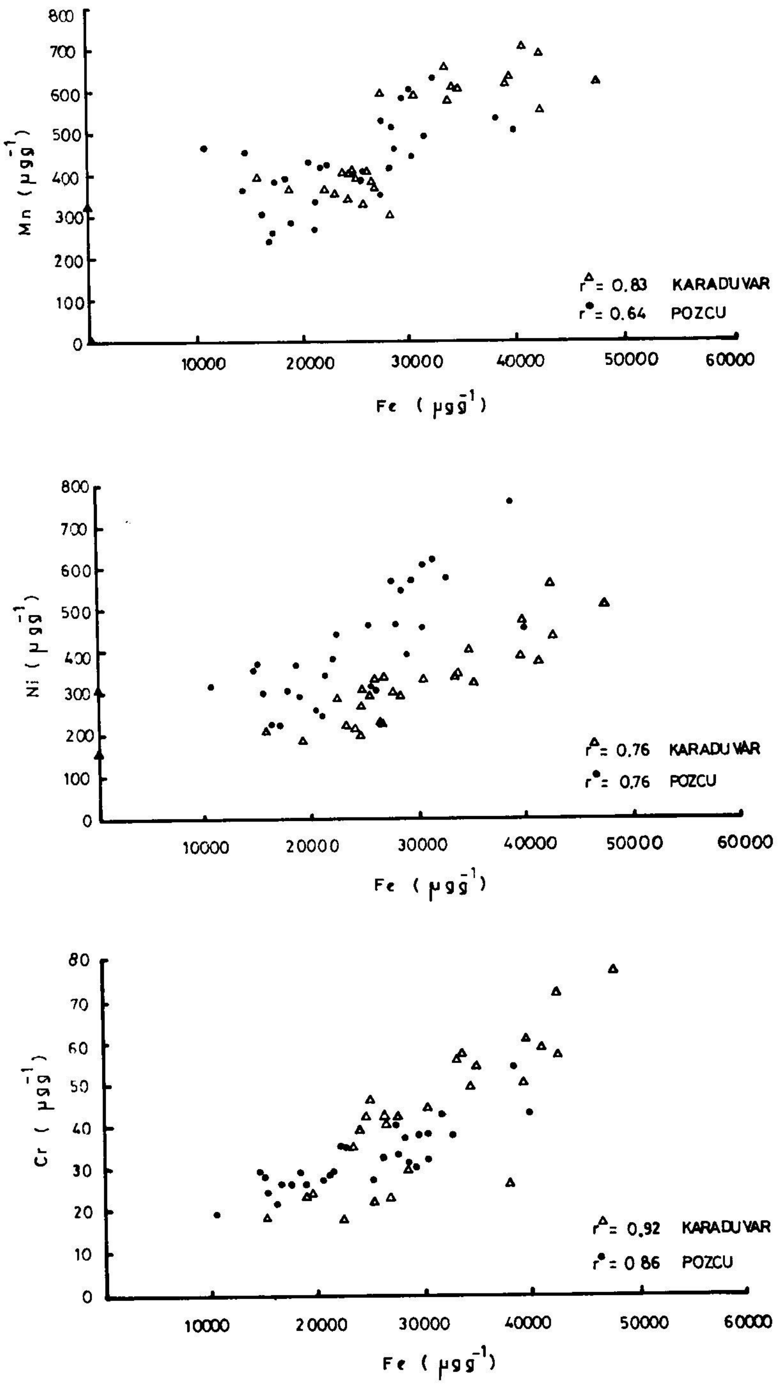


Fig. 5 — Relationships between metal concentrations.

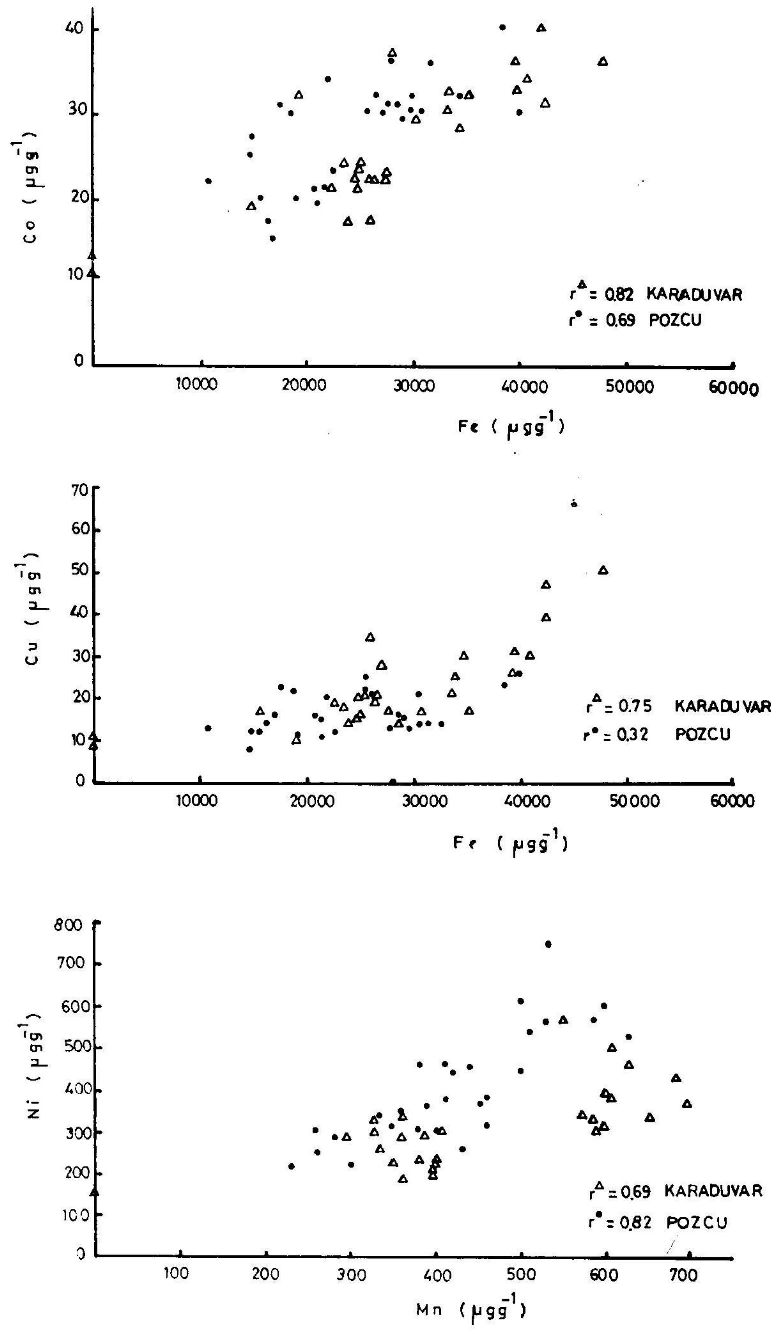

Co (µgg-1)
Fe (µgg-1)
r▵ = 0.82 KARADUVAR
r• = 0.69 POZCU
Cu (µgg-1)
Fe (µgg-1)
r▵ = 0.75 KARADUVAR
r• = 0.32 POZCU
Ni (µgg-1)
Mn (µgg-1)
r▵ = 0.69 KARADUVAR
r• = 0.82 POZCU

Fig. 5 - (cont.)

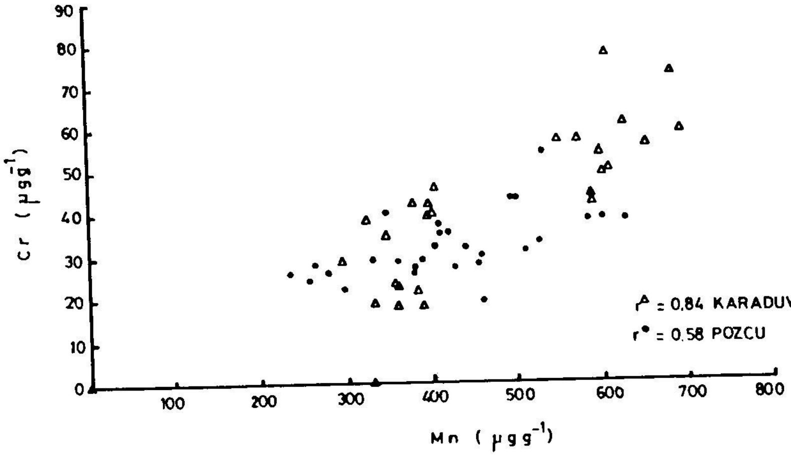


Fig. 5 - (cont.)

Karaduvar sediments also contained appreciable amounts of lithoclastic detrital grains of limestone fragments derived from the hinterland by the seasonal influx of rivers and streams.

4.3. Organic Carbon

The organic carbon contents of the Karaduvar sediments, ranging from 0.2 to 0.6% (mean 0.4%) were similar to those found in the Pozcu sediments (0.1 to 0.7%, mean 0.5%).

Petrographical investigations in this study, along with results from previous works (Bastürk, 1979 and Yilmaz, 1986) showed that the majority of organic matter is provided by both marine and terrestrial sources.

4.4. Heavy Metals

As shown in Table 1, heavy metal concentrations with the exception of *Co* and *Pb* are different in the two sampling areas. The metals *Fe*, *Mn*, *Zn*, *Cr* and *Cu* were found in higher abundances in the Karaduvar sediments than in the Pozcu sediments. *Pb* and *Co* levels were almost the same in both areas, whereas *Ni* was found in higher amounts in the Pozcu sediments.

In order to find the degree of relationship between the heavy metals themselves and the carbonate and organic carbon contents of the studied sediments, correlation matrices (Table 2) were used. Strong and positive correlations of *Fe* and *Mn* with the *Cr*, *Co* and *Ni* in both Karaduvar and Pozcu sediments (see also Fig. 5) suggested the association of these metals largely with *Fe* and *Mn*, or *Fe*- and *Mn*-oxides/hydroxides, respectively.

On the other hand, the correlation of *Cr* with the carbonates (in Karaduvar sediments) and organic carbon (in Pozcu sediments) indicates that *Cr* may also be present to some extent, associated with the carbonate and organic matter phases.

Ni contents can also be found in greater or lesser amounts with clays and organic matter, as inferred from the positive and significant correlations existing between *Ni* and clays and organic carbon in the Pozcu sediments.

Fe seems to be the favored phase for *Cu* in the Karaduvar sediments (Fig. 5). However, *Cu*-bonding with clays, organic matter and *Mn* is also possible. In contrast, the *Cu*-concentrations of the Pozcu sediments are more related to the organic material, as seen from the favored correlation between *Cu*- and organic carbon contents.

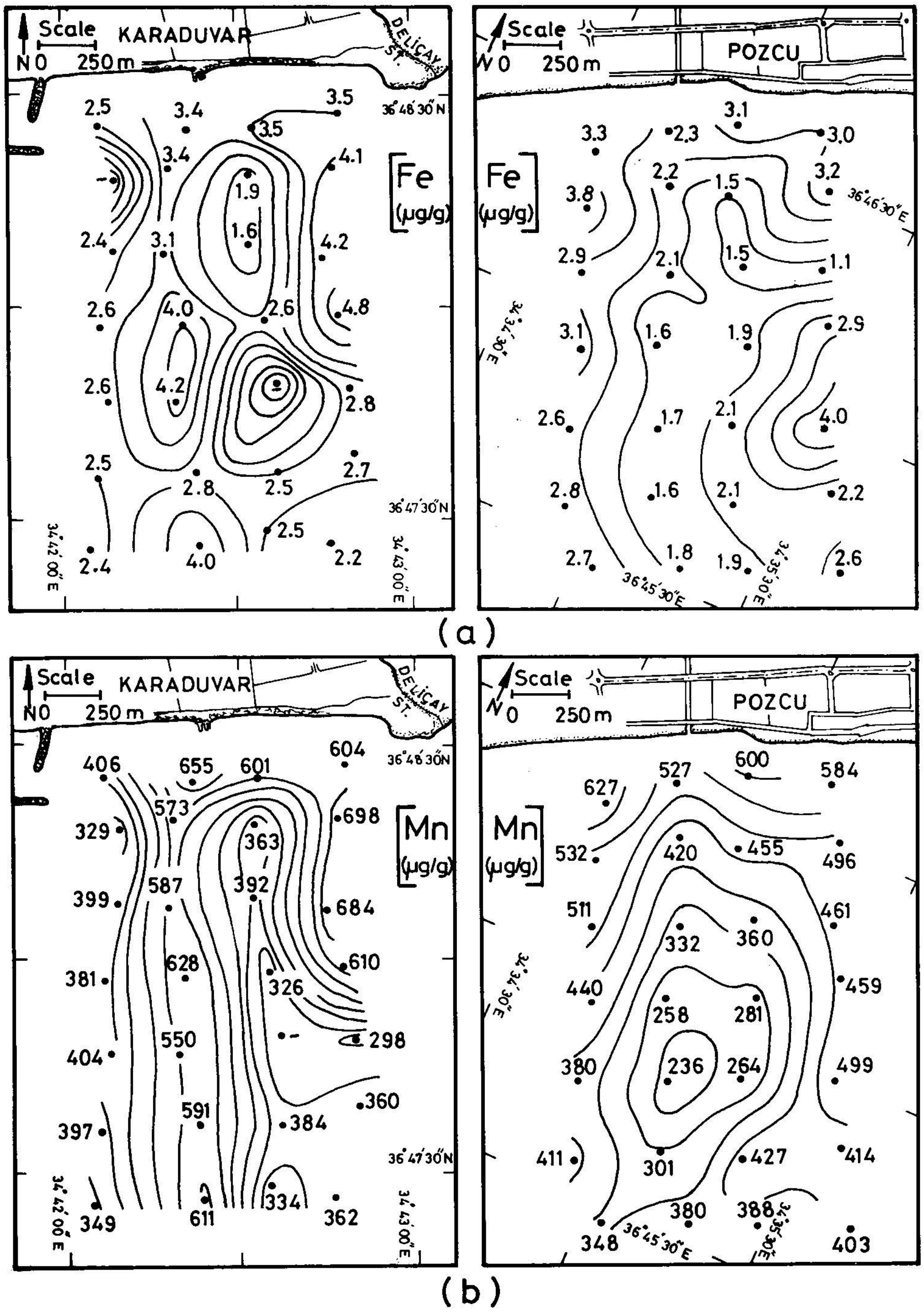


Fig. 6 — Areal distribution of metal concentrations (*Fe*, *Mn*, *Ni* and *Zn*).

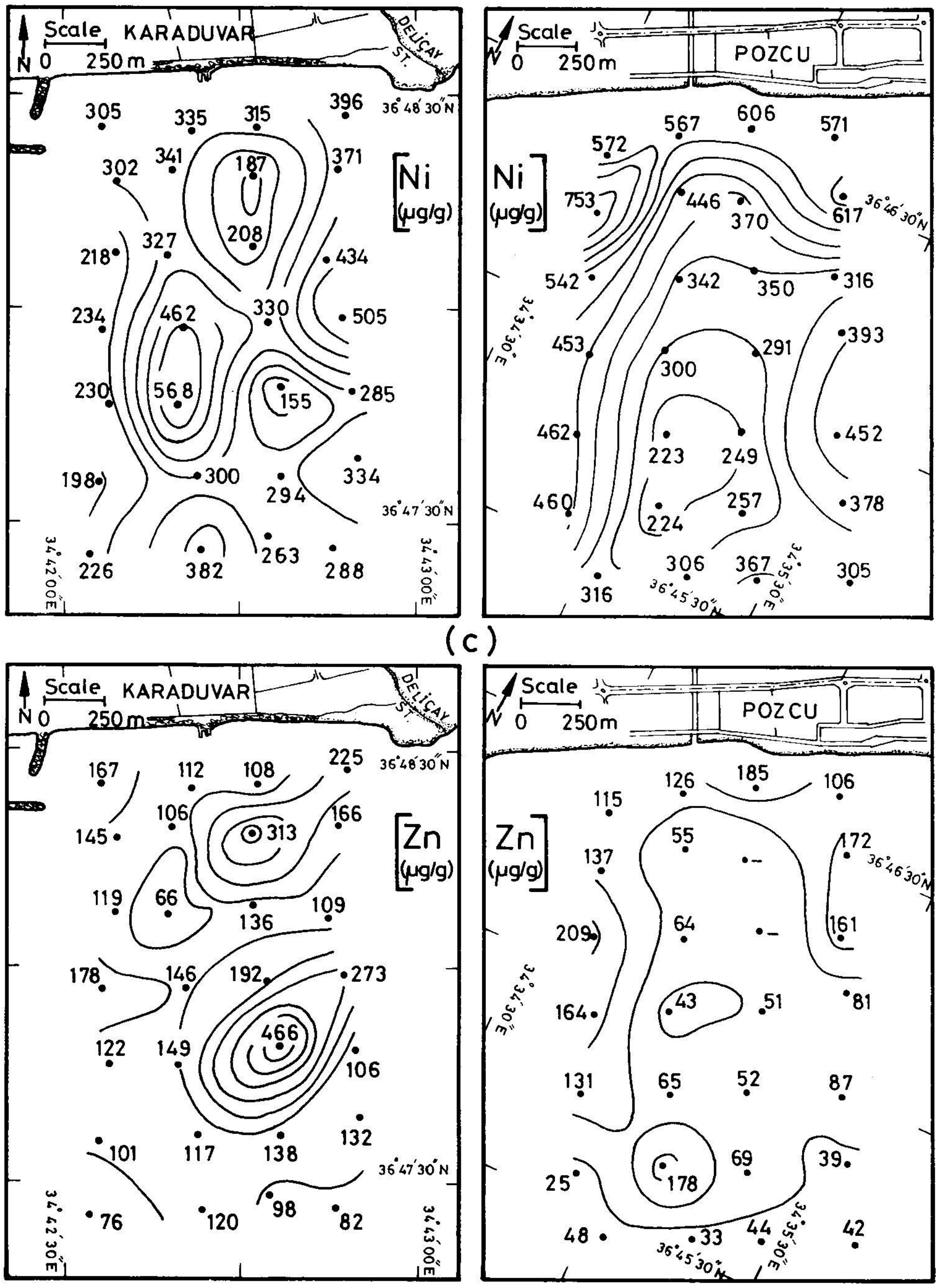

Scale
0 250 m
KARADUVAR
DELİÇAY ST.
36°48'30"N
36°47'30"N
34°42'00"E
34°43'00"E
Ni (µg/g)
POZCU
36°46'30"N
36°45'30"N
34°34'30"E
34°35'30"E
(c)
Zn (µg/g)
34°42'30"E
(d)

Fig. 6 - (cont.)

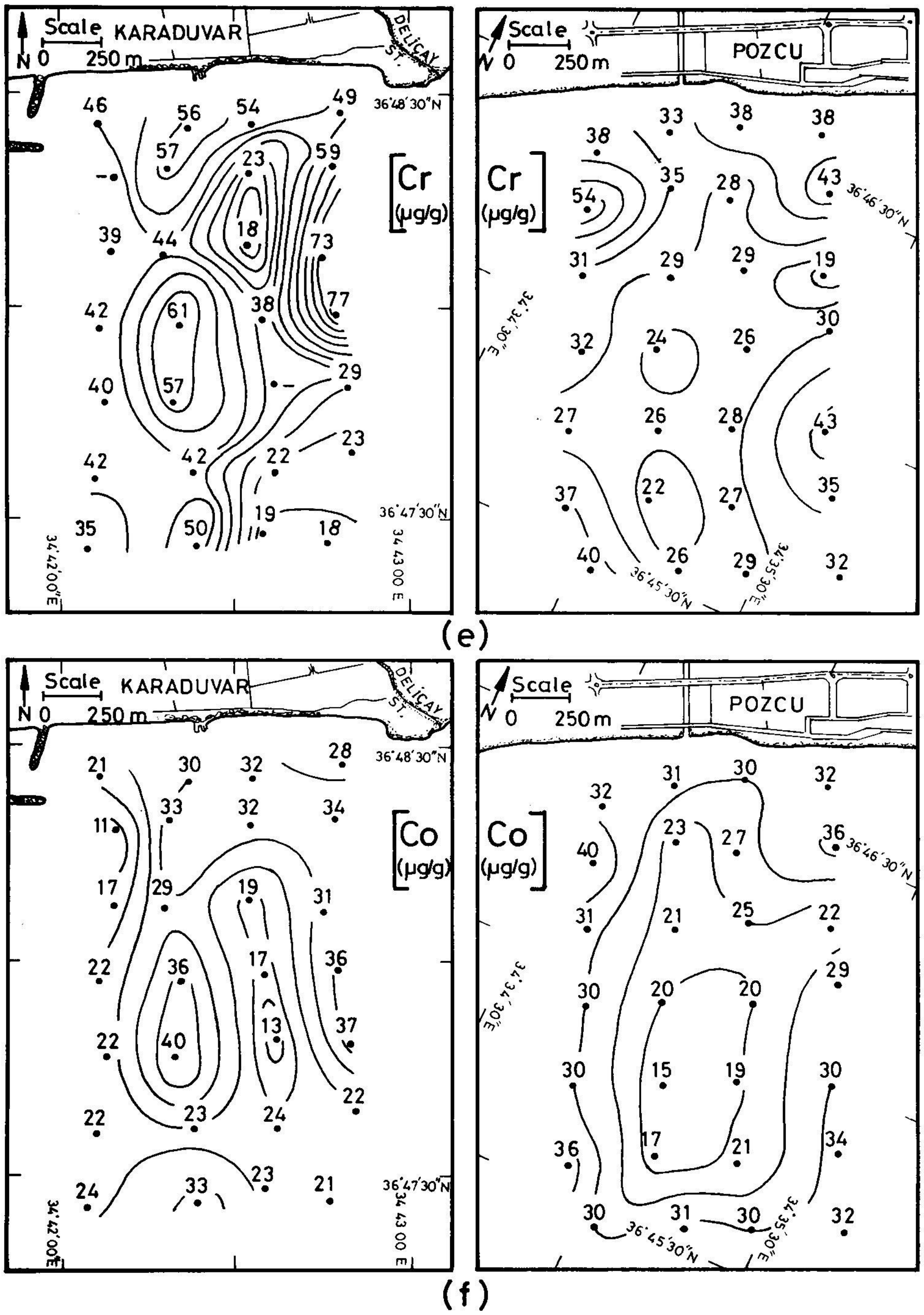


Fig. 7 — Areal distribution of metal concentrations (*Cr*, *Co*, *Cu* and *Pb*).

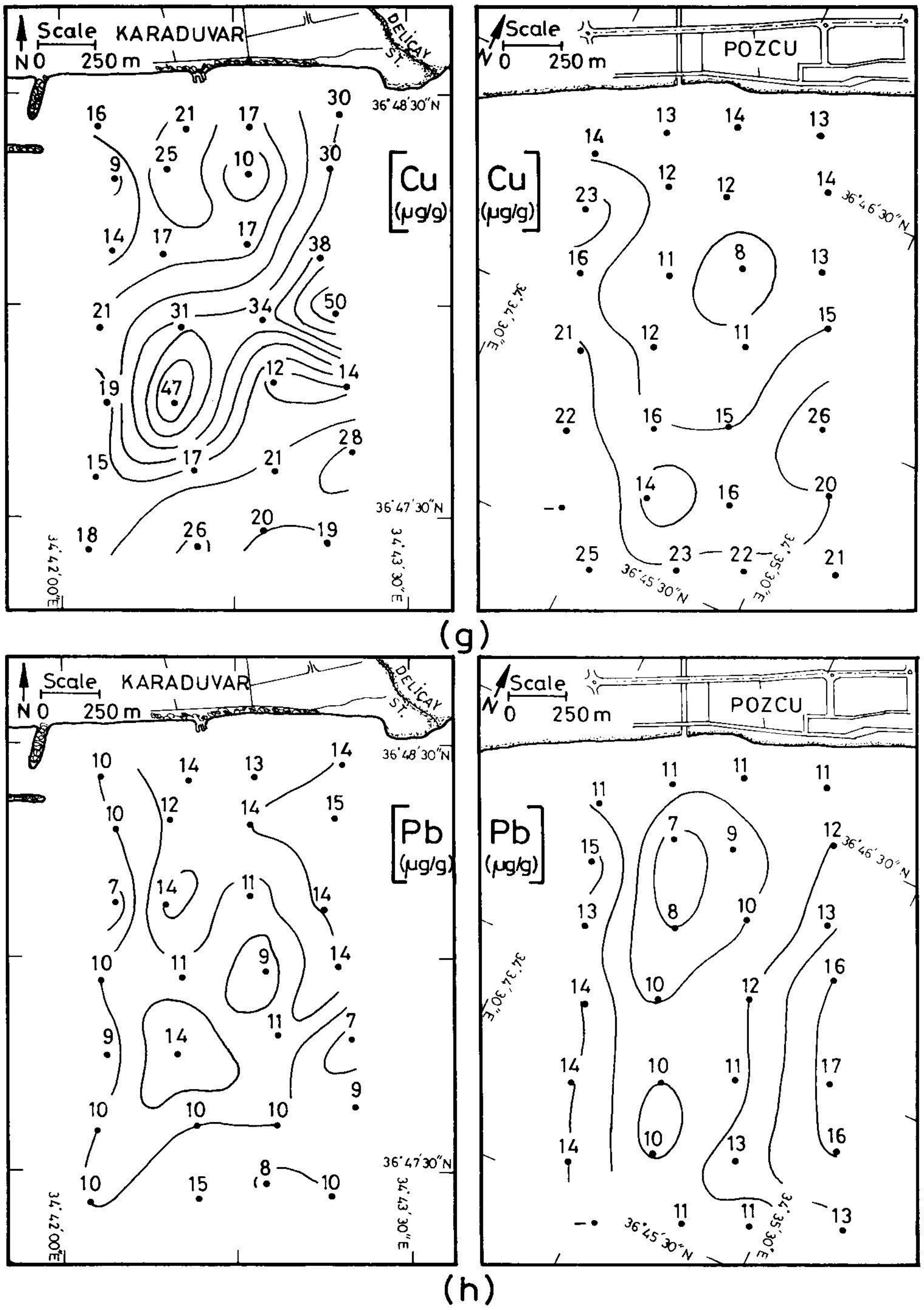


Fig. 7 - (cont.)

Pb appears to be associated widely with carbonates in the Pozcu sediments, in contrast to its more significant relationship with the *Mn*-phase in the Karaduvar sediments.

Lack of significant correlations of *Zn* with any other phase suggests no preferred associations in either of the sampling areas.

As obtained so far, *Fe* and *Mn* seem to be the dominant types of heavy metal bonding in the Karaduvar and Pozcu sediments, followed by the clays, organic matter and carbonates. This is in good agreement with the worldwide investigations on heavy metals by numerous authors (e.g. Förstner and Wittman, 1979), where the *Fe*- and *Mn*-phases are reported as being the most important heavy metal bondings commonly found in marine sediments.

In order to trace the heavy metal sources of the Karaduvar and Pozcu sediments, the heavy metal contents in this study are compared with shales, limestones and sandstones from the worldwide geological record, as these materials are known to be counterparts for clay, carbonate and sand-rich unconsolidated sediments (Table 3). Compared to the shale values, the sediments from Karaduvar and Pozcu are depleted in iron, manganese, chromium, copper and lead, suggesting lithogenic sources. The lower concentrations of these elements are probably due to variations in the grain-size and mineral compositions of the studied sediments.

It must be pointed out, that the more clayey Pozcu sediments did not show the highest *Fe, Mn, Cr, Cu* and *Zn* levels measured in this study, which means that the *Fe* and *Mn* phases were not concentrated only in the clay sized sediment fractions, but also in the coarse fractions. This can be seen from studies of the grain-size parameters, where the gravel, sand and silt dominate the clays.

The *Co*, and to some extent *Zn*, were comparable with average shales. *Zn* concentrations from Karaduvar as well as *Ni* from both Karaduvar and Pozcu sediments showed higher levels compared to shales. High zinc contents of the Karaduvar sediments, may be partly due to man-made activities. Zinc is used intensively for water pipes and tubes in and around the study area, and may be introduced to the sediments via the Delicay Stream, which drains into the Sea at Karaduvar.

The relatively higher *Ni* concentrations of the Pozcu and Karaduvar sediments are thought to have been provided by minerals of the ultramafic-basic-ophiolitic rock series from the hinterland, a finding which can be supported by petrographical studies on sediments containing ophiolitic rock fragments.

Furthermore, if one takes a close look at Figures 6 and 7, the role of the Delicay stream in the transportation or supply of heavy metals, particularly zinc, deserves attention. Here, heavy metal concentrations usually decrease offshore in a SW direction off the Karaduvar area. In contrast, the concentrations off the Pozcu area, where the sedimentation is not influenced directly by any stream or river draining into the Sea, were randomly distributed.

The varying concentrations of heavy metals in each of the studied areas can be explained best in terms of variations in the grain-size and mineralogical compositions of sediments.

5. Conclusions

The associations of heavy metals in recent inshore sediments of the Mersin Bay have been discussed. The amounts of heavy metals (*Fe, Mn, Zn, Pb, Cr* and *Co*) in this study were generally in good agreement with those from geological weathering. Hence, the majority of heavy metals is believed to have been introduced into the Bay from coastal and hinterland areas. The Zinc concentrations seem partly to be influenced by anthropogenic activities. The higher quantities of Nickel were probably derived from the ultramafic-ophiolitic rock series on the hinterland. Strong correlations between the *Fe, Mn* and other metals studied suggest the association of these metals largely with the *Fe* and *Mn* phases, probably hydrous oxides of *Fe* and *Mn*.

References

Balkas T.I., Tugrul S. and Salihoglu I.; 1982: *Trace metal levels in fish and crustacea from northeastern Mediterranean coastal waters*. Mar. Environ. Res., 6, 281-289.

Bastürk Q.; 1979: *Distribution of Pcb's and organochlorine residues in Marine Sediments and Organisms*. M.S. Thesis, Inst. of Mar. Sci. Middle East Technical University, Erdemli/Icel (Turkey), pp. 92., (unpublished).

Bodur M.N.; 1987: *Recent inshore sedimentation in the Bay of Mersin*. M. Sc. thesis, Inst. Mar. Sci. Middle East Technical University, Erdemli/Icel (Turkey), 132 pp., (unpublished).

Buket B. and Ataman G.; 1982: *Petrographic and petrologic characteristics of Erzincan-Refahiye Ultramafic and Mafic rocks*. Yerbilimleri, 9, 5-17.

Capan U.Z.; 1981: *Statistical interpretation of results from major element analyses of rocks from five ophiolite massives along Taurus Belt, Southern Turkey: I. Comparison of mean values (Schaffe's Test)*. Yerbilimleri, 7, 105-114.

Evans G.; 1971: *The recent sedimentation of Turkey and the adjacent Mediterranean and Black Seas: A review*. In: Geology and History of Turkey. A.S. Campbell (Ed.). Petrol. Explor. Soc. Libya, Tripoli, pp. 385-406.

Folk R.L.; 1974: *Petrology of Sedimentary Rocks*. Hemphill Publ. Co., Austin, Texas 78703, 182 pp.

Förstner U. and Wittman G.T.W.; 1979: *Metal Pollution in the Aquatic Environment*. Springer Verlag, Berlin, 486 pp.

Gaudette H.E., Flight W.R., Toner L. and Folger D.W.; 1974: *An inexpensive titration method for the determination of organic carbon in recent sediments*. J. Sedim. Petrology, 44, 249-253.

IMS-METU; 1986: *Akdeniz Eylem Plani II*. Asama uzun sureli izleme programi (Med-Pol II) Sonuc Raporu, Erdemli/Icel (Turkey), pp. 14-22.

Mange-Rajetzky M.A.; 1979: *The mineralogy and provenance of the Quaternary sediments of the southern Turkish Coast, between Karatas and Antalya*. D.I.C., Thesis, University of London, U.K., 148 pp., (unpublished).

Mange-Rajetzky M.A.; 1981: *Detrital blue sodic amphibole in recent sediments, southern coast, Turkey*. J. Geol. Soc. London, 138, 83-92.

Mange-Rajetzky M.A.; 1983: *Sediment dispersal from source to shelf on an active Continental Margin, South Turkey*. Mar. Geol., 52, 1-26.

Müller G.; 1967: *Methods in sedimentary petrology*. E. Schweizbart'sche Verlags buch., Stuttgart, 216 pp.

Özkan M.A.; 1978: *The analysis of selected trace metals in marine sediments-effect of sediment structure on extraction efficiency*. M.Sc., Thesis, Inst. of Mar. Sci., Middle East Technical University, Erdemli/Icel (Turkey), 70 pp., (unpublished).

Shaw H.F. and Bush P.R.; 1978: *The mineralogy and geochemistry of the recent surface sediments of the Cilicia Basin, NE Mediterranean*. Mar. Geol., 26, 115-136.

Ternek Zati.; 1962: *Geological map of Turkey (1/500000)*. Adana sheet. M.T.A. (Maden Tetkik Arama) publ., Ankara (Turkey).

Turekian K.K. and Wedephol K.H.; 1961: *Distribution of the elements in some major units of the earth's crust*. Geol. Soc. America Bull., 72, 175-192.

Yalcin M.N. and Görür N.; 1983: *Sedimentological evolution of the Adana Basin*. In: Geology of the Taurus belt proceedings. Tekeli Okan. and Göncüoglu M.C. (Eds.). International Symposium (1983), Ankara/Turkey, Maden Tetkik Arama, pp. 165-172.

Yilmaz A.; 1986: *The origin and the nature of humic substances in the marine environment*. Ph. D. Thesis, Inst. of Mar. Sci., Middle East Technical University, Erdemli/Icel (Turkey), pp. 63-72., (unpublished).

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