Sediment Characteristics and Phase Association and Mobility of Fe, Mn, Zn, Cu, Pb and Cd in Core Sediments from Lake Edku

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ABSTRACT. The acid soluble and total concentrations of Fe, Mn, Cu, Zn, Pb and Cd were measured in sediment cores from Lake Edku; one of the Nile Delta coastal lagoons, southern Mediterranean Sea. The proportions of sand, silt and clay and the contents of $CaCO_3$ and organic carbon were also determined.

The results show that the average total concentrations of Fe, Mn, Zn, Cu, Pb and Cd are 57787 \pm 19447, 943 \pm 395, 81 \pm 19, 55 \pm 21, 42 \pm 10 and 3.4 \pm 0.7 μ g g⁻¹ respectively. The percentage of the acid leachable fraction of these metals in the given order are: 18, 64, 30, 52, 61 and 30.

The importance of the different binding substrates was inferred from the statistical relationships. The results indicate two groups of metal associations: Fe, Zn and Cu are preferentially associated with clay and to lesser extent with silt; calcareous shells are the favorite sites for the second group comprising Mn, Pb and Cd. The statistical relationships between the acid leachable metal phases and the different substrates maintain the same trend but with more specific and improved correlations.

The geochemical mobility of metals was inferred using a relative conditional measure referred as Lability Index. The studied metals showed a general mobility decrease with depth in cores.

Introduction

The study of trace metals geochemistry in lake sediments offers valuable information for understanding the historical development of the basin. Hakanson and Jansson (1983) stated that lake sediments can be regarded as environmental tachometer, therefore, the anthropogenic impact on the natural environment can be readily assessed (Forstner 1977).

Apart from direct waste outfalls, recent industrialization has considerably enhanced atmospheric trace metals precipitation in aquatic environments (Carignan and Nriagu 1985). This is confirmed by the study of dated sediment cores as well as air pollution studies. For example, the annual atmospheric inputs of lead have increased from 3000 tons in prehistoric to about 300,000 tons at present (Patterson and Settle 1987).

Although the elimination mechanisms in lakes are more efficient relative to oceans because of the higher sedimentation rate and high productivity (Sigg *et al.* 1984), the effect of man's activities can not be totally masked.

Very little is known about the characterization and distribution of trace metals in Lake Edku and the Nile Delta coastal lagoons in general. The present study aims principally at the assessment and characterization of the presence of Fe, Mn, Cu, Zn, Pb and Cd in lake Edku sediments as well as at the evaluation of the role of the different substrates in the transfer of these metals to the sediments.

Area of Study

Lake Edku is one of the brackish-water coastal lagoons of the Nile delta (Fig. 1). The lake is separated from the Mediterranean Sea by a sand coastal barrier yet, lakeseawater exchange was maintained through a 2 m deep and narrow channel. The lake is very shallow having a mean depth of about 1 m and a surface area of about 115 km².

About $1000 \times 10^6 \text{ m}^3$ of drainage water are discharged annually into the southeastern part of the lake. This leads to an almost permanent westward flow of fresh water in the southern part of the lake (Dowidar *et al.* 1976). The southern part of the lake (Fig. 1) as well as the surrounding shores are characterized by extensive sedentary vegetation and accumulation of free floating plants. These plant communities create a sort of sheltered environment favorable for several types of animal life.

The lake prober is divided into several sub-basins by means of small islets and sometimes belts of islets. According to Sestini (1988), these islets represent old beach ridges or banks of old river channels.

Material and Methods

Three sediments cores were collected to represent the three main subenvironments of the lake; the lake-sea communication vicinage, the central basin and the southeastern basin affected directly by the drainage water (Fig. 1).

Immediately after collection, the cores were sectioned at the desired intervals and the sediments were then dried at 70°C. A carefully homogenized portion of each interval was ground, using agate mortar, for the determination of organic carbon, car-



bonate and trace metal concentrations. For the determination of the total trace metal concentration, samples were digested in a digestion bomb using 3:3:1 (v/v) mixture of HNO₃, HF, HClO₄ respectively. A one gram subsample of each nonpowdered sediment was taken for the extraction of the labile metal fraction using 1 M HCl; the sediment acid ratio was 1/25 and samples were shaken for 24 hours. Trace metals in the extracts were measured using Flame Atomic Absorption Spectrophotometer (Varian 1250). The relative standard deviation for eight replicates of a test sample ranged between 5 and 10% for the ensemble of metals and for the determination of both total and acid leachable forms.

The organic carbon content was determined using the wet oxidation method of Walkly and Black (1934). The carbonate content was estimated from the weight loss after treatment with 0.2 M HCl. Proportions of sand, silt and clay were also determined.

Results and Discussion

Sediment Types

The sediments in Lake Edku are derived principally from its cultivated catchment through the drainage system. Material from soil erosion and/or soil wash may ultimately find their way to the lake bottom.

Despite the well defined sediment source, the cores examined showed marked variations in sediment types. This, most likely, resulted from differences in the local environmental conditions. The nature of the local environment may affect the characteristics of the original material through the action of chemical, biological and physical processes.

For example, core 1, taken close to the lake sea communication, contains substantial amounts of beach sand, the fines (< 62μ m) in this core constitute only 27% of the sediment (Table 1). A great deal of the sand fractions composed of plant fibers. This is supported by the positive correlation between sand and organic carbon (r = 0.84). However a negative correlation was found between clay and organic carbon contradicting the classic trend of clay-organic matter association. Obviously, the beach sand contributing to the sediments of this area carry along significant portion of plant debris from the nearby vegetated lake shores. Generally, the sediments of this core showed the highest organic carbon concentrations (Table 1). The concentrations of sand and organic carbon show a general downward decrease whereas, the clay increases. The distribution of silt was consistent with depth and the carbonate content showed the highest concentrations in the upper and lowermost layers (Fig. 2).

The sediments of the three upper intervals (0-18 cm) of core 2 did not show any marked difference in textural appearance from their counterparts in core 1. However, it contained lower organic carbon and higher carbonates. The deeper layers of this core are basically different. They comprise distinctive rusty mud dotted with more bright tan-colored spots. This coloration is probably due to an episode of iron

Core	Sample	Interval (cm)	Fe	Mn	Zn	Cu	Pb	Cd	Sand	Silt	Clay	тос	CaCO ₃
	1	0.4	51(12	1790	07	12	44	2.0	-11	17	10		20
1		4 10	51012	1/00	91	45	1 44	3.0	13	1/	10	2.5	20
1	2	4-10	52045	012	90 74	47	21	26	01	10	15	10.5	24
	3	10-20	76170	91J 1116	/4 07	40	50	3.0	52	10	10	4.2	21
Maan	4	20-30	59606	1110	97	0/	30	4.5	33 45	19	20	1.1	20
wicali			36070	1257	91	51	40	2.2	00	19	10	4.0	24
	1	0-5	23938	1194	48	29	42	2.9	76	15	9	1.1	44
	2	5-10	29648	979	50	28	40	4.1	73	17	10	1.4	40
	3	10-18	30763	680	46	26	39	4.0	74	13	13	0.8	38
2	4	18-39	95165	475	103	100	42	3.4	0.0	22	78	0.3	4
	5	39-41	66159	387	91	70	26	2.8	9	18	73	0.5	11
Mean			49135	743	68	51	38	3.4	46	17	37	0.8	27
1													
	1	0-2	43817	1228	65	46	58	4.0	53	25	22	2.6	46
	2	2-4	70372	949	84	63	35	2.8	24	46	30	2.0	26
	3	4-6	70770	815	88	62	45	2.8	19	36	45	2.1	26
	4	6-8	72524	820	91	63	42	3.2	18	36	46	2.1	27
3	5	8-10	67948	737	81	58	43	3.6	18	38	44	2.5	33
Ů	6	10-15	58699	344	95	96	40	2.4	35	26	39	2.7	28
	7	15 - 20	83723	1388	99	63	68	5.0	25	23	52	2.2	24
	8	25-40	56381	351	70	55	51	3.6	0.0	30	70	2.8	11
Mean			65529	829	84	63	48	3.4	24 0	33	43	2.4	28
Lake													
average			57787	943	81	55	42	3.4	45	23	32	2.6	27

TABLE 1. Total trace metals concentrations ($\mu g g^{-1}$ and % of sand, silt, clay, TOC and CaCO₃.

precipitation (Berner 1971) or to the formation of Fe-III humate complexes (Stumm and Morgan 1981). The dotted appearance of the sediment could be resulted from differential flocculation. The whole sediment in these layers is made up of silty clay and showed a sharp decline in sand, carbonates and organic carbon (Fig. 2). Obviously, organic matter accumulation was inhibited by highly oxic conditions.

The sediments of core 3 showed the highest percentage of fine materials. The average silt and clay content is 76% of the total sediment. The upper most layers showed the maximum concentrations of sand and carbonates and the lowest clay contents, whereas, at the bottom of the core the opposite trend was observed (Fig. 2).

Trace Metals

Iron

Generally, the sediments of lake Edku are iron-rich, the average of the total iron content in the three cores is 5.8% and may reach values as high as 7-9.5% particularly in the lower core intervals (20-40 cm).

The data indicate that more than 80% of the iron occur in the non-reactive residual fraction (Table 2). The correlation analysis suggests that about 70% of the residual



FIG. 2. Distribution of the major constituents in sediment cores.

iron are associated with silt and clay (Table 3). Not withstanding the negative correlation between iron and sand, the remaining part of iron could be incorporated into crystalline iron oxides or some other heavy minerals of the sand fraction. The inverse correlation between iron and sand is due to the dilution effect of the calcareous shell fragments which composes the essential part of the sand fraction.

Unlike the residual iron, the labile iron phase is weakly correlated with the grain size populations suggesting that the leachable iron rather occurs as discrete hydrous oxides.

Core	Sample	Fe (r)	Fe (L)	% L	Mn (r)	Mn (L)	% L	Zn (r)	Zn (L)	% L	Cu (r)	Cu (L)	- % L	Pb (r)	Pb (L)	% L	Cd (r)	Cđ (L)	%L
		39912	11700	23	296	1484	83	54	43	44	20	23	53	13	32	171	1.7	1.3	43
1	2	45851	8897	1/	384	835	09	10	38	38	21	26	50	8.5	125	/5	2.1	1.0	33
	3	43491	104/4	19	304	549	60	49	25	34	17	31	64	9.5	21	70	2.8	0.8	22
	4	6/9/4	8504	11	/11	405	36	/9	18	18	45	22	35	28	22	44	3.2	1.1	25
Mean		48802	9894	18	439	818	62	60	31	34	26	26	52	15	25	65	2.5	1.1	31
	1	18426	5512	23	127	1067	89	30	18	37	18	11	38	0.5	41	99	12	17	60
	2	23418	6230	21	192	787	80	32	18	37	14	14	50	1.6	39	96	2.8	1.3	32
2	3	25588	5175	17	52	628	92	33	13	29	14	13	48	3.8	36	90	2.6	1.4	35
	4	72317	22848	24	227	248	52	78	25	25	42	58	58	29	13	32	2.8	0.6	17
	5	57390	8769	13	247	140	36	73	19	20	32	38	54	14	11	44	2.2	0.6	21
Mean		39428	9707	20	169	574	70	49	19	30	24	27	48	10	28	70	2.3	1.1	33
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	1	35511	8306	19	230	990	81	46	18	28	15	31	67	20	38	65	2.5	1.5	37
1	2	59108	11264	16	329	620	65	64	20	24	25	38	61	14	21	61	2.0	0.8	28
	3	58240	12530	18	256	559	69	64	24	27	22	39	64	24	21	48	2.0	0.8	28
	4	59289	13235	18	261	559	68	68	23	26	26	37	59	21	21	50	2.5	0.7	20
3	5	55016	12932	19	234	503	68	58	22	28	23	35	60	26	18	41	2.9	0.7	18
	6	49014	9685	17	58	286	83	79	16	17	72	24	25	15	25	62	1.5	0,9	38
	7	77125	6598	8	1255	133	10	82	18	18	35	27	44	48	20	29	4.3	0.7	14
	8	51088	5293	9	265	86	25	35	34	49	22	34	61	41	10	20	3.1	0.5	14
Mean		55549	9980	16	361	467	59	62	22	27	30	36	55	26	22	47	2.6	0.8	25
Lake average		47926	9860	18	323	620	64	57	24	30	27	29	52	17	25	61	2.5	1.0	30

TABLE 2. Residual (r) and leachable (L) trace metal concentrations ($\mu g g^{-1}$) and percentage of the leachable fraction of the total concentration.

TABLE 3. Correlation analysis.A - acid leachable fraction.B - residual fraction.

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	Fe	Mn	Zn	Cu	Pb	Cd
Sand Silt Clay CaCO ₃ TOC Cd Pb Cu Zn Mn Fe	- 0.46 0.32 0.43 - 0.30 ns - 0.45 - 0.43 0.62 ns ns 1.00	0.73 ns - 0.79 0.56 0.44 0.77 0.77 - 0.54 0.34 1.00	ns ns - 0.51 0.75 ns ns 0.30 1.00	- 0.86 0.54 0.83 - 0.69 ns - 0.80 - 0.81 1.00	0.83 - 0.40 - 0.85 0.87 ns 0.96 1.00	0.84 - 0.52 - 0.82 0.82 ns 1.00

	Fe	Mn	Zn	Cı.	Pb	Cd
Sand Silt Clay CaCO ₃ TOC Cd Pb Cu Zn Mn Fe	$\begin{array}{c} -\ 0.74\\ 0.45\\ 0.72\\ -\ 0.64\\ -\ 0.10\\ 0.51\\ 0.79\\ 0.48\\ 0.87\\ 0.60\\ 1.00\end{array}$	ns ns ns 0.71 0.64 ns 0.48 1.00	- 0.51 0.29 0.52 - 0.45 ns 0.51 0.79 1.00	ns ns ns ns ns ns 1.00	- 0.70 0.36 0.70 - 0.50 ns 0.69 1.00	- 0.30 ns 0.34 ns ns 1.00

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ns = not significant at 95%.

The profiles of residual iron in the three cores follow almost similar trends, where, subsurface concentration peaks were noticed at a more or less similar stratigraphic depths (Fig. 3). A concomittant peak of labile iron was observed in core 2 only. Although the other cores did not show the same peak, there is some evidences that active processes of hydrous oxides precipitation did occur at that time span probably all over the western and central parts of the lake. These oxides have possibly been precipitated first as colloids in the different lake subenvironments and then transported as flocs to the deepest central part of the lake.

Paleochlorosity data (Khamis, in prep.) show higher than normal chloride ions concentrations in the interstitial waters taken at similar intervals. This case could probably be resulted from a continuous flood of seawater into the lake for a long period of time. The aggregation and precipitation of iron hydrous oxides and humic material during the mixing of seawater with freshwater is well known (Eckert and Sholkovitz 1976; Stumm and Morgan 1981). In the meantime, the capacity of clays to adsorb humic substances increases with increasing salinity (Rashid *et al.* 1982; Pickering 1980; Schnitzer and Kodama 1977). We suggest that these mechanisms are responsible for the subsurface peak of the labile iron. The yellowish brown pigment which is associated with the subsurface iron peak in core 2 has been maintained because of the deficiency therein of oxidizable organic matter (Berner 1971) as well as the lack of vegetation in the central basin.

Manganese

The results indicate that the major fraction of manganese (65%) occurs in the labile phase (Table 2). It seems that the distribution of manganese throughout the cores is essentially controlled by its redox geochemistry. The profiles of labile manganese (Fig. 3) show a sharp downward decrease in the upper 5-10 cm followed by a more or less gradual decrease. The labile manganese is positively correlated with sand and carbonate and to a lesser extent with the organic carbon (Table 3). This



FIG. 3. Distribution of acid leachable and residual trace metals in sediment cores.

M.A. El-Sayed

suggests that part of this phase is incorporated into a carbonate substrate, most likely into the structure of mollusks shells. Some other parts could be found as a discrete oxides which tend to precipitate in the highly aerated sands on the top of the core. The weak correlation with organic carbon may indicate that organically-bound manganese could be released to the interstitial water through the breakdown of organic materials. The occurrence of labile manganese in high concentrations in the top most sediment layer not consistent with the gradient below may be a result of the limited circulation through sediment-water interface impeded by the rapid precipitation of iron hydrous oxides (Martin *et al.* 1987).

The concentrations of residual manganese on the other hand fluctuate within narrow limits. However, two concentration maxima coinciding with the residual iron maxima of core 1 and core 3 were observed (Fig. 3). In addition, questionable minimum values were noticed in core 2 and core 3 in the layer just overlying the ironrich intervals. The residual manganese is not correlated with any of the sediment parameters, but it is only correlated with iron and other trace metals. This suggests that the inert part of manganese is incorporated probably into iron oxide minerals.

Zinc

Like iron, zinc occurs mainly in the residual form (Table 2). The correlation analysis shows that the residual zinc is strongly correlated with residual iron and weakly correlated with manganese (Table 3). They seem to be associated in crystalline oxides as well as in clay minerals. It is also evident from the profiles of residual zinc that the concentration maxima of zinc coincide with those of iron (Fig. 3).

The labile zinc was found to be mainly organically bound. This was also shown by Forstner (1977) for lacustrine sediments. However, our results do not agree with those of Tessier *et al.* (1980 and 1982) who reported that mobile zinc in stream sediments is mainly correlated with Fe and Mn oxides. Apparently, the association of zinc with organic matter in the lake sediments is related to its importance as micronutrient. Table 2 shows that the highest concentrations of labile zinc are found in core 1 where, the highest organic carbon values are recorded. The correlation analysis shows that both labile and residual zinc are inversely correlated with carbonate (Table 3).

Copper

Almost half of the copper occurs in the labile phase (Table 2). The principal substrates for labile copper are the iron hydroxides and the clay minerals (Table 3). The correlation analysis suggests that copper is especially attached to clays. It could be found as exchangeable cation or specifically adsorbed (Jenne 1977).

The residual copper on the other hand is strongly associated with zinc and weakly correlated with iron. This may suggest that copper and zinc are incorporated in some mineral form.

The depth profiles of copper (Fig. 3) show its irregular distribution, however, increased concentrations are observed at deeper depth intervals. Core 3 showed the highest average concentration for labile and residual copper, indicating probably the influence of the source area.

Lead

The greatest part of lead was found in the HCl leached fraction, it forms on the average about 60% of the total metal (Table 2), nevertheless, values as high as 99% do occur. These high values are shown to be specific to carbonate substrate. The correlation analysis suggests that the acid leachable lead holding substrates are carbonates and manganese phases (Table 3). Therefore, highest lead concentrations are found in the upper sediment layers, being enriched with carbonates and/or manganese oxides. High surface lead concentrations could also be partly attributed to atmospheric input of urban dust enriched in lead (Forstner and Wittmann 1981).

On the contrary, the highest concentrations of residual lead were found associated with sediments of the lower core intervals having the highest clay and residual iron contents (Fig. 1 & 2).

Cadmium

Cadmium was found in relatively high concentrations. Surprisingly most of it was found in the residual form (Table 2). Yet, similar values were also reported by Premazzi *et al.* (1986) for 13 Italian lakes and by Forstner and Wittnam (1981) for Wiskonsin lake.

The sediments of lake Edku were originally derived from agricultural lands which could have been enriched with cadmium through digenetic processes. The use of phosphate fertilizers which are known to contain significant cadmium concentrations (Table 4) may enhance this process. Helios-Rybica and Forstner (1986) suggested that cadmium may substitute for major cations in the octahedral units of clay minerals. They mentioned that the relatively open structure of mixed layer minerals in particular, can offer diffusion-type sorption sites, in which potentially toxic heavy metals may become semi-reversibly incorporated during sediment digeneses. Mineralogical studies of lake Edku sediments (Moussa and Saad; in prep.) showed that the fine silt and clay minerals are composed entirely of mixed layer illite-smictite and subordinate kaolinite.

The labile cadmium was found associated with the same substrates as the labile lead, *i.e.*, the carbonates and manganese oxides, with increasing concentrations in the surface layers, which may suggest its anthropogenic origin.

Judgement of Results

The average concentration values of trace metals were inspected by comparing them with the metal concentrations in the standard shales and related sediment types (Table 4).

The enrichment factors indicate that the lake sediments are particularly enriched with lead and cadmium. The labile forms of these two metals seem to be mainly con-

Sediment type	Fe	Mn	Zn	Cu	Pb	Cd	тос	CO3
Standard shales [*] Fossil lake sediments [*]	46700 18200	850 406	100 105	45	20 16	0.30	- 35	- 36
Recent lake sediments* from remote areas	43400	760	118	45	34	0.4	1.6	16
Soils*	38000	850	50	20	10	0.06	-	-
Clays**	66300	730	. 245	96	53	- 1	-	-
Silts**	17700	400	49	20	17	_	_	·
Super-phosphate fertilizer*	1190	225	363	16	0.7	4.90	-	_
Lake Edku	57787	943	81	55	42	3.40	2.6	40
Enrichment factor (lake/shale)	1.2	1.1	0.8	1.2	2.1	11.30	-	-

TABLE 4. Trace metal concentrations ($\mu g g^{-1}$) in standard shales and other sediment types.

*c.f. Forstner and Wittmann (1981)

**Calvert (1976)

tributed from atmospheric fallout. As a matter of fact, no point source was felt in the lake. Forstner and Wittmann (1981) stated that typical non-point sources for elevated metal concentrations in inland lakes are represented by the runoff from agricultural land and by atmospheric precipitation. Generally, we can safely conclude that the lake sediments are not polluted with respect to other metals.

Relative Mobility of Metals

To appraise the geochemical mobility of sediment associated metals we introduce the Lability Index as a relative conditional measure. It is defined as the ratio of the acid leachable metal concentration $(\mu g g^{-1})$ to the metal concentration in the residual phase $(\mu g g^{-1})$. The greater the value of this index for a given metal, the greater is its mobility. This index can give a good estimate of the geochemical reactivity of metals and it offers the possibility of reliable comparison between varying environments having completely different total metal concentration when the methods of chemical attack are normalized.

This index may also be of great interest in environmental studies since it permits an approximate evaluation of the part of the metal that may exchange with the interstitial and overlying waters and therefore, may affect the bottom organisms.

Although the method we have applied in this work for the extraction of labile metal forms (1M HCl) may be considered as relatively severe, still this relative measure can be of much help.

The lability index for the studied metal (Table 5) generally decreases with depth indicating greater metal stabilities at the deeper core intervals. This seems to be particularly related to the concomitant increase in the clay content with depth. However, the distribution of copper lability index with depth in core 2 shows a completely inverse trend (Fig. 4). Obviously, this is related to the association of copper with the hydrous iron oxides enriched in the sediments in the deeper intervals. The lability

Interval (cm)	Fe	Mn	Zn	Cu	Pb	Cd						
Core 1												
0-4 4-10 10-20 20-28	0.29 0.20 0.24 0.13	5.01 2.17 1.51 0.57	0.79 0.62 0.50 0.22	1.14 1.25 1.79 0.50	2.44 2.94 2.25 0.77	0.76 0.48 0.34 0.34						
Core 2												
0-55-1010-1818-3939-41	0.30 0.27 0.20 0.32 0.15	8.40 4.10 12.10 1.10 0.57	0.59 0.58 0.40 0.32 0.26	0.61 0.99 0.90 1.36 1.17	82.60 42.20 9.40 0.50 0.80	1.42 0.46 0.54 0.21 0.27						
	Core 3											
0-22-44-66-88-1010-1515-2025-40	$\begin{array}{c} 0.23 \\ 0.19 \\ 0.22 \\ 0.22 \\ 0.24 \\ 0.20 \\ 0.09 \\ 0.1 \end{array}$	4.30 1.88 2.18 2.14 2.15 4.93 0.11 0.32	$\begin{array}{c} 0.40 \\ 0.31 \\ 0.37 \\ 0.33 \\ 0.38 \\ 0.21 \\ 0.22 \\ 0.98 \end{array}$	$2.02 \\ 1.55 \\ 1.77 \\ 1.42 \\ 1.48 \\ 0.34 \\ 0.77 \\ 1.55 \\ $	$ 1.89 \\ 1.54 \\ 0.91 \\ 1.02 \\ 0.69 \\ 1.63 \\ 0.41 \\ 0.25 $	$\begin{array}{c} 0.50\\ 0.40\\ 0.40\\ 0.28\\ 0.24\\ 0.60\\ 0.16\\ 0.16\\ \end{array}$						

TABLE 5. Distribution of lability index in the core samples.

index of cadmium and, to some extent lead, can be correlated with that of manganese which showed the highest index and therefore, seems the most reactive metal.

Considering the lability index as a reliable measure for the metal mobility, manganese, lead and copper appear more reactive than zinc, cadmium and iron.

Conclusion

The concentrations of Fe, Mn, Zn and Cu demonstrate that the sediments of lake Edku are nonpolluted with respect to these metals. The measured concentrations rather reflect the lithological influence of the catchment area as well as the enhanced geochemical activity. Therefore, the mean concentrations of these metals can be regarded as the background values.

On the other hand, the concentrations of Pb and Cd indicate some enrichment with these two metals. Atmospheric precipitation is probably the main factor which is responsible for Pb enrichment, whereas, Cd seems to originate from the drainage of the soil of the catchment area.





M.A. El-Sayed

In the context of the relative importance of the different substrates, it is revealed that the inorganic carbon plays a major role in the elimination of some trace metals. The build up process of calcareous shells results probably in the incorporation of Pb, Cd and Mn in the shells. On the other hand, manganese hydrous oxides were found to be important sinks for lead and cadmium. Copper is shown to be particularly sequestrated by a discrete iron hydrous oxide phase in addition to adsorption onto clay mineral surfaces. Zinc was mainly associated with the organic matter.

The mobility of the studied metals as revealed from the postulated Lability Index generally decreases with increasing depth in core. Manganese, copper and lead appeared more mobile than zinc and cadmium; iron was the least reactive.

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References

- Berner, R.A. (1971) Principles of Chemical Sedimentology. McGraw-Hill, Inc., New York, 240 p.
- Carignan, R. and Nriagu, J.O. (1985) Trace metal deposition and mobility in the sediments of two lakes near Sudbury, Ontario. Geochem. Cosmochem. Acta 49: 1753-1764.
- Dowidar, N.M., Morcos, M.A., Saad, M.A. and El-Samra, M.E. (1976) Hydrographic observations on pollution in Abu Qir Bay, Alexandria, Egypt. Acta Adriatica 18: 381-396.
- Eckert, J.M. and Sholkovitz, E.R. (1976) The flocculation of iron, aluminium and humates from river water by electrolytes. *Geochem. Cosmochem. Acta* 40: 847-848.
- Forstner, U. (1977) Metal concentrations in recent lacustrine sediments. Arch. Hydrobiol. 80: 172-191.
- Forstner, U. and Wittmann, G.T.W. (1981) Metal Pollution in the Aquatic Environment. Springer-Verlag, Berlin, 486 p.
- Hakanson, L. and Jansson, M. (eds.) (1983) Principles of Lake Sedimentology. Springer-Verlag, Berlin, 416 p.
- Helios-Rybica, E. and Forstner, U. (1986) Effect of oxyhydrate coatings on the binding energy of metals by clay minerals. In: Sly, P.G. (Ed.), Sediments and Water Interactions. Springer-Verlag, New York, pp. 381-385.
- Jenne, E.A. (1977) Trace elements sorption by sediments and soils; sites and processes. In: Chappell, W.R. and Petersen, K.K. (Ed.), Molybdenum in the Environment. Marcel Dekker Inc., New York, pp. 425-553.
- Khamis, M., Geochemistry of Phosphorus in Lake Edku. M.Sc. Thesis, Alexandria University, (in prep.).
- Martin, J.M., Nirel, P. and Thomas, A.J. (1987) Sequential extraction techniques: Promises and problems. Mar. Chem. 22: 313-341.
- Moussa, A.A. and Saad, N.A., Mineral Composition of Lake Edku Sediments. (in prep.).
- Patterson, C.C. and Settle, D.M. (1987) Review of data on eolian fluxes of industrial and natural lead to the lands and seas in remote regions on a global scale. *Mar. Chem.* 22: 137-162.
- Pickering, W.F. (1980) Zinc interaction with soil and sediments. In: Nriagu, J.O. (Ed.), Zinc in the Environment, part 1, Willey Inter. Pub., New York, pp. 72-107.
- Premazzi, G., Provini, A., Gagginoi, G.F. and Parise, G. (1986) Geochemical trends in sediments from 13 Italian subalpine lakes. In: Sly, P.G. (Ed.), Sediments and Water Interactions. Springer-Verlag, New York, pp. 157-165.
- Rashid, M.A., Buckley, D.E. and Robertson, K.R. (1982) Interactions of marine humic acid with clay minerals and natural sediment. *Geoderma* 8: 11-27.

M.A. El-Sayed

- Schnitzer, M. and Kodama, H. (1977) Reactions of minerals with soil humic substances. In: Dixon, J.B. et al. (Eds.), Minerals in Soil Environments. Soil Sci. Soc. Am., Madison, Wisconsin, U.S.A., pp. 741-770.
- Sestini, G. (1988) Nile Delta: a review of depositional environments and geochemical history. In: Whateley, M.K.G. and Pickering, K.T. (Eds.), Deltas: Sites and Traps for Fossil Fuels. Geol. Soc. Spec. Pub. No. 00, 000-000: 3-31.
- Sigg, L., Stumm, W. and Zinder, B. (1984) Chemical processes at the particle-water interface, implications concerning the form of occurrence of solute and adsorbed species. *In:* Kramer, C.J.M. and Duinker, J.C. (Eds.), *Complexation of Trace Metals in Natural Waters*. pp. 251-266.
- Stumm, W. and Morgan, J.J. (1981) Aquatic Chemistry. John Willey & Sons, New York, 780 p.
- Tessier, A., Cambell, P.G.C. and Bisson, M. (1980) Trace metals speciation in the Yamasaka and St. Francois rivers (Quebec). Can. J. Earth Sci. 17: 90-105.
- ——— (1982) Particulate trace metal speciation in stream sediments and relationships with grain size: implication for geochemical exploration. J. Geochem. Explor. 16: 77-104.
- Walkley, A. and Black, T.A. (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid and titration method. *Soil Sci.* 37: 29-38.

خواص الـرواسب وصـور ترابـط وتحـركيـة الحـديد والمنجنـيز والـزنك والنحاس والرصاص والكادميـوم في أعمـدة رواسب بحـيرة إدكـو

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المستخلص . قدرت التركيزات الكلية وكذا المستخلصة بحامض مخفف لكل من الحديد والمنجنيز والزنك والنحاس والرصاص والكادميوم في أعمدة رواسب بحيرة إدكو وهي واحدة من بحيرات دلتا النيل ، كما عينت نسب الكربونات والمواد العضوية ومكونات الرواسب من الرمل والغرين والصلصال .

تشير النتائج إلى أن متوسط التركيزات الكلية لكل من الحديد والمنجنيز والزنك والنحاس والسرصاص والكادميوم هي على التوالي (٥٧٦٨٧ – ٩٤٩ – ٨١ – ٥٥ – ٤٢ – ٤ , ٣ ميكسروجبرام / جرام) وكانت نسبة تركيز الجزء المستخلص بالحامض المخفف إلى التركيز الكلي بنفس الترتيب السابق هي (١٨٪ – ٤٢٪ – ٣٠٪ – ٢٥٪ – ٢١٪ و ٣٠٪) .

دلت العلاقات الإحصائية على وجود مجموعتين من العناصر وذلك حسب صور توافقها مع الأرضيات المرابطة : الحديد والزنك والنحاس متوافق بشكل أفضل مع الصلصال وبشكل أقل مع الغرين ، بينما تشكل الهياكل الجيرية الموقع المفضل للمجموعة الثانية المكونة من المنجنيز والرصاص والكادميوم ، وبتطبيق المعاملات الإحصائية على الجزء من العناصي المستخلص بالحامض المخفف تأكد هذا الاتجاه وبصورة أكثر وضوحًا .

استخلصت التحركية الجيوكيميائية للعنـاصر باستخدام مقياس شرطي سمي دليل المتاحية ، وقد ثبت أن تحركية العناصر تقل بصفة عامة بزيادة العمق في عامود الرواسب كما كانت حركية المنجنيز والرصاص والنحاس أكثر من حركية الزنك والكادميوم والحديد .