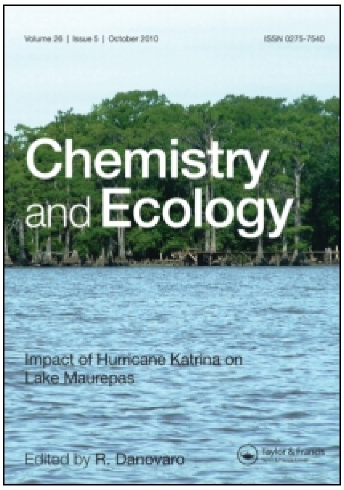

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Phosphorus in Sediments of Lake Edku, Egypt. The Influence of Chemical and Grain Size Parameters

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PHOSPHORUS IN SEDIMENTS OF LAKE EDKU, EGYPT. THE INFLUENCE OF CHEMICAL AND GRAIN SIZE PARAMETERS

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Lake Edku is one of the Nile Delta shallow brackish water coastal lagoons with communications with the southeastern Mediterranean.

Sediment samples were recovered from the top 10 cm of the lake bottom to study principally their total, inorganic and organic phosphorus. Related sediment parameters such as particle size, organic carbon, carbonate and iron contents were also studied in detail.

It is shown that the lake sediments are generally a sand-silt-clay mud enriched with carbonate (11.4–42%), organic carbon (0.9–11.4%) and iron (1.6–5.6%).

The total phosphorus content in these sediments is 503–1329 μg/g, inorganic phosphorus, 468–954 μg/g and organic phosphorus, 35–526 μg/g.

KEY WORDS: sediments – organic and inorganic phosphorus – Lake Edku – Nile Delta – Coastal lagoons

INTRODUCTION

The level of total phosphorus in waters of the Nile Delta coastal lagoons has often been studied by biologists and chemists. Also, the concentration and geographical distribution of total phosphorus in sediments has been frequently studied (e.g. El-Wakeel and Wahby, 1970 a,b). Yet the discrimination between the two principal forms of phosphorus i.e. organic and inorganic, and their substrates is poorly known.

The sediments of the Nile Delta coastal lagoons are derived principally from alluvial soils. Therefore, their chemistry is expected to reflect the fundamental pedological characteristics of the watershed, even though modifications related to sediment-water interaction may take place.

Lake Edku may serve as an example of these lagoons. It is an extremely shallow brackish-water basin having a depth range of 40–150 cm and a total area of 115 km^2. The lake lies 60 cm above sea level, exchanging water with the Mediterranean Sea through a narrow channel. However, this exchange is limited (Dowidar *et al.*, 1976). The principal water source is runoff from the surrounding cultivated area. This amounts to 1000 × 10^6 m^3 per year, discharged to the eastern end of the lake.

A large part of the lake is covered by a dense carpet of attached and free-floating plants. These plants flourish particularly in the southern and eastern areas, creating marsh-like conditions.

The broad objective of the present work is to evaluate the role of sedimentary factors which may control the concentration and distribution of the inorganic and organic phosphorus forms in the surface sediments of Lake Edku.

MATERIALS AND METHODS

Twenty-eight sediment samples were recovered using a small grab sampler from the top 10 cm of bottom sediments in such a way as to include the different lake basins. Taking advantage of the scattered islets, the whole lake basin was subdivided into 7 zones from A to G from which 4 samples were collected from each (Figure 1).

Representative portions of the air-dried sediments were obtained by repeated quartering of the whole sample. These portions were subsequently oven-dried at 110 °C and used for chemical analysis. Phosphorus extractions were done following the method used by Aspila *et al.* (1976). Total phosphorus was extracted by ashing the sample at 550 °C for 2.5 h and subsequent shaking with 1N HCl for 16 h. Inorganic phosphorus was extracted by shaking the oven-dried sediment with 1 N HCl for 16 h. Phosphorus determinations in the two extracts were made according to the method of Murphy and Riley (1962). The difference between these two determinations is taken to represent organic phosphorus. The recovery data and precision of the method are discussed in detail by Aspila *et al.* (1976); the percent relative standard deviation for total phosphorus was 1.2. The total iron concentrations were measured in HF-HCl-HNO_3 digested samples by flame atomic absorption spectrophotometry (Varian 1250). The organic carbon contents were determined by the dichromate wet oxidation method of Walkley and Black (1934). The carbonate contents were determined by treating the sediment with dilute HCl followed by back

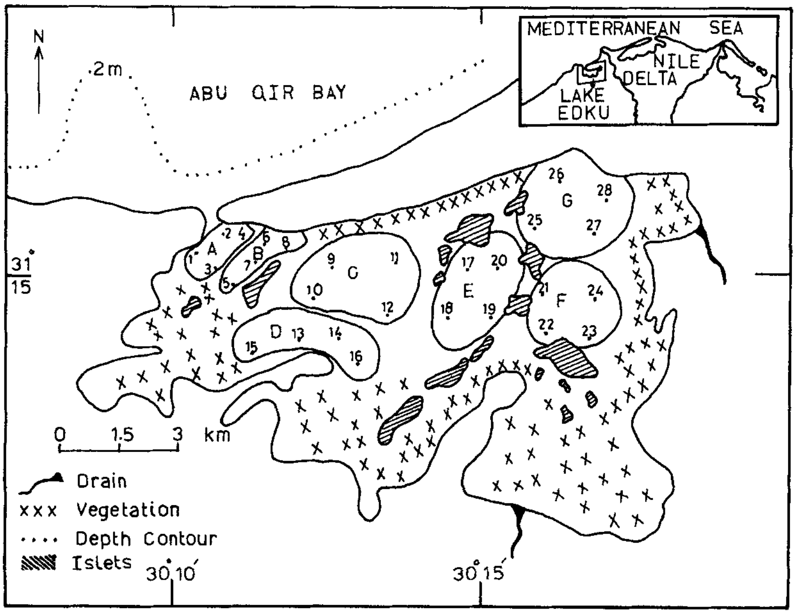

Figure 1 Area of study and sediment sampling sites.

Table I Chemical and grain size composition of sediments.

Zone	Sample	$CaCO_3$ %	TOC %	Fe %	TP $\mu g\ g^{-1}$	IP $\mu g\ g^{-1}$	OP $\mu g\ g^{-1}$	Sand %	Silt %	Clay %	Mean size ϕ
A	1	11.5	1.1	3.4	666	595	70	74	20	6	4
	2	14.1	0.9	4.2	814	743	72	86	10	4	3
	3	12.0	6.6	5.1	952	729	223	50	32	18	5
	4	15.3	3.4	4.4	801	680	122	68	19	13	4
	X	13.2	3.0	4.3	808	687	121	70	20	10	4
	SD	1.5	2.3	0.6	101.3	57.5	62.1	13	7.8	5.6	0.7
B	5	15.3	4.8	4.7	806	685	122	45	25	30	6
	6	18.2	5.2	4.0	931	712	220	49	29	22	4
	7	11.4	5.2	4.6	993	770	224	50	36	14	5
	8	16.0	6.3	4.2	908	726	181	54	32	14	4
	X	15.2	5.4	4.4	910	723	186	50	30	20	5
	SD	2.5	0.6	0.3	67.4	30.8	41	32	4	6.6	0.6
C	9	42.1	1.2	1.6	503	468	35	85	8	7	2
	10	20.1	4.4	4.5	707	627	81	37	34	29	6
	11	24.6	0.9	3.7	697	603	94	66	21	13	4
	12	25.1	1.7	3.3	760	621	140	60	28	12	4
	X	28	2.1	3.3	667	579	87	62	23	15	4
	SD	8.4	1.4	1.0	97.7	65.2	37.1	17.1	9.7	8.3	1.3
D	13	22.9	2.3	5.6	776	666	110	23	44	33	6
	14	29.5	2.2	3.7	760	628	132	31	44	25	6
	15	21.7	2.3	4.6	829	767	62	15	45	40	7
	16	17.2	2.1	5.2	830	692	138	15	46	39	7
	X	22.8	2.2	4.8	799	688	110	21	45	34	7
	SD	4.4	0.1	0.7	31.1	50.7	29.9	6.6	0.8	6.0	0.5
E	17	42.0	7.0	2.8	1018	786	232	30	48	22	6
	18	40.8	8.3	1.9	1051	704	347	19	65	16	6
	19	17.0	10.0	2.7	1260	734	526	10	60	30	6
	20	24.4	11.4	2.8	1173	713	461	8	74	18	6
	X	31.1	9.2	2.6	1125	734	39	17	61	22	6
	SD	10.7	1.7	0.4	96.8	32.1	112.3	8.6	9.3	5	0.4
F	21	21	11.4	–	1202	704	398	14	58	28	7
	22	19.4	10.6	1.8	1329	819	509	8	60	32	6
	23	24.5	10.6	2.8	1114	681	433	11	71	18	6
	24	26	8.4	2.3	948	665	283	18	47	35	6
	X	22.7	10.3	2.3	1148	717	406	13	59	28	6
	SD	2.6	1.1	0.4	138.3	60.7	81.4	3.82	8.54	6.4	0.31
G	25	17.1	8.9	3.3	1116	688	428	12	58	30	7
	26	23.4	7.9	3.6	1116	816	300	21	38	41	6
	27	n.d.	3.9	5.7	1230	954	273	20	38	42	6
	28	22.0	5.0	4.1	1001	804	197	10	40	50	8
	X	20.8	6.4	4.2	1116	816	300	16	44	40	7
	SD	2.7	2.1	0.7	81	94.4	83.2	7.8	8.4	10	0.8
Lake mean		22.0	5.5	3.7	940	706	229	36	41	23	6
SD of mean		8.2	3.4	1.1	200.7	86.9	141.2	24.7	17.1	12.6	1.3

TOC = Total Organic Carbon
TP = Total Phosphorus
X = Mean
IP = Inorganic Phosphorus
OP = Organic Phosphorus

titration of the excess acid. In addition, grain-size analysis was carried out according to the standard sedimentological method as described in Folk (1974).

Finally, a correlation matrix was constructed for all the data obtained.

RESULTS AND DISCUSSION

Particle Size Distribution

The data (Table I) reveal that the sediment particle size generally decreases eastwards. The sediment average grain size in zone A is 4 ± 0.7 ϕ and in B is 5 ± 0.6 ϕ. This reflects the effect of the relatively higher silt and clay contents in the second zone. The sand in these two zones is represented mostly by fine and very fine sand fractions comprising, principally, quartz enriched with heavy minerals. Presumably, these sands are derived mainly from the nearby coastal marine belt. Contributions from the neighbouring islets and lake shore, mostly in the form of coarse plant remnants, was noticed particularly in sediments of zone B.

Zone C comprises a transitional area of shelly mud in the central part of the lake. A significant portion of the sand fraction in this zone is composed of mollusc shells, reflected by a larger local mean grain size (Table I). Apparently, because of its relatively greater depth, the central area may act as a trap for the transported materials. The shells and their fragments are easily resuspended by agitation of the bottom in surrounding zones and are then moved by traction until they are finally deposited in the relatively deeper water of this zone.

The sediments in zone D show greater fineness. Their average mean size is 6.5 ± 0.5 ϕ. A notable enrichment by silt and clay at the expense of sand is noticed in this zone. It is also shown that the proportionate amounts of silt maintain almost the same concentration (44–46%) at all sampled locations.

The finest sediments are found in the eastern part of the lake which includes the E, F and G zones. This area is the immediate recipient of the catchment runoff. The sediments in E and F zones have similar grain size distribution with the silt fraction forming about 60%. However, in zone G the sand/silt/clay ratio becomes 16:44:40. Generally, the average mean grain size values in these three zones are very close, being 6.2, 6.7 and 6.8 ϕ respectively.

In spite of the well defined sediment source, the sediments of Lake Edku are characterized by their heterogeneity. In addition, significant variations in sediment composition from one location to another are common, even within the same zone.

Organic Matter

Apparently, much of the organic matter in Lake Edku is associated with silt. The primary production in the lake was given by Samaan (1974) as 0.6 g C/m^2-day for phytoplankton and 1.32 g C/m^2-day for macrophytes. In addition, a terrestrial contribution in the form of organic detritus enters the lake with drainage water.

In general, the data in Table I show that the lake sediment is much enriched with organic carbon, reflecting the high rate of organic matter accumulation. In addition to contribution from local plants and animals, the chance for suspended organic detritus to reach the bottom is great because of the extreme shallowness of this basin. This high rate of accumulation must have been balanced by extensive recycling, otherwise the bottom conditions would turn to complete anoxia. Studies by Khalil

Table II Correlation matrix.

	mean	sand	silt	clay	TOC	$CaCO_3$	IP	OP	Fe
mean	1.00								
sand	−0.91	1.00							
silt	0.70	−0.87	1.00						
clay	0.72	−0.65	0.19	1.00					
TOC	0.50	−0.63	0.77	0.07	1.00				
$CaCO_3$	−0.48	0.21	0.02	−0.44	−0.03	1.00			
IP	0.66	−0.55	0.33	0.59	0.34	−0.53	1.00		
OP	0.52	−0.66	0.80	−0.08	0.91	−0.14	0.40	1.00	
Fe	0.08	0.11	−0.36	0.33	−0.57	−0.54	0.28	−0.50	1.00

Critical value (1-Tail, 0.05) = + or −0.34
Critical value (2-Tail, 0.05) = + or −0.40

(in prep.) show that the surface as well as the bottom water of the lake is well oxygenated. However, she noticed that the bottom water in the eastern part(J) of the lake (enriched with organic matter) becomes oxygen-poor during the summer season. According to Mueller and Suess (1979), the ratio between the recycled and accumulated organic matter in sediments is controlled by the bulk sedimentation rate. In areas of high sedimentation rates, the ratio between carbon accumulation and combustion rates is 1:1.1 (Balzer *et al.*, 1986).

The organic carbon content is highly variable in the different parts of the lake. In general, the coarser sediments of the western part of the lake have low to moderate organic carbon contents, whereas the finer sediments of the eastern parts are significantly enriched with organic carbon. Organic carbon constitutes about 1% at the lake-sea communication outlet (zone A), increasing sharply to 6.6% within a short distance (zone B). The contribution of plant detritus from the nearby vegetated islets, coupled with a lesser intensity of the winnowing action, must be responsible. In the central area of the lake (zone C), the organic carbon concentration is probably lowest, apparently because of the abundance of carbonate and the lack of vegetation. In zone D the organic carbon distribution is distinctive. It maintains almost the same concentration of about 2.2% basinwide. In the zones in the eastern part of the lake the organic carbon concentration is at much higher values. The mean content in the sediments of E and F zones is about 10%, and in zone G it is 6.4%. The relationship between organic carbon and particle size is confirmed by the positive correlation of organic carbon content and ϕ mean grain size as well as by the negative correlation of organic carbon and sand (Table II). It should be noted, however, that the correlation is particularly strong for silt ($r = 0.77$) but not for clay. This might suggest that some of the silt fraction could be clay firmly cemented by organic matter or that the organic detritus predominates in the silt size range.

Carbonate

Sediment examination revealed the ubiquity of whole, and fragments of, pelecypod and gastropod shells in the coarse sand fraction together with foraminiferal tests and ostracod shells in the medium sand fractions. It is thus evident that the shells of these organisms are the principal contributors of carbonate in sediments. In spite of this, the correlation of sand to carbonate content is shown to be insignificant (Table II). Apparently, this occurs because much of the medium and fine sand

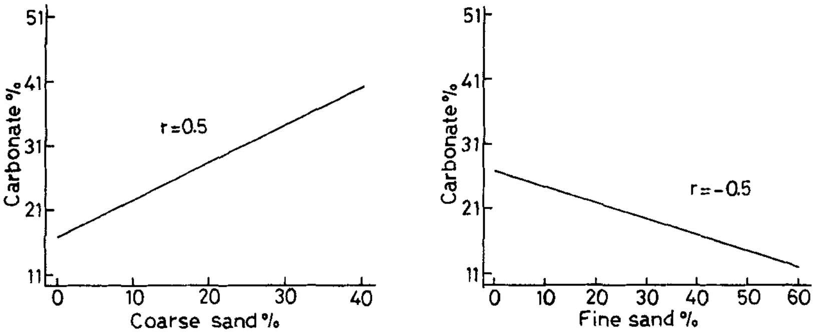

Figure 2 Correlation of carbonate content to both coarse and fine sand fractions.

fractions is composed of quartz. This was tested by carrying out a simple correlation of carbonate content to both the coarse and fine sand fractions separately (Figure 2). Shell materials may be found everywhere in the lake irrespective of sand content.

In general, the carbonate content of sediments varies between 11.4 and 42%, with an average content of 22% (Table I). The lowest values of carbonate (11.5–18.2%) were found in the vicinity of the lake-sea communication i.e. in A and B zones where quartz sand predominates. Within a short distance (zone C), the carbonate concentration is almost doubled (20–42%) and lies within this range in the remainder of the lake. It is interesting to note that the carbonate content in the eastern part of the lake markedly exceeded the total sand content. The substrate in this part of the lake is characterized by the abundance of the very fragile shells of *Biompholaria alexandrina*. It is thus reasonable to suggest that considerable amounts of these shells must have disintegrated to fine particles through agitation of substrate and/or by erosion. Furthermore, fine carbonate particles could also be produced by plants of this highly vegetative area.

It is thus evident that the distribution of carbonate in the lake sediments can be explained by various factors:

1. the types and growth rates of different organisms found in the various lake subenvironments
2. the distribution of carbonate producing plants in the lake
3. the movement of loose shells and their fragments over the bottom.

The effect of carbonate input from fresh and marine water inflows is rather indirect. Inflowing Ca^{2+} and HCO_3^- and CO_2^{2-} ions are readily utilized in calcareous shell formation and endogenic formation of calcite by algae and macrophytes. There is no reason to believe that direct chemical precipitation of calcite may take place. Neither the salinity of the lake water nor the concentration of carbonate ions are suitable for this.

Although aeolian transport of carbonates has been previously recognized (Emelyanov *et al.* 1979) by the presence of dolomite crystals in the Nile sediments, its influence on the total carbonate content can be neglected.

Iron

The iron concentration in sediments varies between 1.6 and 5.7 % with a mean value of 3.7 %. Iron content is poorly correlated to the different particle size fractions

(Table II). Generally, this might result from the partition of iron among several sedimentary phases. However, the poor correlation with sand is due essentially to the large quartz fraction and the limited amounts of mineral sand fractions. The weak correlation with clays suggests possibly the presence of iron as a discrete hydrous oxide phase independent of the amount of clay. While the negative correlation with silt is apparently an indirect result of the high organic content of the silt fraction and the negative correlation of iron with organic carbon.

Table (1) shows that the sediments in two of the studied lake zones (E and F) have notably lower iron contents (1.8–2.8 %) compared with the other zones (3.3–5.7 %). The sediments in these two zones are characterized by their high (up to 11 %) organic carbon content. This high organic content may play a dual role in lowering iron concentration. In the first place, as a principal component of sediment, it dilutes iron. Secondly, the high organic content promotes reducing conditions in sediments, favouring iron reduction. Iron oxides can be reduced in the process of organic matter decomposition, mediated by bacterial action (Stumm and Morgan, 1981; Jansson, 1986). The resulting Fe^{2+} is more soluble and at the same time accelerates the dissolution of the oxide (Schwertman and Taylor, 1977). Enhanced solubility of iron can also be attributed to the presence of organic chelators (Cole, 1979). The study of sediment interstitial water in Lake Edku (Khalil, in prep.) shows that iron concentrations increase when the oxygen and pH of bottom water decrease i.e. if anoxic conditions develop at the sediment-water interface. This has also been shown by Burns and Nriagu (1976) for Lake Erie.

Phosphorus

The concentration of total phosphorus in sediments varies between 503 and 1329 μg/g with an overall lake mean value of 940 μg/g. This value falls in the range of 650–1780 μg/g for the soil parent material in the catchment area (Balba, 1985). In spite of the fact that the recycling of phosphorus in the two environments is substantial and conservative, these concentration are still informative in some way of the sediment source. However, a significant part of the soil phosphorus is attributed to the use of phosphoric fertilizers. The greatest part of added fertilizer is recovered in solution upon soil flooding (Sah and Mikkelsen, 1986) and eventually finds its way to the lake through drainage water. In general, the phosphorus supply in drainage water from the agricultural area is about 10 times greater than from the background (Håkanson and Jansson, 1983). This is responsible evidently for the excessive growth of algae and other plants in the southern and eastern peripheries of the lake (Shukla *et al.*, 1971).

As expected, the major part of the sediment phosphorus in Lake Edku is inorganic. Its concentration ranges from 468 to 954 μg/g, with a mean value of 706 μg/g. This is 75% of the total phosphorus compared with 92% of total in the Nile Delta soil parent material (Balba, 1985). In contrast, organic phosphorus ranges between 35 and 526 μg/g, mean 292 μg/g, that is 7–42% of the total phosphorus. It may thus provide a locally important reservoir of phosphorus.

The inorganic phosphorus is mainly associated with clays. A small part seems to be organically bound (Table II). According to Mattson *et al.*, (1950) organic matter — Fe,Al oxide-hydroxide gels are the main materials adsorbing inorganic phosphorus. Also, Peterson (1986) found that iron and aluminium-bound phosphorus is usually found associated with humus in clays. This organically-bound phosphorus can participate readily in microbial transformations in water and sediments (Sommers *et al.*, 1972).

The organic phosphorus content, on the other hand, is strictly proportional to organic carbon (r = 0.91). A direct relationship between organic phosphorus and silt content was noticed (r = 0.8), evidently an indirect effect resulting from the intimate association of organic carbon and silt (r = 0.77). This view is supported by an insignificant correlation between organic phosphorus and the clay content, and the fact that the clay fraction is poor in organic carbon. Williams *et al.* (1976) mentioned that although the organic phosphorus in Lake Erie is correlated significantly with clays, it is the organic carbon of the clay fraction and not the clay itself which was the main determinant of organic phosphorus.

It is not an easy task to decide whether the areal distribution of phosphorus concentration is determined by the geographical location of sampling sites or the local sediment characteristics. In fact these three are inseparable. Yet the data show generally that the main controlling factors of phosphorus concentration are grain size, carbonate and organic carbon contents. Although many studies emphasize the close association of inorganic phosphorus and iron in lake sediments, in this study such an interrelationship is not so clear. However, this can be attributed to the predominance of inert iron forms (residual iron) in the sediments (Moussa and El-Said, 1990). The two elements might possibly show an enhanced correlation if data on labile iron and/or phosphorus were available. However, factors such as pH, E_H and the concentrations of competing ligands may affect the ability of sediments and iron to adsorb inorganic phosphorus (Young and Comstock, 1986). The organic phosphorus on the other hand showed an inverse relationship (r = –0.5), with iron conforming with the organic carbon–iron correlation (r = –0.57). However, Khalil (in prep.) found a significant direct relationship between iron and organic phosphorus in interstitial waters of Lake Edku sediments. This suggests the association of both in more labile forms.

In general, the pattern of phosphorus distribution in the study area distinguishes 4 areas of the lake:

a) the lake–sea communication vicinity
b) the central basin
c) the southwestern basin
d) the whole eastern part of the lake.

The lowest phosphorus concentrations are found in the central basin (Table I). Obviously, this can be attributed to the notably higher amounts of sand and carbonate coupled with the lower levels of organic carbon.

Moderate concentrations are found in the vicinity of the lake-sea communication area as well as in the southwestern basin, even though conditions in these two areas are basically different. The two areas show a marked difference in water characteristics. In addition, the sediments in the former area contain mainly coarse grained materials (70% sand and 30% fines) overwhelmed by quartz, while in the latter the sediments are principally in the fine fraction (20% sand and 80% fines). Evidently, the predominance of quartz sand in the former area has resulted in lower phosphorus concentrations. In the second area however, the substrate is muddy and is densely covered by rooted plants. It is assumed (McRoy and Barsdate, 1970; McRoy *et al.*, 1972) that these plants are very effective in taking up sediment phosphorus. Moreover, the relatively lower organic matter from this area may deprive the sediments of phosphorus (Balzer *et al.*, 1986).

The highest phosphorus concentrations are found in the eastern part of the lake (Table I). Here it is clearly shown that organic phosphorus is almost as important as inorganic phosphorus. Its concentration is 3–4 times greater in the eastern part of the lake than in the other areas. This is clear, recalling that this part(J) of the lake is characterized by high organic production. The decomposition and excreta of indigenous organisms should contribute a significant portion of organic phosphorus. Also, the increase in organic phosphorus can, to a lesser extent, be related to the contribution from the neighbouring agricultural lands. Glase and Barlow (1986) mentioned that phytin, which contributes about 50% of the organic phosphorus in soil, is commonly leached by water and becomes an important constituent of the influent drainage waters.

In general, mass balance calculations (Khalil, in prep.) show that about 1/3 of the inflowing phosphorus is retained in the lake.

CONCLUSIONS

The sediments in Lake Edku are principally of sand-silt clay mud admixed with considerable amounts of mollusc shells and lower amounts of plant detritus, resulting in high carbonate and organic matter contents. The concentration of these two components coupled with grain size variation plays a marked role in controlling local phosphorus concentration, although a significant role is played by organic matter. Notably lower iron concentrations are shown in the sediments of the eastern part of the lake which is highly enriched with organic matter. This is attributed to dilution of iron by organic matter and/or iron mobilization under reducing conditions. The latter impedes iron precipitation and hence the coprecipitation of phosphorus. On the other hand, however, the high organic content results in a higher phosphorus concentration by contributing organic phosphorus up to 42% of the total.

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