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DISTRIBUTION OF ORGANIC CARBON, NITROGEN AND PHOSPHORUS IN THE RECENT SEDIMENTS OF THE MEDITERRANEAN CONTINENTAL SHELF OF EGYPT

RASPODJELA ORGANSKOG UGLJIKA, DUŠIKA I FOSFORA U RECENTNIM SEDIMENTIMA KONTINENTALNOG PLATOA EGIPATSKE OBALE SREDOZEMNOG MORA

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The distribution of organic carbon, nitrogen and phosphorus was studied in sediment samples from the continental shelf of Egypt between El Agamy and El Arish. On the average, the sediments contained 7.61 mg/g carbon, 1.36 mg/g nitrogen and 0.0905 mg/g phosphorus dry weight. The distribution and the close correlation between the three elements studied indicate their close association. The spatial distribution of the elements, the tendency of decreasing concentrations as we moved farther away from the Nile mouths and the lake's openings and the relative richness of the sediments in the cones in front of two major estuaries of the river, suggest that the River Nile and the drainage water from the Delta are the main source of these elements in the investigated area.

INTRODUCTION

Since historical time the Nile River has been transported high amounts of nutrient rich sediments to the Southeastern Mediterranean Sea. Before the construction of High Aswan Dam, the annual discharge was loaded with about 120 million tons of sediments (Aleem, 1972; Halim, 1960), mentioned that the total annual input of nutrients in the different forms carried to the Mediterranean by flood amounts to 286×10^3 and 5.7×10^3 tons of available silicate and phosphate respectively. These values are, however, underestimated as no less considerable amount remains adsorbed on suspended material which sooner or latter is settled to the bottom. These sediments are derived mainly from the volcanic Abyssinian plateau of East and Central Africa (Kholief *et al.*, 1969). The relative abundance of sand, silt and clay in the terrigenous deposits of the Nile sediments are in the ratio of 20.45 and 35% respectively (Quelennec and Kruk, 1976).

Considerable marine geological investigations have been carried out in the Southeastern Mediterranean Sea off the Egyptian coast. Studies on the organic coupounds of surface sediments of the study area are very scare. The present study was deemed necessary to fill the important gaps. It aims at studying the levels of organic carbon, nitrogen and phosphorus in the recent sediments along the Mediterranean continental shelf of Egypt between El Arish, and to evaluate the importance of these elements as a store providing nutrients to the overlying water for increase of the biological productivity of the Southeastern Mediterranean. The present study was carried out in the framework of the project entitled »Biological productivity of the Southeastern Mediterranean in the post High Dam period« co-sponsored by the U. S. Agency for International Development (AID) and the Department of Oceanography, Alexandria University.

MATERIAL AND METHODS

The investigated area covers the contiental shelf and a part of the continental slope of the Southeastern Mediterranean Sea of the Egyptian coast. It extends from El Agami in the west to El Arish to the east and lies between longitudes 29°45' and 35°45' E with a depth ranging between 8 250 m (Fig. 1).

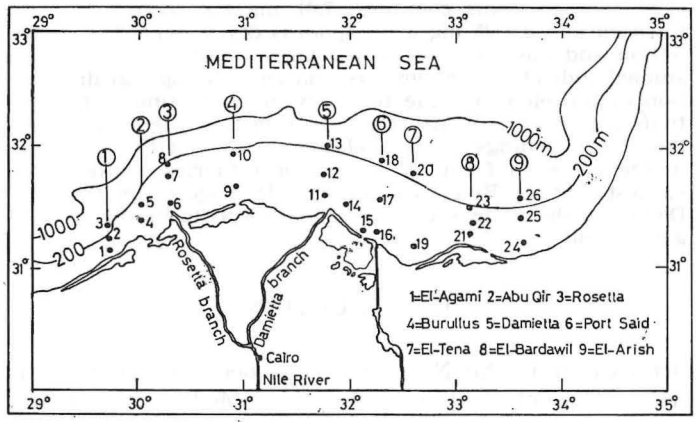

Figure 1. Area of study and sampling locations.

Twentysix sediment samples were collected using a Pettersen grab sampler with a movable upper lid that covers surface area of 65 cm by 35 cm. The samples were arranged in 9 sections more or less perpendicular to the coast namely, from west to east, El Agami, Abu Qir, Rosetta, Burullos, Damietta, Port-Said, El Tena, El Bardawil and El Arish. Two additional stations were sampled off El Diba and El Gamil. Each of the 9 main sections comprises 3 stations representing the inner shelf, to the depth of about 50 m, middle shelf as far as 75 m, and the outer shelf as far as the continental slope. These

subdivisions reflect mojor topographic differences and area also convenient from the point of view of the effect of wave energy upon the bottom, and of the study of sediment distribution.

On board and immediately after collection, the pH of the samples were measured using a portable pH meter (Digi-Sense LED). Two open-ended plastic tubes of 10 cm length and 5 cm diameter were pressed vertically full into the middle of grab sample, thus representing the upper 10 cm layer of almost undisturbed bottom sediment of each sample. The samples were preserved in alufoil and stored freezed at —20°C to avoid lump formation and bacterial decomposition of organic matter. Before processing, samples were left at room temperature for several hours and throughly mixed, then washed with disstiled water to remove salts. The washed samples were dried in a ventilated oven at 105°C, then pulvarized to pass a 0.45 mm nylon sieve.

The organic carbon was determined by the chronic acid oxidation method described by El Wakeel and Riley (1957). The estimation of the organic matter content is usually derived indirectly from the organic carbon content multiplied by a conversion factor. Trask (1939), suggested a factor of 1.8 for marine sediments which was adapted in the present study. The organic nitrogen was determined by the combination of microkjeldahl technique for the digestion and distillation of sediments according to Niederl and Niederl (1942). For the determination of total and inorganic phosphorus, the method described by Aspila *et al.* (1976) was used. The organic phosphorus was obtained by substraction.

RESULTS AND DISCUSSION

Results of chemical analysis are given in Table 1. The distribution patterns of studied elements are shown in Figs. 2, 3, 4. From these figures it is evident that organic carbon, nitrogen, and phosphorus have very similar patterns of areal distribution. Each element has its highest concentration near the Nile mouths and lake opening, the concentration decreases towards the open sea.

Organic carbon

The organic carbon content in the inner shelf sediments varies from 0.93 to 12.85 mg/g with an average of 8.67 mg/g. In the middle shelf, it ranges between 0.87 and 15.51 mg/g with an average of 7.01 mg/g, while in the outer shelf sediments the organic carbon varies from 1.12 to 10.31 mg/g with an average value of 6.45 mg/g. The overall average in the studied samples was 7.61 mg/g.

The most conspicuous feature in the distribution pattern of organic carbon (Fig. 2) is the presence of high carbon content in the area between Damietta and El Bardawil; the highest concentration occurred in Port-Said middle shelf. Such distribution may be attributed to the deposition of fine-grained sediments together with organic debris carried by the Nile River. Beside the general eastward circulation, there exist local gyres and vortices in the area off Port-Said. Such a condition results in a heavy precipitation of most sediment load carried by these currents, thus leading to the enrichment of the sediment

Table 1. Organic carbon, nitrogen, phosphorus (mg/g) and ph in the upper 10 cm sediments at each station in the study area, as well as the concentractions of chlorophyll *a* in the water column (mg/m^3).

Section	Sample No.	Depth m	pH	Organic Carbon	Organic Matter	Organic Nitrogen	Total Phosphorus	Inorganic Phosphorus	Organic Phosphorus	Chlorophyll *a*
	1	30	8.25	0.93	1.68	0.119	0.081	0.0729	0.0081	0.385
El Agami	2	115	8.05	0.98	1.76	1.171	0.1334	0.1229	0.0105	0.364
	3	250	8.08	1.12	2.01	0.155	0.2445	0.2345	0.01	0.1896
Abu Qir	4	23	7.8	9.87	17.76	1.727	0.3745	0.2713	0.1032	1.693
	5	86	7.2	0.87	1.56	0.085	0.3617	0.3554	0.0063	0.253
Rosetta	6	14	7.87	7.93	14.28	1.9	0.733	0.604	0.1354	0.799
	7	80	7.89	6.1	10.98	1.859	0.7363	0.582	0.1543	0.43
	8	168	7.8	7.0	12.6	1.527	0.8387	0.7413	0.079	0.262
Burullus	9	25	7.77	6.86	12.35	1.394	0.6767	0.5763	0.1004	0.751
	10	125	7.38	7.07	12.72	1.32	0.5567	0.4637	0.0932	0.353
Damietta	11	19	7.62	10.75	19.35	2.118	0.7647	0.6287	0.136	0.926
	12	64	8.08	9.04	16.26	0.934	0.763	0.6863	0.077	0.299
	13	210	7.77	7.46	13.44	1.541	0.5887	0.4807	0.1081	0.302
El Diba	14	17	7.97	11.01	19.82	3.357	0.9717	0.7747	0.197	0.992
El Gamil	15	9	7.79	11.51	20.72	2.662	0.9179	0.7423	0.1756	1.359
Port Said	16	15	7.28	12.85	23.12	1.685	0.7603	0.647	0.1133	0.581
	17	33	7.7	15.51	27.92	2.53	0.849	0.6345	0.2145	0.378
	18	240	7.42	10.31	18.55	1.759	0.635	0.5355	0.0995	0.261
El Tena	19	8	7.14	11.28	20.3	0.997	0.446	0.4065	0.0395	0.794
	20	235	7.28	7.52	13.44	1.926	0.417	0.312	0.105	0.292
Bardawil	21	14	7.32	6.91	12.44	1.002	0.5737	0.4999	0.0738	0.473
	22	46	7.42	9.17	16.4	0.854	0.4377	0.3787	0.059	0.331
	23	179	7.14	7.33	13.3	1.003	0.4103	0.3171	0.0932	0.221
El Arish	24	16	7.18	4.84	8.71	0.864	0.3451	0.2811	0.064	0.722
	25	58	7.21	7.37	13.4	1.01	0.2354	0.1827	0.0527	0.174
	26	246	7.29	3.75	6.74	0.846	0.138	0.0945	0.0435	0.099

* After Moustafa (1985).

with organic matter components. The isopleths described a northeasterly direction from the inner shelf of Rosetta and Burullos, indicating that the concentration of organic carbon in the sediments of the outer shelf area between Rosetta and El Bardawil are almost homogenous. The relatively high content in the inner shelf of Abu Qir (9.87 mg/g) may be attributed to the westward flow of the Nile water from Rosetta branch (prior to 1965) with its sediment load. The effect of this westward flow has been traced westward to west of Alexandria (Dowidar, 1965); El Wakeel *et al.*, 1974). It is also important to note that the level of organic carbon content in El Arish area is comparatively higher than that of El Agami and represents an eastward extension of the Port-Said area rich in organic carbon. The low organic carbon content in the Agami section is mostly due to type of sediments which is mainly carbonate sand. Such sediments tend to be well ventilated where the light organic matter is mostly washed away and the supply of oxygen is sufficient to result in rapid decay of organic matter. In addition, this area is poor in phytoplankton (Moustafa, 1985).

The high organic carbon of the bottom sediments of the Nile Delta relative to the other areas off the Egyptian coast may be correlated, besides other

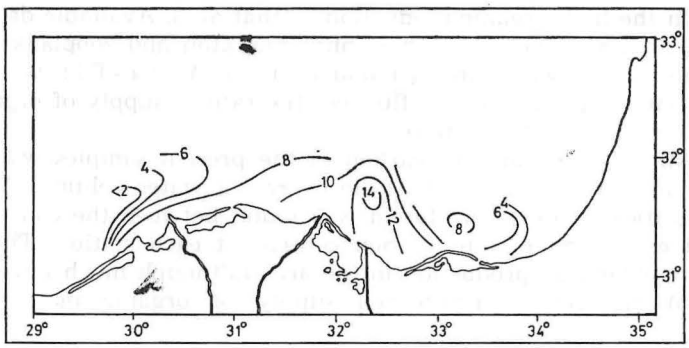

Figure 2. Areal distribution of organic carbon in the surficial sediments of the study area.

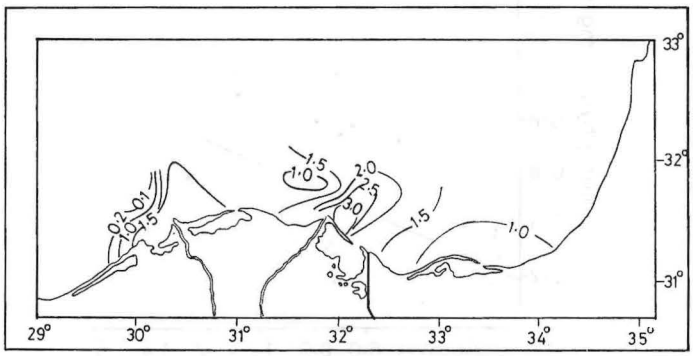

Fig.3.

Figure 3. Areal distribution of organic nitrogen in the surficial sediments of the study area.

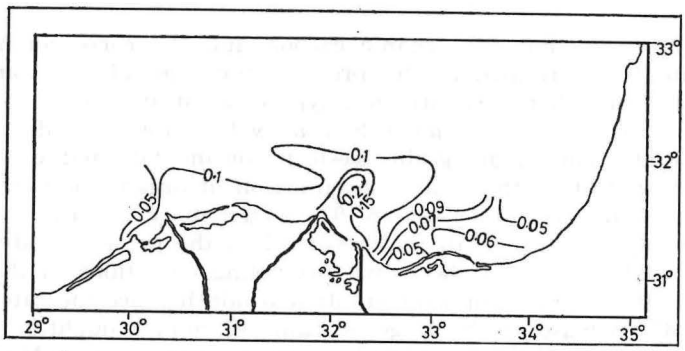

Figure 4. Areal distribution of organic phosphorus in the surficial sediments of the study area.

factors, with the high organic production in that area. Available data (D o w i-d a r, 1984) indicate that the highest phytoplankton and zooplankton biomass occur in the area between Abu Qir and El Tena. V i t a - F i n z i *et al.*, 1980, suggested that the productivity influences the rate of supply of organic matter and therefore its contents in the sediments.

The distribution of organic carbon in the present samples was correlated with the plankton concentration in the overlying water column. As shown in Fig. 5 a significant direct correlation was found between the concentration of chlorophyll *a* and the organic carbon content at each station. This indicates that the phytoplankton production in the area (although much lower than that before 1965) still acts as a potential supply of organic matter in surface sediments.

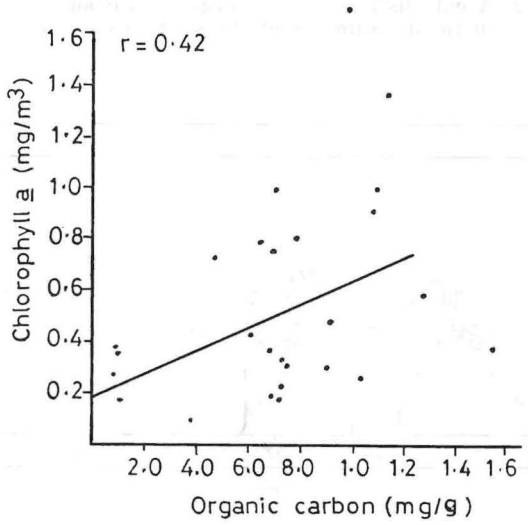

Figure 5. Relation between organic carbon in the sediments and the chlorophyll *a* in the overlying water column in the study area.

Table 2 shows that the organic carbon and the corresponding organic matter contents determined in the present study are almost comparable to those reported for other areas off the Egyptian coast and for the other basins, characteristic for the Mediterranean Sea, as well as for other deltas, but broader than that recorded along the western continental shelf of Egypt. It is interesting to note that the mean concentration of organic matter determined in 1966 (M o h a m m e d, 1968) and in 1975 (S u m m e r h a y e s and M a r k s, 1976) are nearly identical with that recorded in the present study. Assuming that these results represent the actual prevailing conditions in the area, this may indicate that the rate of sedimentation would balance the rate of erosion. Prior to 1965, because of the large amounts of mud brought to the coastal region by the Nile and rather weak wave climate of the eastern Mediterranean, depositional factors prevailed near the coast particularly in the neighbourhood

Table 2. Results of organic compounds of sediments collected from different areas off the Egyptian coast and other basins, characteristic of the Mediterranean, as well as other deltas.

Area		O. C. %	O. M %	O. N. %	T. P. %	O. P. %	C/N	C/P	References
Northern Mediterranean	Mean	<1.0							Yilmaz & Salihoglu 1988
Gulf of Trieste North Adriatic	Mean	1.6		0.31	0.004	0.002	6.0	200	Faganeli *et al.* 1985
Gulf of Trieste North Adriatic	Range	0.5—1.5		0.08—0.15	0.002—0.004		<10.0	100—200	Faganeli *et al.* 1988
Strymoniskos Bay N. Agean Sea	Range	0.2—2.0							Conispoliatis 1985
Mississippi Delta	Range	0.48—0.96	0.86—1.72						
Rhone Delta	Mean	0.184							Shepard, 1956
South India									Keller & Lamber, 1972
Delta	Mean	0.739							
Nile sediments	Mean	1.194							Subb, 1960
Arab's Bay	Range	0.23—0.58	0.414—0.918	0.018—0.06					Emelyanov, 1972
Mediterranean Sidi Abdel Rahman-Mersa	Mean	0.35	0.63	0.037					Nasr, 1978
Matruh, S-E	Range	0.09—0.82	0.16—1.48	0.014—0.19					Shatta, 1979
Mediterranean	Mean	0.36	0.64	0.03					
Abu Qir Bay	Range	0.04—1.871	0.072—3.37	0.016—0.161					Moussa, 1973
	Mean	0.70	1.26	0.058					
Continental shelf off	Range	0.16—1.6	0.29—2.9	0.02—0.18	0.008—0.018				
Alexandria	Mean	0.843	1.5	0.08	0.03				El-Sayed, 1974
Continental shelf between Rosetta &	Range	0.1—1.14	0.18—2.05						Mohammed,
Port Said	Mean	0.7	1.26						1968
El Agami-El	Range	0.081—1.55	0.156—2.79	0.01—0.336	0.008—0.097	0.021—0.0006	11.3—3.3	56—285	
Arish	Mean	0.752	1.353	0.134	0.051	0.0091	6.15	87.5	present study

of the main discharge points. Since 1965, the balance between the forces controlling deposition and those controlling erosion has been upset. The sediments supply has been cut off and the threat of wave action to the stability of the coastline has much increased. However, erosion processes are by no means confined to the coastal region, but may affect the sea bed to considerable depths. Sumerhayes and Marks (1976) discussing this point mentioned that the data should be related to the processes of offshore erosion, the rate and condition of resuspension of bottom sediments of the Nile Delta.

Organic nitrogen

The concentration of organic nitrogen ranges between 0.085 and 3.357 mg/g. Low values were recorded off Agami section and middle shelf of Abu Qir, while the highest contents occur off El Diba and El Gamil (Table 1). The average organic nitrogen in the studied samples is 1.36 mg/g. The areal distribution of organic nitrogen (Fig. 3) shows that the highest concentrations occurred in the area between Damietta and Port-Said with a gradual decrease eastward and westward. The high organic nitrogen of the inner shelf sediments off El Diba and El Gamil is due to highs exposure to an increased rate

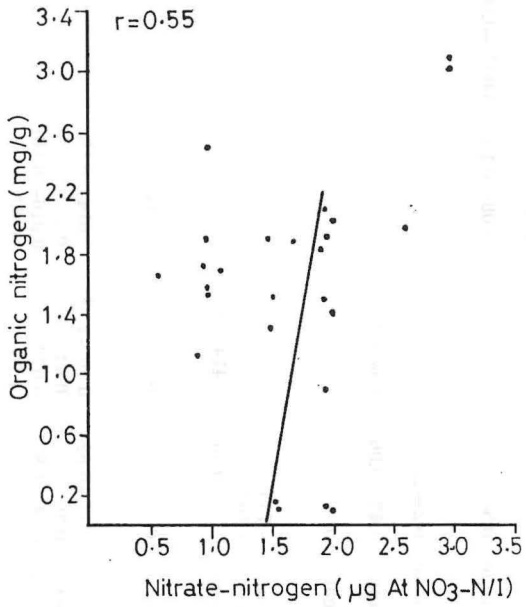

Figure 6. Relation between organic nitrogen in the sediments and nitratenitrogen in the overlying water column in the studied sediment samples.

of deposition of fine sediments and organic debris. Coleman *et al.* (1981) mentioned the presence of organic silty clays and organic debris in the area from Damietta to Port-Said. Furthermore, this area is also highly productive,

which is directly affected by the brackish water outflow from lake Manzalah. Unfortunately, the middle station of El Tena section was not sampled, however, the organic nitrogen content of the offshore station was remarkably higher than that of the coastal area of this section, probably reflecting the current pattern in that region. The distribution of organic nitrogen is closely related to that of organic carbon ($r = 0.827$), indicating a common origin.

In the investigated area a significant positive correlation was found between organic nitrogen content of the sediments and the concentration of dissolved inorganic nitrate-nitrogen in the water column (Fig. 6). This may indicate that the Nile sediments off the Egyptian coast act as a source of inorganic nitrogen to the overlying water column.

Carbon/nitrogen ratio

Table 3 shows that the C/N ratio varies from 3.28 to 11.3 with an average of 6.15. This average ratio is almost identical to that given for marine plankton, i. e. 6.62 (Montegut and Montegut, 1983). The low value of C/N may indicate considerable preferential removal of carbon relative to nitrogen due to the rapid oxidation of carbonaceous materials. Trask (1955) mentioned that in most marine sediments, the nitrogen forms a fairly constant proportion of organic matter and that the average C/N is about 10 ranging bet-

Table 3. Carbon/nitrogen and Carbon/nitrogen/phosphorus ratios in the sediments of the study area.

Section	Station	C/N	C : N : P
El Agami	1	7.8	114.4 : 14.7 : 1
	2	5.73	65.3 : 11.4 : 1
	3	7.23	112.0 : 15.5 : 1
Abu Qir	4	5.72	95.6 : 16.7 : 1
	5	10.24	138.1 : 13.5 : 1
Rosetta	6	4.17	58.6 : 14.0 : 1
	7	3.28	39.5 : 12.1 : 1
	8	4.6	71.9 : 15.7 : 1
Burullus	9	4.9	68.3 : 13.9 : 1
	10	5.4	75.9 : 14.2 : 1
Damietta	11	5.09	79.4 : 15.6 : 1
	12	9.7	117.4 : 12.1 : 1
	13	4.84	69.1 : 14.3 : 1
El Diba	14	3.3	55.9 : 17.0 : 1
El Gamil	15	4.3	65.6 : 15.2 : 1
Port Said	16	7.63	113.4 : 14.9 : 1
	17	6.13	72.3 : 11.8 : 1
	18	5.86	103.6 : 17.7 : 1
El Tena	19	11.3	285.6 : 25.3 : 1
	20	3.9	71.6 : 18.3 : 1
El Bardawil	21	6.9	93.6 : 13.6 : 1
	22	7.4	155.4 : 14.5 : 1
	23	7.3	78.7 : 10.8 : 1
El Arish	24	5.6	75.6 : 13.6 : 1
	25	7.3	139.9 : 19.2 : 1
	26	4.4	82.2 : 19.5 : 1
Average		6.15	87.5 : 15.2 : 1

ween 8 and 12. On the other hand, phytoplankton contributed a considerable portion of organic matter in the sediment. According to Stephens and Strickland (1963) the portion content of phytoplankton decreases as nitrate becomes exhausted, while carbohydrates and lipids increase. This may partly explain the differences of C/N in organic matter (Montegut and Montegut, 1983).

Organic phosphorus

The concentration of organic phosphorus in the upper 10 cm layer of the recent sediments in the investigated area ranges between 0.0063 and 0.2145 mg/g with an average value of 0.0905 mg/g. The spatial distribution of organic phosphorus (Fig. 4) shows nearly the same as that of organic nitrogen. The highest concentrations occurred in the area between Damietta and Port-Said. The maximum content was recorded in the middle shelf sediments off port-Said (0.2143 mg/g). The area off Rosetta shows also comparatively high values. On

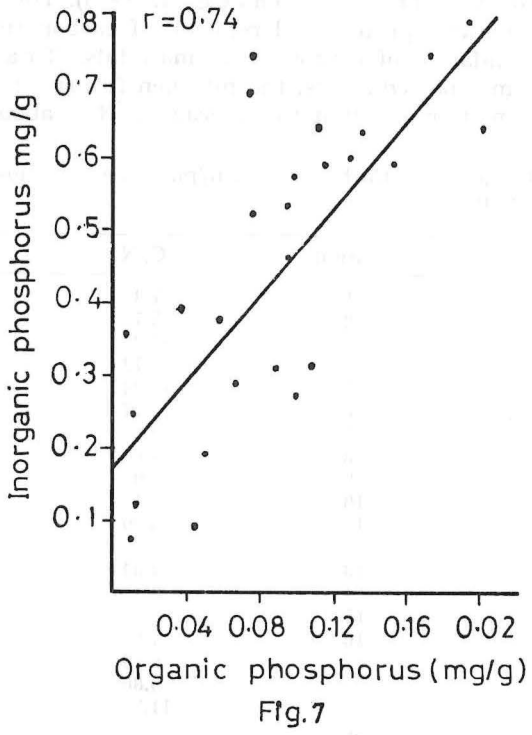

Figure 7. Relation between organic and inorganic phosphorus in the studied sediment samples.

the other hand, the lowest concentration values were found in El Agami (average 0.0095) and El Arish (average 0.0534) sections. On the whole, the concentration of organic phosphorus decreases seawards. The correlations of orga-

nic phosphorus with organic carbon and organic nitrogen are highly significant (r = 0.762 and 0.954 respectively), probably indicating a common origin,

It is important to note that the upper 10 cm layer sediment in the present study represents the zone of bioturbation in which oxidation of organic matter occurs both by chemical and bacterial activity. The pH of the sediments was always on the alkaline side varying from 8.25 to 7.14 (Table 1) and the oxygen saturation at the base of water column ranged between 60—80%. In these sediments the inorganic phosphorus content was remarkably high being on the average about 82% of the total phosphorus, a significant part of this amount is probably due to phosphate adsorbed on the sediment particles. This part of inorganic phosphorus is readily released to the overlying water volumn deffi-cient in its phosphate content. A significant direct correlation (Fig. 7) was found between the inorganic and organic phosphorus fractions in the studied sediments.

Carbon/nitrogen/phosphorus

Table 3 shows that the average C/N/P ratio is 87.6:15.2:1 by weight, the corresponding average ratio in plankton is 106:16:1 (Redfield *et al.*, 1963). It may be of interest that the ratio of the carbon contents is lower than the normal ratio in the plankton, this may be due to the preferential oxidation of carbon than nitrogen and phosphorus in such oxic medium. The N/P ratio, i. e. 15.2 seems to be identical to that found in the plankton. It may be concluded that the Nile sediments are still rich in nitrogen and phosphorus contents and may, after oxidation, act as a reservoir of inorganic nutrients which are brought up to the euphotic zone by mixing processes, particularly in winter, consequently increasing the biological production of the study area.

CONCLUSION

The distribution of organic carbon, nitrogen and phosphorus in the recent sediments are in agreement with the assumption that the major source of these elements to the studied area is the Nile River and the drainage water from the Delta. The distribution and the close correlation between the three elements studied indicate their close association.

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RASPODJELA ORGANSKOG UGLJIKA, DUŠIKA I FOSFORA U RECENTNIM SEDIMENTIMA KONTINENTALNOG PLATOA EGIPATSKE OBALE SREDOZEMNOG MORA

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KRATKI SADRŽAJ

Izučavana je raspodjela organskog ugljika, dušika i fosfora na uzorcima sedimenata sakupljenim na kontinentalnom platou Egipta između El Agami-ja i El Arish-a. U prosjeku su sedimenti sadržavali 7.61 mg/g ugljika, 1.36 mg/g dušika i 0.0905 mg/g fosfora (izraženo u suhoj težini). Raspodjela i korelacija između ova tri elementa ukazuje na njihovu međusobnu povezanost. Prostorna raspodjela ovih elemenata, tendencija opadanja njihovih koncentracija udaljavanjem od ušća Nila i ušća jezera kao i činjenica da su sedimenti ispred dva glavna ušća Nila relativno bogati ovim elementima govori o tome da su vode rijeke Nil glavni izvor ovih elemenata u istraživanom području.