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MAJOR CONTROLS OF METALS' DISTRIBUTION IN SEDIMENTS OFF THE NILE DELTA, EGYPT

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ABSTRACT

The sediment samples that are collected during R/V CHAIN 1975 cruise to the southeastern Mediterranean have been used to determine the major controls of metals' distribution. The sediment samples were analysed mineralogically, chemically and texturally. The parameters measured included carbonate minerals, total carbonate, organic carbon, iron, manganese, copper, zinc, chromium, lead, nickel, cobalt, vanadium, calcium, magnesium, strontium, sand, silt and clay. The statistical analysis of data showed that four major factors control the distribution of metals in sediments of the Nile cone; These are: Factor 1 terrigenous mud-calcareous sand; Factor 2 Aragonite mud-terrigenous sand; Factor 3 Algal sand; and Factor 4 Aragonite. The percentages of terrigenous sand, mud and calcareous components of the Nile cone sediments greatly affect the elements spatial distribution. In addition to that, minor controls such as precipitation and coprecipitation may affect the elemental distribution. The distributions of iron, manganese, copper, zinc, chromium, lead, nickel, cobalt, and vanadium are associated mainly with the terrigenous mud fraction of the sediment whereas, calcium and strontium are mainly related to calcareous sands. Iron, copper, cobalt, lead and vanadium are partially related to montmorillonite. Lead is associated with acid feldspars and chromium is mainly controlled by terrigenous sand. The distribution of calcium and strontium is controlled by the coarse-calcareous fraction of sediments. Magnesium and manganese are associate with algal sand. The aragonite and calcite minerals are forming the majority of carbonate mud, which controls partially the distribution of calcium, strontium, lead and copper.

INTRODUCTION

In 1975 the German R/V CHAIN surveyed the continental shelf off the Nile Delta. The cruise furnished a wide base for further studies on the Nile Delta sediment especially those dealt with sediment transport and dynamics. The Nile Delta is a fragile environment since it is subjected to erosion of its shores as a result of cease of sediment supply resulting from the construction of the High Dam at Aswan. Since then, many studies on the Nile Delta shore erosion have been published; among them are the studies of sedimentary processes in the Nile Delta sponsored by UNESCO, 1973 and 1976, Frihy (1975), Anwar *et al.* (1981), El-Fishawi and El-Askary (1981), Inman and Jinkins (1984), Moufaddal (1995) and AboZed (1996). The geochemistry of the continental shelf off the Nile Delta suffers but so a little attention from scientists that only few published papers could be hardly found in literature e.g. Saad *et al.* (1980), Salem (1981), Abouldahab (1985), El-Sayed *et al.* (1988), El-Sayed and Rifaat (1993). Those studies focused on the metal enrichment in sediments of the nearshore marine environment of the Nile cone due to human activities. On the other hand, the study of Rifaat *et al.* (1992) gave a detailed and better understanding of the partition and behaviour of some metals in Nile shelf sediments but the spatial distribution was not considered

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due to the relatively few samples collected. In the present paper, we used the sediment samples (118 samples) collected during R/V CHAIN 1975 cruise to the southeastern Mediterranean in order to the reveal the spatial distribution of sediment components in the Nile shelf. In addition, the factor analysis was used to interpret the major controls influencing such distribution.

Nile Cone Settings

The morphology of the continental shelf off the Nile Delta was described by Misdorp and Sestini (1976). Off the delta, the shelf consists of a series of terraces separated by low slopes that is cut by some drowned channels and by one major submarine canyon (Rosetta Canyon). On the upper terrace are some low east-west trending ridges (Rosetta Banks, Damietta Banks and Burullus Banks). The surface of the lower terrace is highly reflective and continues landward. The western lower terrace is relatively smooth in contrast to the eastern lower terrace, which is rough. The outer shelf associated with the western lower terrace is covered by mud. This mud is weakly stratified, thins seaward, has been locally eroded, and appears to bury probable algal reefs. West of the delta the shelf has a different morphology. There is a rugged inner shelf consisting of linear coast-parallel ridges, and a smooth outer shelf with Pinnacles that may be small algal reefs. Many authors e.g. Aleem (1972), El-Din (1974) and Saad (1984) studied the hydrography of the Mediterranean water, off the Nile Delta. They showed that before the construction of the first Aswan Dam, up to 100 billion m^3 of water discharged annually from the Nile into the Mediterranean. After the construction of the High Dam no fresh water reaches the sea and the shelf is covered by typical Mediterranean water with salinity approaching 39‰. In addition, the transport of sediment to the Mediterranean shelf off the Nile Delta diminished as a result of damming the river. Both Rosetta and Damietta Cones are covered with mud and sandy mud that also cover the shore face around the main river mouths. Away from the mouths, the shore face, or coastal slope is covered with sand. Sands cover also much of the floor of Abu Quir Bay, as well as the upper terrace off Damietta. Terraces off Lake Burullus are covered with mud, which also predominate on the middle slope, while coarse materials cover much of the lower terraces especially those of the eastern one. Mud cover much of the outer shelf slope north of Rosetta; further east, this slope is covered by coral or mixtures of coral and mud (Misdorp and Sestini, 1976). The nearshore mud and sand are terrigenous, as are the mud at the outer shelf edge, while the sands of the outer shelf are calcareous, and consist mainly of coralline algae. A major facies boundary separates the sediments off the delta from the bioclastic and pelletoidal carbonate sands and mud that occur off Alexandria (Summerhayes *et al.,* 1978).

Off the delta, the mud and sands of the inner and middle shelf contain very little biogenic carbonate. The mud and mud-sand mixture from the outer shelf is moderately calcareous, and the sands and some of the sand-mud mixture from the lower terraces are highly calcareous. The mud fraction of the eastern part of the Nile Shelf deposits is dominantly terrigenous. The sediments of the western part of the Nile Shelf are mainly aragonite and calcite carbonate. The bioclastic component of the sand fraction includes mollusks, echinoids, and benthonic foraminifer. The bioclastic fraction that occurs among the coarse terrigenous sands of the lower terrace off Lake Burullus is reworked and iron-stained (relict). The carbonate sands of the lower terraces usually have assemblages dominated by coralline algae. Maerl, in which branching coralline algae dominate over encrusting ones, and over bryozoa and mollusks, cover much of the outer shelf between Damietta and Rosetta. Further east, encrusting coralline algae are dominant, forming an algal reef-sand assemblage associated with rugged, reef-like structures. The biodetrital mixtures of the calcareous sediments in the western part of the Nile Shelf include coralline algae, mollusks, benthonic foraminifer, echinoid remains, and fecal pellets. On the outer shelf these components are mixed with planktonic foraminifer, pteropods, and bryozoans (Summerhayes *et al.,* 1978). Carbonate pelletoids mixed with this same detritus dominate the sand fraction on the middle shelf (El-Sayed, 1974). The carbonate mud of the western shelf is composed of high strontium aragonite contributed by pelletoids and probably by Halimeda (Stoffers *et al.,* 1980). The terrigenous components are composed of 1) detrital sands which are primarily quartz admixed with pyroxenes, amphiboles, epidote, garnet, zircon, tourmaline, rutile and apatite (Stanley *et al.,* 1979); 2) detrital mud which composed of 15% kaolinite, 8% illite, 72% montmorillonite and 5% chlorite (El-Sammak, 1987).

MATERIALS AND METHODS

The details of sediment samples collection are mentioned in Summerhayes *et al.,* (1978). The uppermost few centimeters of the 118 sediment samples (Fig. 1) collected during the R/V Chain cruise in 1975 to the southeastern Mediterranean Sea, were analysed mineralogically, chemically and texturally. Mineralogical analysis involved quantitative X-ray diffractometry to determine the percentages of carbonate minerals in sediments. Chemical analyses included the determination of carbonate and organic carbon contents (gasometrically), iron, manganese, copper, zinc, chromium, lead, nickel, cobalt, vanadium, calcium, magnesium, and strontium (using Atomic Absorption Spectrophotometry Varian Model 10+). Textural analysis comprised the determination of percentages of sand, silt and clay. The detailed analytical techniques are mentioned in Rifaat *et al.,* (1992). The statistical analysis (Factor Analysis) is applied to the acquired data matrix to determine the relationships between the sediment components and delineate the major controls influencing their spatial distribution patterns.

RESULTS AND DISCUSSION

Distribution of chemical constituents of sediments

Table 1 shows the mean concentration, standard deviation, minimum and maximum values of the measured components in sediments. The textural and mineralogical analyses were used in the statistical processing of data.

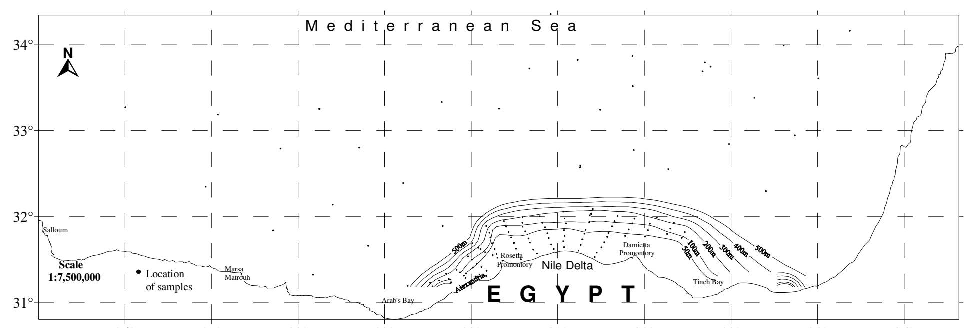

Figure (1) Area of study and location of sediment samples.

Table 1 Mean concentrations of metals in sediments.

	Mean	Standard Error	Standard Deviation	Minimum	Maximum
$CO3^{2-}$%	39.05	2.78	30.45	0	92
Fe%	3.83	0.22	2.43	0.3	8.2
Mn ppm	774.63	35.94	393.71	75	2810
Cu ppm	41.64	1.9	20.76	10	81
Zn ppm	61.7	3.11	34.12	11	221
Cr ppm	72.68	4.25	46.51	8	274
Pb ppm	10.36	0.33	3.63	3.5	23.2
Ni ppm	48.88	2.51	27.54	2	112
V ppm	91.64	5.66	62.01	4.2	319
Ca%	16.31	1.04	11.4	0.5	38.3
Mg%	1.78	0.06	0.62	0.1	5.2
Sr ppm	1697.2	139.63	1529.61	200	7350

Carbonate

The carbonate content in sediments of the Nile continental shelf ranges from <1% to 92% with an average of 39%. The distribution of carbonate follows the sediment composition in that it increases as the amount of bioclastics increase. It reaches its minimum value (<1%) in front of the Nile Delta and increases both seaward in the outer shelf (~80%) and westward in the inner shelf where it reaches its maximum concentration (~90%) (Fig. 2A).

Calcium

The concentration of calcium is well correlated with total carbonate in sediment. The calcium in bottom sediments ranges from 0.5% to 38.3% with an average of 16.3%. The sediment of the inner shelf off the Nile Delta have calcium concentration varies between 0.5 and ~15% while the outer shelf sediment shows values between 15% and 20% except in front of Damietta mouth where it reaches values as high as ~30%. Sediments of the western shelf (west of Alexandria show a dramatic seaward decreases of calcium concentration from over 30% to values ranging from 15% to 20% in the outer shelf mud (Fig. 2B).

Magnesium

The distribution of magnesium in the continental shelf sediments reveals that the sediment of the inner shelf off the Nile Delta contains magnesium ranging between 1% and 2% except in front of Burullus outlet where it reaches minimum concentration. Sediments of the outer shelf contain magnesium ranging from 2% to 3%. West of Alexandria and in Abu Quir Bay the inner shelf sediments have magnesium content <1% increasing seaward. It should be noted that the distribution of magnesium in sediments does not match those of carbonate and calcium (Fig. 2C) which may be attributed to a terrigenous source of magnesium such as feldspars minerals (plagioclase).

Strontium

Strontium in sediments of the continental shelf varies between 200ppm and 7350ppm with an average of 1697ppm. The distribution of strontium correlates well with those of carbonate and calcium. The inner shelf off the Nile Delta, is covered by sediments having strontium content <500ppm. The outer shelf sediments have strontium concentration ranging from 500ppm to 1500ppm. The sediments west of Alexandria which are mainly calcareous contain strontium concentrations of as high as 7000ppm in the inner shelf decreasing seaward until it reaches ~2000ppm in the outer shelf (Fig. 2D).

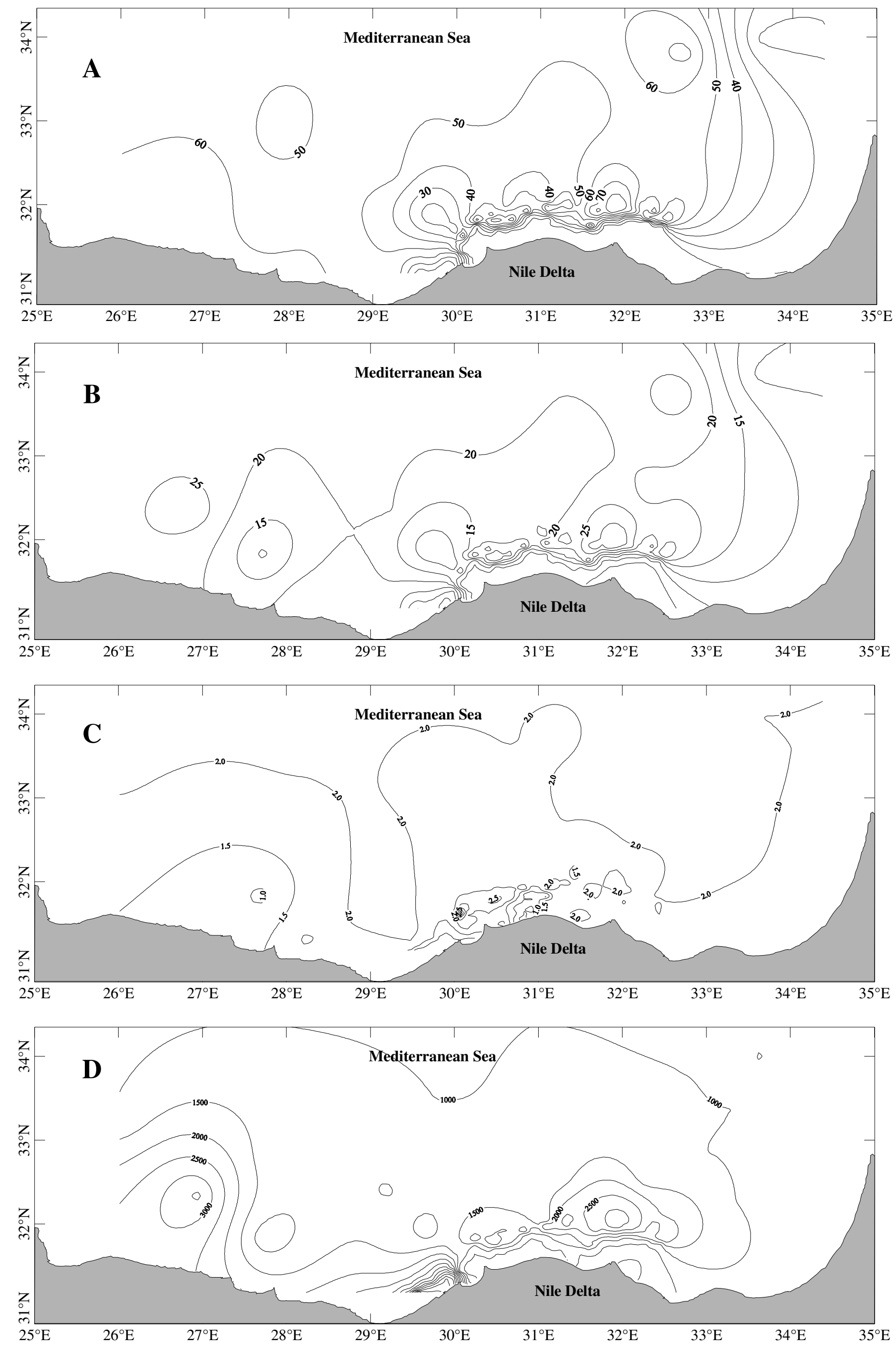

Figure (2) Distribution of total carbonate and metals in sediments of the Nile Cone
(A) Total Carbonate% (B) Calcium% (C) Magnesium% (D) Strontium ppm

Iron

Iron in bottom sediments of the continental shelf ranges from 0.3% to 8.2% with an average of 3.8%. In front of Rosetta and Damietta mouths the iron concentrations are the highest (~8%) among other areas. Between the two mouths iron concentrations in sediments range between 4% and 6% in the inner shelf decreasing seaward to 2%-4% in the outer shelf sediments. West of Alexandria the iron in sediments of the inner shelf ranges between 0.5% and 1% increasing seaward to 2% in sediments of the outer shelf (Fig. 3A).

Manganese

The sediments of the inner shelf off the Nile Delta contain manganese concentrations ranging from 500ppm and 1000ppm except at Rosetta and Damietta mouths where it reaches values as high as 2000ppm decreasing seaward to <500ppm. West of Alexandria, manganese in sediments of the inner shelf ranges from <100ppm to 500ppm increasing seaward to >1000ppm in sediments of the outer shelf (Fig. 3B).

Copper

The copper concentration in sediments of the continental shelf off the Nile Delta ranges from 10ppm to 81ppm. The maximum concentrations (~80ppm) being found just off Rosetta and Damietta mouths. The inner shelf sediments contain copper ranging from 10ppm to 30ppm increasing to about 50ppm in sediments of the outer shelf. The western part of the shelf off Alexandria is characterised by lower copper values (10ppm-20ppm) in the sediments of the inner shelf increasing seaward to reach about 50ppm-60ppm in sediments of the outer shelf (Fig. 3C).

Zinc

Zinc concentration in sediments of the shelf ranges between 11ppm and 221ppm with an average of 62ppm. At Abu Quir Bay, Rosetta mouth, and Damietta mouth and just east of Damietta the zinc reaches its maximum concentration. The rest of the inner and outer shelf is covered with sediments having zinc concentrations ranging between 50ppm and 70ppm. West of Alexandria zinc concentration in sediments falls below 20ppm nearshore increasing seaward to about 70ppm in the outer shelf sediments (Fig. 3D).

Chromium

The chromium in sediments varies between 8ppm and 274ppm with an average value of 73ppm. The maximum concentrations are observed near Rosetta and Damietta mouths, while sediments having chromium contents of 100-150ppm cover the rest of the shelf off the Nile Delta. The western shelf, west of Alexandria, is covered by sediments having chromium concentrations below 25ppm in the inner shelf increasing to 50-100ppm in the outer shelf sediments (Fig. 4A).

Lead

Lead concentration ranges between 3.5ppm and 23.2ppm with an average of 10.4ppm. The inner shelf sediment off the Nile Delta and west of Alexandria has lead concentration of 4-7ppm increasing seaward to about 11-13ppm. It is just off Damietta mouth where the sediments contain lead as high as ~20ppm (Fig. 4B).

Nickel

Nickel reaches its maximum concentration (>100ppm) in front of Rosetta and Damietta mouths. In between the concentration of nickel ranges from 10 to 65ppm decreasing seawards to 25-45ppm in the outer shelf sediments. West of Alexandria, the concentration of nickel in the inner shelf sediments ranges between <10ppm to 30ppm increasing seaward to about 45ppm in sediment of the outer shelf (Fig. 4C).

Vanadium

The concentration of vanadium ranges between 4.2ppm and 319ppm with an average of 91.6ppm. Off Rosetta mouth, Damietta mouth and just east of Lake Burullus outlet where vanadium reaches its maximum concentration (>200ppm). The rest of the inner and outer shelf sediments have vanadium concentration ranges from 50ppm to 100ppm usually increasing seaward (Fig. 4D).

FACTOR ANALYSIS

The results of factor analysis show that the distribution of the constituents in sediments of the Nile shelf is controlled by four factors (Table, 2). **Factor 1** involves the association of iron, manganese, copper, zinc, chromium, lead, nickel, cobalt, vanadium, organic carbon, silt and clay with the inverse association as indicated by the negative loadings on calcium, strontium, carbonate, magnesian calcite, aragonite and sand. It represents the interaction of terrigenous mud with the calcareous sediments. The most simple explanation of this factor is that the distribution of positively associated metals is controlled by the amounts of terrigenous mud (silt and clay) contributed to the sediments. On the other hand, calcium and strontium are controlled by the sand sized calcareous fraction of sediments. Although this is true as a major explanation for the distribution of metals in Nile shelf sediments, the metals distributions are controlled by several processes such as adsorption and ion exchange, precipitation, co-precipitation, association with organic particles, and transportation with detrital sediments (Rifaat *et al.,* 1992). Lead is probably associated with detrital high-lead acid feldspars content. Furthermore, vanadium, lead, cobalt, magnesium, iron and copper are partially related to montmorillonite especially that clays of Nile shelf sediments are dominantly montmorillonite (El-Sammak, 1987). In addition to that, the iron-manganese association may be related to the occurrence of an iron-manganese hydroxide phase that is capable of scavenging metals such as vanadium, chromium, cobalt, nickel, and copper (Spencer *et al.,* 1968). The carbonate content of the Nile shelf sediments together with calcium and strontium and their related minerals are controlled by the sand sized calcareous debris and acts as dilutant to the terrigenous fraction of the sediments.

Factor 2 is an aragonitic mud that describes the relation of carbonate, aragonite, calcite, calcium, strontium, lead, copper and organic matter. It clearly delineates the existence of aragonite and calcite in the fine carbonate sediments and that part of the lead and copper in sediments are precipitated with carbonate. Further, it clearly reveals that calcite is only related to the fine carbonate fraction of the sediment. The inverse association in this factor is indicated by the negative loadings on sand and chromium and may be interpreted as the effect of terrigenous sand.

Factor 3 shows high positive loadings on magnesium, magnesian calcite and moderate positive loading on manganese. Since magnesium has showed no relation to total carbonate content in sediment, the association with magnesian calcite reveals that the presence of magnesium in sediments is largely controlled by the content of magnesian calcite rather than existence as magnesium carbonate minerals. However, this factor could be interpreted as algal sand.

Factor 4 clearly involves aragonite. The positive loadings of aragonite and strontium together with the negative loading of calcite indicate that strontium is principally associated with aragonite. Stoffers *et al.* (1980) and El-Sayed (1985) have shown that the carbonate mud off Alexandria is composed of high strontium aragonite contributed by pelletoids and probably by Halimeda.

Table 2 Factor of analysis of observed parameters.

Variable	Factor1	Factor2	Factor3	Factor4
Iron	0.980	-0.021	0.064	0.100
Manganese	0.765	-0.225	0.406	0.068
Copper	0.887	0.352	0.012	0.020
Zinc	0.864	0.066	-0.005	0.057
Chromium	0.793	-0.383	0.049	0.238
Lead	0.448	0.475	0.020	-0.241
Nickel	0.899	0.140	0.006	0.194
Cobalt	0.920	0.003	0.135	0.150
Vanadium	0.872	-0.225	0.153	0.215
Calcium	-0.812	0.462	0.248	0.188
Magnesium	0.265	0.241	0.900	0.124
Strontium	-0.688	0.489	-0.239	0.387
Carbonate	-0.815	0.457	0.290	0.160
Organic Carbon	0.524	0.589	-0.380	0.100
Calcite	-0.066	0.419	0.158	-0.669
Magnesian Calcite	-0.646	0.200	0.701	-0.012
Aragonite	-0.679	0.481	-0.256	0.405
Sand	-0.735	-0.593	0.174	0.053
Silt	0.718	0.518	-0.217	0.071
Clay	0.612	0.604	-0.103	-0.201
Eigen Value	10.78	3.12	1.90	1.14
% of Trace	53.90	15.60	9.50	5.70
Cum. % of Trace	53.90	69.50	79.00	84.70

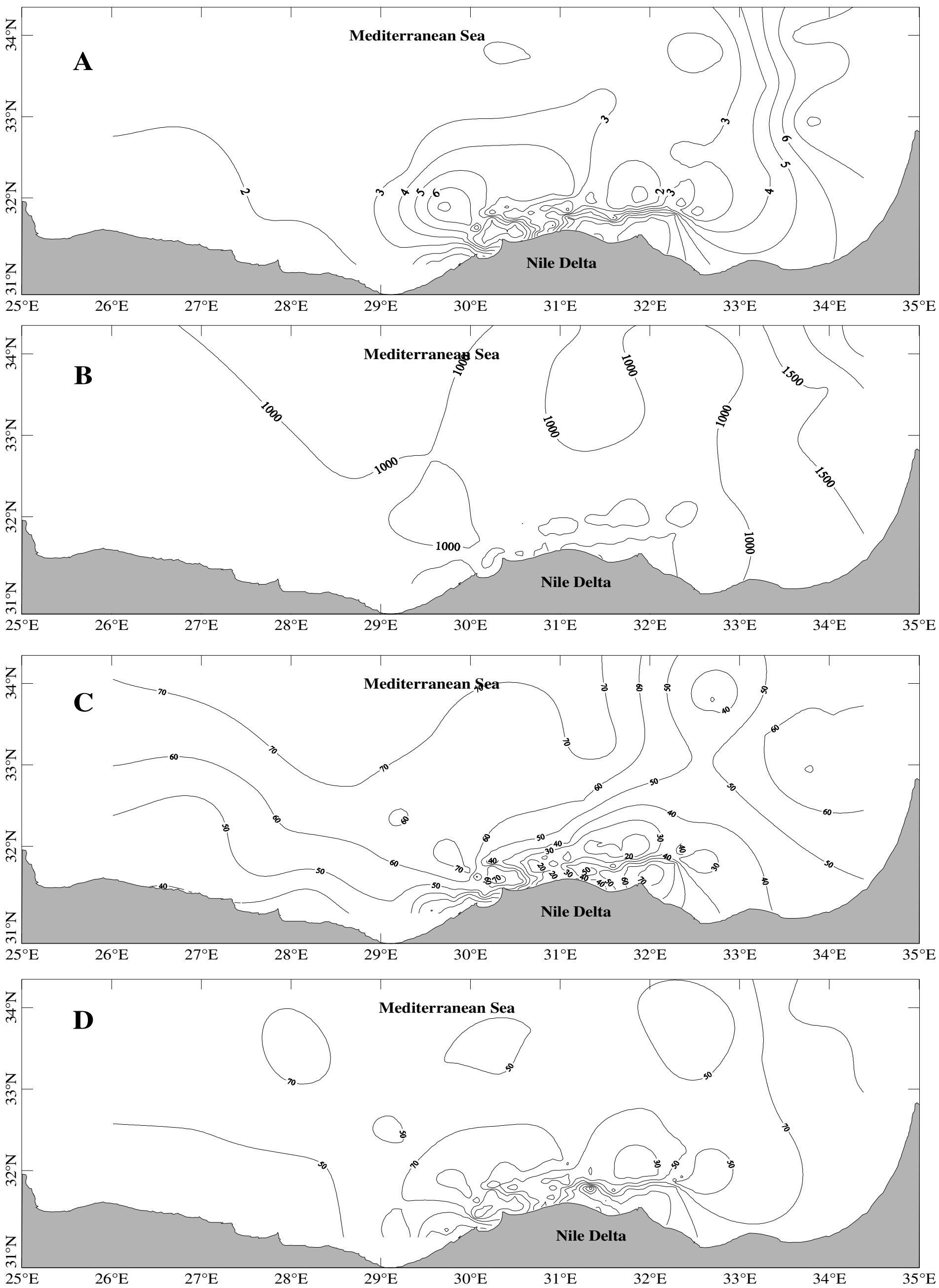

Figure (3) Distribution of metals in sediments of the Nile Cone
(A) Iron% (B) Manganese ppm (C) Copper ppm (D) Zinc ppm

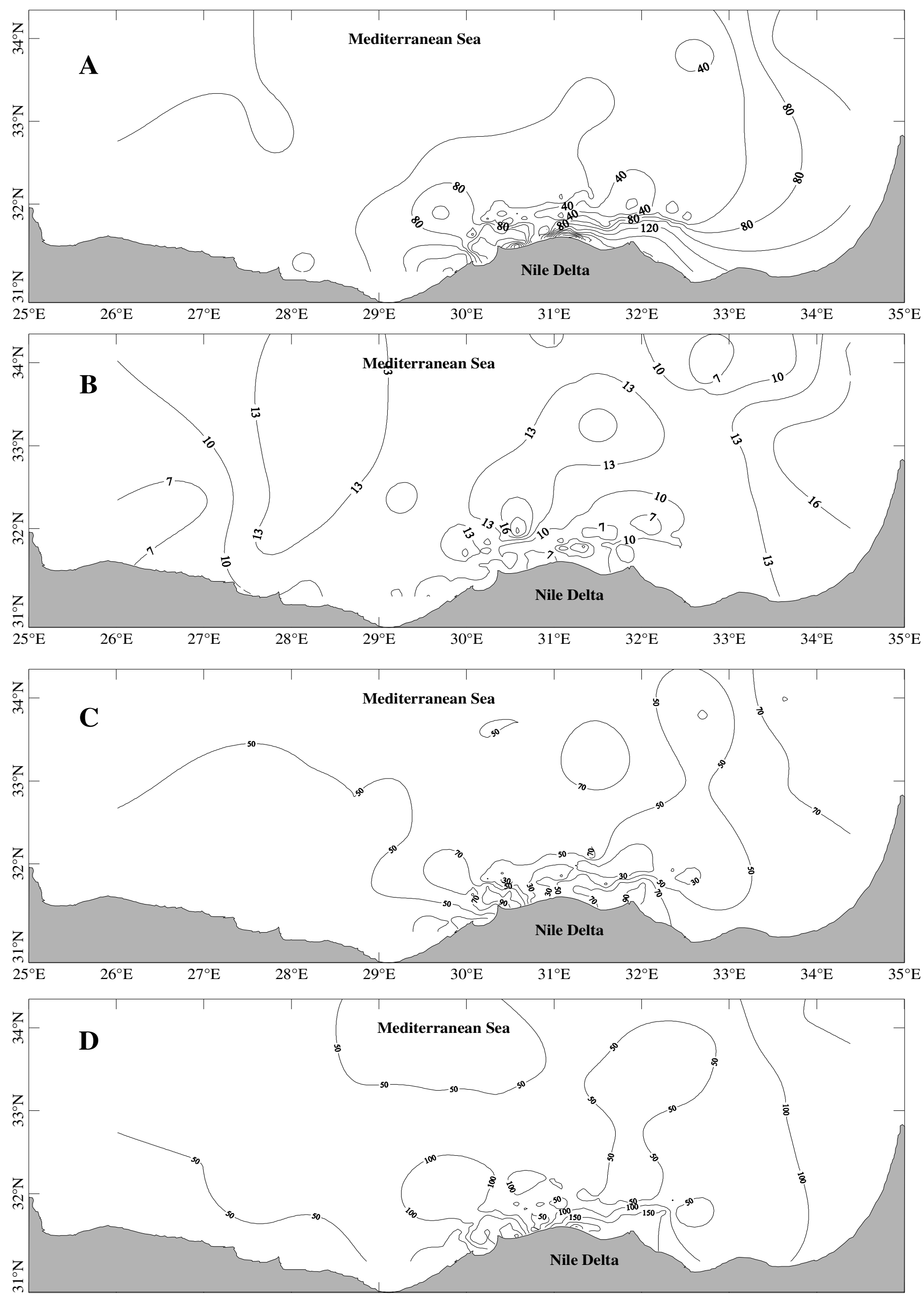

Figure (4) Distribution of metals in sediments of the Nile Cone
(A) Chromium ppm (B) Lead ppm (C) Nickel ppm (D) Vanadium ppm

CONCLUSION

The percentages of terrigenous sand, mud and calcareous components of the Nile cone sediments greatly affect the elements spatial distribution. In addition to that, minor controls such as precipitation and coprecipitation may affect the elemental distribution. The distributions of iron, manganese, copper, zinc, chromium, lead, nickel, cobalt, and vanadium are associated mainly with the terrigenous mud fraction of the sediment whereas calcium, strontium are mainly related to calcareous sands. Iron, copper, cobalt, lead and vanadium are partially related to montmorillonite. Lead is largely related to acid feldspars and chromium is mainly controlled by terrigenous sand. The distributions of calcium and strontium are controlled mainly by the coarse calcareous fraction of sediments. Magnesium is related largely and manganese partly to algal sand. The aragonite and calcite minerals are forming the majority of carbonate mud, which controls partially the distributions of calcium, strontium, lead and copper.

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