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Metal Composition of Recent Carbonate Sediments off Jeddah, Kingdom of Saudi Arabia

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ABSTRACT. The metal concentrations in recent carbonate sediments off Jeddah were studied to determine the factors affecting their distributions. Sixty bottom sediment samples were collected by SCUBA Diving and the moderately acid soluble fractions were dissolved to determine the concentrations of Calcium, Magnesium, Strontium, Sodium, Potassium, Manganese, Zinc, Copper and Cadmium. The biogenic components of the sediments were determined under binocular microscope and comprised coralline algae, coral debris and molluscan shell fragments. Multivariate statistical analysis (R-Mode Factor Analysis) was applied to extract the factors affecting metal distribution in sediments. This study showed that the levels of metals in sediments are in the range of natural unpolluted carbonate sediments and are controlled by the biogenic composition (source material). The percentages of coralline algae control the levels of sodium, potassium, manganese, copper, zinc and cadmium whereas percentages of molluscan debris control the levels of strontium in sediments. The average concentrations of strontium, manganese, zinc, copper and cadmium are 0.5%, 16.8 ppm, 7.66 ppm, 5.37 ppm and 2.3 ppm, respectively. The sediment environment off Jeddah is relatively clean compared with other areas in the Red Sea. However relevant government agencies are requested to maintain the present marine environment quality by regular monitoring of the metal inputs.

Introduction

In the last decade attention has been devoted to the protection of environment against human activities. The presence of coral reefs in the nearshore areas subject these very sensitive marine organisms to the direct inputs of man's activities into the marine environment. A great deal of attention has been directed to the ecology of Red Sea environment especially coral reefs off Jeddah. Some studies concerning the ecology of coral reefs off Jeddah has been conducted, *e.g.* Behairy & Jaubert (1983) and Montaggioni *et al.* (1986). The studies on the metal content in the coral reefs sediments of the Red Sea is relatively few. Regular studies and monitoring procedures should be conducted to know the progressive levels of different pollutants especially toxic ones and their effect on the coral reefs environment.

The nearshore bottom sediments off Jeddah composed mainly of carbonate detritus of the adjacent corals together with coralline algae, molluscan shell fragments, foraminifers and others. The metal contents of sediments may reflect the present quality of the marine environment. Hence, elevated metal concentrations in sediment reflect abnormal inputs to the marine environment and depict the need to apply measures of controlled discharges. Moreover, the elevated metal concentrations in the coral reefs' environment represent a real threatening to the growth and existence of nearshore corals in the Red Sea. This study determines the levels and factors affecting the distribution of some environmentally important metals in the sedimentary debris of the coral reefs off Jeddah.

Sediments and Sedimentary Environment

According to Montaggioni *et al.* (1986), the coral reefs' structure off Jeddah can be divided, based on the physiographical and biological activities into six zones namely, the offshore reef bodies, the offshore inter-reef areas, the fringing forereef zone, the fringing reef flat zone, the fringing backreef zone and the beach zone. However, most bottom sediments off Jeddah are carbonate and are the result of disintegration of coral reefs and biogenic material such as coralline algae, molluscan shell fragments, foraminifers, bryozoans and others. The surface seawater salinity varies from 39‰ to 40‰ (Behairy & Jaubert, 1983). The average seasurface temperature is 31°C in June and 26.5°C in January. The tidal range is around 0.3 m (Montaggioni *et al.*, 1986). Seiches of meteorological origin may frequently lower the sea level and restrain coral growth (Guilcher, 1982). The sediment environment off Jeddah is "Oxic"; dissolved oxygen concentrations vary from 4.6-5.6 mg/l (Behairy & Jaubert, 1983). The surface currents trend to the Northwest following a course parallel to the coast.

Material and Methods

Sixty bottom sediments samples off Jeddah were collected by SCUBA diving. The area of study is shown in Fig. (1). The sediments were washed with deionized distilled water, air dried and ground in an agate mortar to pass the .063 mm mesh sieve. Representative subsamples were attacked with 1N HCl to dissolved the carbonate materials following the methods mentioned in Robinson (1980).

The metals (calcium, magnesium, strontium, sodium, potassium, manganese, zinc, copper and cadmium) concentrations were determined using Atomic Absorption Spectrophotometry against the respective metal standards and the standard river sediments 1645 from the NBS; the results were found satisfactory (1-6% from the accepted values). Percentages of coral debris, coralline algae debris, molluscan debris were determined using binocular microscope.

Statistical Analysis

The results of chemical and microscopic analyses of

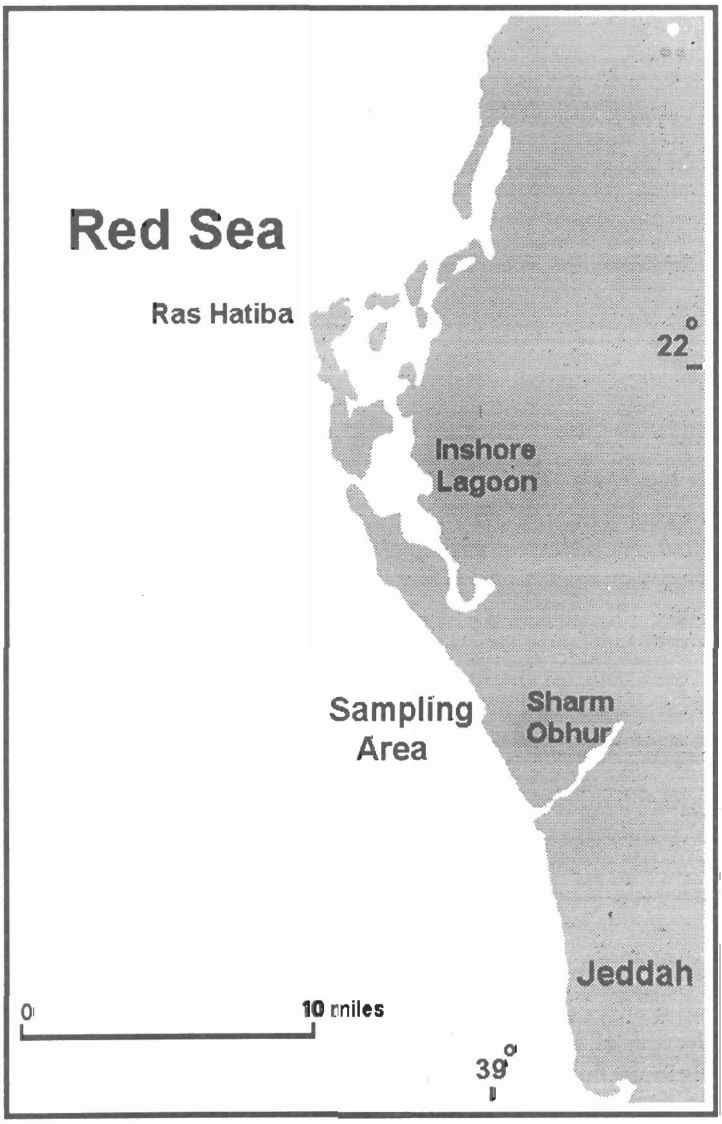

FIG. 1. Area of study.

sediments were processed statistically. The R-Mode Factor Analysis is applied to extract the factors controlling the metals in the sediments. The method depends on summarizing the information within the original complex data matrix converting them onto a more simple from that could be observed and interpreted. The data have been standardized, and the correlation matrix among variables was calculated. The Eigenvectors and Eigenvalues were extracted and used to produce the factor loadings matrix. The Varimax rotation was applied until the most simple structure was achieved; (see Davis, 1973). The computer program (RFACOR) was designed and written by the author.

Results and Discussion

The results of chemical and microscopical analyses of sediments are presented in Table (1) while the R-Mode Factor Analysis results are listed in Table (2).

The carbonate sediments off Jeddah consist mainly of the biogenic debris of corals, coralline algae and the shell fragments of mollusks. The minor component comprises bryozoans, foraminifers, sponges and mineral grains. The areal distribution of biogenic components is as follows: coral detritus occurs in higher abundance in the sediments of the offshore zone, coralline algae are the most abundant towards the beach and molluscan fragments are common throughout the entire area (Montaggioni *et al.*, 1986). The ranges of biogenic components are as follows: coral debris 12-64% (mean = 40.13% ± 13.8); coralline algae 4-65% (mean = 25.41% ± 14.22); and molluscan debris 13-72% (mean = 32.54% ± 11.61) (see Table 1). These values are approximately the same compared with the data obtained by Behairy and Jaubert (1983) and Montaggioni *et al.* (1986) for the sediments off Jeddah. The average concentration of metals (Table 1) in the carbonate sediments off Jeddah conforms well with the average concentration of metals in natural unpolluted carbonate sediments of different origins. The geochemical predictive models for metals in marine sediments (Rifaat *et al.*, 1992) and models for precipitation of metals with calcite (Davis *et al.*, 1987 and Comans & Middelburg, 1987) shows that zinc, copper and cadmium are present in sediment in the carbonate form and are, mainly, precipitated biogenically. However, the Varimax rotated factor matrix of the data (Table 2) shows that the metal composition of sediments are controlled by five factors. The five factors explain about 80% of the information contained in the original data matrix and these are :

Factor 1

It represents the inverse relationship of Ca-Sr and Mg-Mn associations and characterized by high positive loadings on calcium and strontium, and high negative loadings on magnesium and manganese.

Factor 2

This factor represents the association of sodium, potassium and manganese and is most probably oxyhydroxide association in which these metals precipitates as oxides and oxyhydroxides on the surfaces of carbonate particles especially coralline algae debris (Table 1).

Factor 3

It shows an association of high negative loading on coral debris with moderate loading on calcium and inverse association of high positive loading on molluscan debris with moderate loading on strontium.

Factor 4

This factor shows the strong association of coralline

TABLE 1. Average biogenic and elemental composition of bottom sediments off Jeddah.

	Mean	S.D.	Min.	Max.	Corals*	Coralline algae*	Mollusks*	Carbonate sediment		
								Mediterranean**	Northern Red Sea+	Ghardaqa Red Sea++
Corals debris %	40.13	13.8	12.6	64.5	–	–	–	–	–	–
Coralline algae debris %	25.41	14.22	4.5	65.4	–	–	–	–	–	–
Molluscan debris %	32.54	11.61	13.8	72.0	–	–	–	–	–	–
Calcium %	33.49	0.9	30.5	35.9	35.2-41.0	27-34.4	32-39.9	16-27	13.1-39	7.4-18.9
Magnesium %	1.58	0.32	0.9	2.4	0.06-5.0	1.7-7.2	0.005-2.4	–	0.64.1.99	1.3-3.27
Strontium %	0.50	0.06	0.35	0.63	0.28-1.0	0.12-0.56	0.01-0.55	–	–	0.2-1.11
Sodium ppm	147.17	94.65	20.0	467.0	3300-4500	800-1420	2100-5300	< 1-2775	–	488-1629
Potassium ppm	155.40	83.48	2.0	397.0	100-120	115-6900	130-260	19-108	–	543-706
Manganese ppm	16.81	6.8	8.7	38.9	2-10	3-392	1-190	21-172	2-418	73.2-2012
Zinc ppm	7.66	4.0	5.3	30.6	< 2-104	9-470	0.59-51	2-47	10-230	7.2-58.7
Copper ppm	5.37	3.33	1.3	25.1	1-14	1-443	0.29 - 42	3-42.5	3-79	5.5-17.7
Cadmium ppm	2.3	0.5	1.8	6.0	–	–	0.05-2.8	< 0.06-1.97	–	–

*Milliman (1974), **Rifaat (1990), +Beltagy (1984), ++El-Sayed (1984).

TABLE 2. Results of factor analysis of bottom sediments off Jeddah.

Eigen values matrix

Variable	Eigen value	Percent of trace	Cum. percent of trace
CORALS	3.82	31.85	31.85
COR.ALG	1.72	14.32	46.17
MOL.	1.69	14.12	60.29
Ca	1.31	10.90	71.19
Mg	1.09	9.12	80.31
Sr	0.71	5.87	86.18
Na	0.57	4.78	90.97
K	0.38	3.14	94.11
Mn	0.31	2.59	96.69
Zn	0.27	2.23	98.92
Cu	0.11	0.91	99.83
Cd	0.02	0.17	100.00

Varimax rotated factor loading matrix

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
CORALS	0.04	– 0.14	– 0.81	– 0.44	– 0.27
COR.ALG	– 0.19	0.26	– 0.05	0.80	0.38
MOL.	0.12	– 0.05	0.86	– 0.39	– 0.16
Ca	0.75	0.18	– 0.28	0.19	– 0.30
Mg	– 0.88	0.10	– 0.13	0.27	0.13
Sr	0.85	– 0.06	0.24	– 0.27	– 0.16
Na	0.06	0.76	– 0.08	– 0.12	– 0.02
K	– 0.08	0.82	0.08	0.07	– 0.08
Mn	– 0.52	0.51	0.20	0.21	0.10
Zn	– 0.20	– 0.04	0.06	0.22	0.86
Cu	– 0.18	– 0.20	– 0.02	0.81	– 0.08
Cd	– 0.19	– 0.05	– 0.01	– 0.05	0.90

algae – copper and moderate relation with magnesium, manganese and zinc. The inverse relation is indicated by the negative loadings on corals debris, molluscan debris and strontium.

Factor 5

This factor represents the strong correlation of cadmium and zinc with coralline algae as indicated from the high positive loading on both Cd and Zn and moderate loading on Coralline algae. The inverse relationship is indicated by the association coral debris – calcium.

Although Behairy and Jaubert (1983) and Montaggioni *et al.* (1986) mentioned that the source of iron, copper and zinc in the carbonate sediments off Jeddah is mainly terrestrial, the most important criterion is that the biogenic comparison is the main control of metal concentration in sediments. The coralline algae affect the concentration of sodium, potassium, manganese, copper, zinc and cadmium whereas strontium is mostly controlled by the molluscan content of the sediments with certain metals. Billings and Ragland (1968), and Friedman (1969) have attributed the distribution frequency of rare elements to the different distributions of calcite and aragonite bioclasts. Also, St. John (1974) observed that massive types of corals concentrate more cadmium than branching forms. The most important feature in Table (2) is that the distribution of calcium and magnesium is common with no specific biogenic component acting as a controller factor.

Conclusions

The sediments off Jeddah composed primarily of biogenic debris of corals, coralline algae and molluscan shell fragments. The corals debris increases seaward while the coralline algae decreases seaward. Molluscan shell fragments concentrate in the nearshore area. The metal concentrations in the sediments are still within the levels of the natural unpolluted carbonate sediments. The distribution of metals is controlled by the biogenic composition of sediments. Percentages of coralline algae control the distribution of sodium, potassium, manganese, copper, zinc and cadmium whereas molluscan debris control the distribution of strontium in sediments. The present cleanliness of the offshore marine environment off Jeddah dictates the need to regularly monitor the levels of pollutants in the various components of the marine environment. This task can be achieved by laying programs of periodic sampling and testing of seawater, biological materials and sediments from the offshore area off Jeddah. As for the future exploitation of the coast, the coastal management should include strict application of environmental laws that inhibit construction of coastal industries lacking proper treatment units of the wastes before dumping into the sea.

References

Behairy, A.K.A. and **Jaubert, J.** (1983) *Ecology of a coral reef complex and a lagoon near Sharm Obhur, Red Sea (Jeddah, Saudi Arabia).* Final Report, Joint Res. Program KAU-Nice Univ., 197 p.

Beltagy, A.I. (1984) Elemental geochemistry of some recent marine sediments from North Red Sea. *Bull. Inst. Oceangr. & Fish.*, **10:** 1-12.

Billings, G.K. and **Ragland, P.C.** (1968) Geochemistry and mineralogy of the recent reef and lagoonal sediments south of Belize (British Honduras). *Chem. Geol.*, **3:** 135-153.

Comans, R.N.G. and **Middelburg, J.J.** (1987) Sorption of trace metals on calcite: applicability of the surface precipitation model. *Geochim. Cosmochim. Acta*, **51:** 2587-2591.

Davis, J.C. (1973) *Statistics and Data Analysis in Geology.* John Wiley & Sons Inc., New York-London-Sydney-Toronto, 550 p.

Davis, J.C., Fuller, C.C. and **Cook, A.D.** (1987) A model for trace metal sorption processes at the calcite surface: adsorption of Cd^{2+} and subsequent solid solution formation. *Geochim. Cosmochim. Acta*, **51:** 1477-1490.

El-Sayed, M.Kh. (1984) Reefal sediments of Al-Ghardaqa, Northern Red Sea, Egypt. *Mar. Geol.*, **56:** 259-271.

Friedman, G.M. (1969) Trace elements as possible environmental indicators in carbonate sediments. *Soc. Econ. Paleontol. Mineral. Spec. Publ.*, **14:** 193-198.

Guilcher, A. (1982) Physiography of the Red Sea coast and coastal waters: a summary of the present state of knowledge with suggestions for further research, *J. Fac. Mar. Sci.*, **2**(1402H): 27-36.

Milliman, J.D. (1974) *Marine Carbonates*, Springer Verlag, Berlin-Heidelberg-New York, 375 p.

Montaggioni, L.F., Behairy, A.K.A., El-Sayed, M.Kh. and **Yusuf, N.** (1986) The modern reef complex, Jeddah area, Red Sea: a facies model for carbonate sedimentation on embryonic passive margin. *Coral Reefs*, **5:** 127-150.

Rifaat, A.E. (1990) *Geochemical model of some elements of environmental importance in sediments from the Mediterranean continental shelf of Egypt.* Ph.D. Thesis, Fac. Sc., Alex. Univ., 172 p.

———, **El-Sayed, M.Kh., Beltagi, A., Morsy, M.A.** and **Nawar, A.** (1992) Geochemical predictive models of manganese, zinc, nickel, copper and cadmium in Nile shelf sediments. *Mar. Geol.*, **108:** 59-71.

Robinson, P. (1980) Determination of calcium, magnesium, manganese, strontium, sodium, and iron in the carbonate fraction of limestones and dolomites. *Chem. Geol.*, **28:** 135-146.

St. John, B.E. (1974) Heavy metals in the skeletal carbonate of scleractinian corals. *Proc. 2nd Int. Coral Reef Symp.*, **2:** 461-469.

التركيب المعدنى للرسوبيات الكربوناتية الحديثة أمام منطقة جدة بالمملكة العربية السعودية

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المستخلص: تمت دراسة التركيزات الفلزية فى رسوبيات الكربونات الحديثة أمام منطقة جدة لتحديد العوامل المؤثرة في توزيعها، وقد تم جمع ستين عينة بواسطة الغطس واستخدمت الأحماض المخففة لتذويب عناصر الكالسيوم والمغنسيوم والسترونشيوم والصوديوم والبوتاسيوم والمنجنيز والزنك والنحاس والكادميوم. وقد تم تعيين المحتوى الرسوبي الكربوناتي الناشىء بفعل الكائنات البحرية باستخدام المجهر واشتملت على الطحالب المرجانية والفتات المرجانى وفتات الأصداف والمحاريات المختلفة. استخدم التحليل الإحصائى العديد المتغيرات (التحليل العاملى لجدول المضاهاة) لاستنباط العوامل المؤثرة في التوزيع الفلزى فى الرسوبيات. أظهرت الدراسة أن مستويات العناصر موضوع الدراسة في الرسوبيات تقع ضمن مجال تركيزاتها فى رسوبيات الكربونات الطبيعية فى المناطق البحرية غير الملوثة. ويتحكم الإنتاج الكربوناتى الناشىء بفعل الكائنات البحرية فى توزيع العناصر فى الرسوبيات. وبصفة خاصة تتحكم نسبة الطحالب المرجانية فى مستويات وتوزيع عناصر الصوديوم والبوتاسيوم والمنجنيز والنحاس والزنك والكادميوم بينما تتحكم نسبة فتات الأصداف والمحاريات فى مستويات السترونشيوم فى الرسوبيات.

وتبلغ متوسطات تركيزات عناصر السترونشيوم والمنجنيز والزنك والنحاس والكادميوم ٥ر٠٪، ٨ر١٦ جزء في المليون، ٧٧ر٦ جزء في المليون، ٣٧ر٥ جزء في المليون، ٣ر٢ جزء في المليون علي الترتيب. وتوضح متوسطات تركيزات العناصر السابقة أن رسوبيات البيئة البحرية المتاخمة لمنطقة جدة نظيفة نسبيا بالمقارنة بالمناطق الشبيهة الأخرى بالبحر الأحمر. وعلى هذا فإن الحالة الراهنة للبيئة البحرية أمام منطقة جدة تحتم اتخاذ إجراءات تكفل إبقائها بعيدة عن التلوث مع المتابعة الدورية لنوعية الصرف وخاصة المحتوى على ملوثات معدنية إلى المنطقة البحرية.