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Sedimentological Aspects and Environmental Conditions Recognized from the Bottom Sediments of Al-Kharrar Lagoon, Eastern Red Sea Coastal Plain, Saudi Arabia

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ABSTRACT. Most of the Red Sea lagoons have received little attention and none of these lagoons is particularly studied from sedimentological point of view. Al-Kharrar Lagoon, north of Jeddah is a subtropical lagoon on the Red Sea coastal plain. An attempt has been made to study the textural composition and the gross mineralogy of the bottom sediments. Conditions of sedimentation, facies changes and source of rocks have also been studied. On the basis of sedimentological and mineralogical investigations, two sedimentary facies could be recognized in the bottom sediments of Al-Kharrar Lagoon; a carbonate facies appears coarser and prevailed in the northern half of the lagoon which is affected by the longshore currents of the open Red Sea through the inlet. A second fine grained clastic facies characterized the southern end of the lagoon and is dominated by the land derived material drifted by the flash floods through the ancient wadies during the rainy seasons.

Introduction

Along the Red Sea coasts there are extensive areas intruded by coastal lagoons (Sharms). Some of these lagoons are hypersaline and most of them are surrounded by largely developed sabkhas and mangrove vegetation. The coastal lagoons break the continuity of the Pleistocene reef complexes and remain as remnant of much larger body of water.

Al-Kharrar lagoon lies on the coastal plain northwest of Rabigh city on the western coast of Saudi Arabia between latitudes 22º45′ and 23º00′N and longitudes and 38º45′ and 39º00′E (Fig. 1). It is connected to the adjacent Red Sea through a narrow channel on its northwestern side and extends for about 20 km along the coast. The southern and eastern parts of the lagoon are bounded by extensive intertidal and supratidal flats.

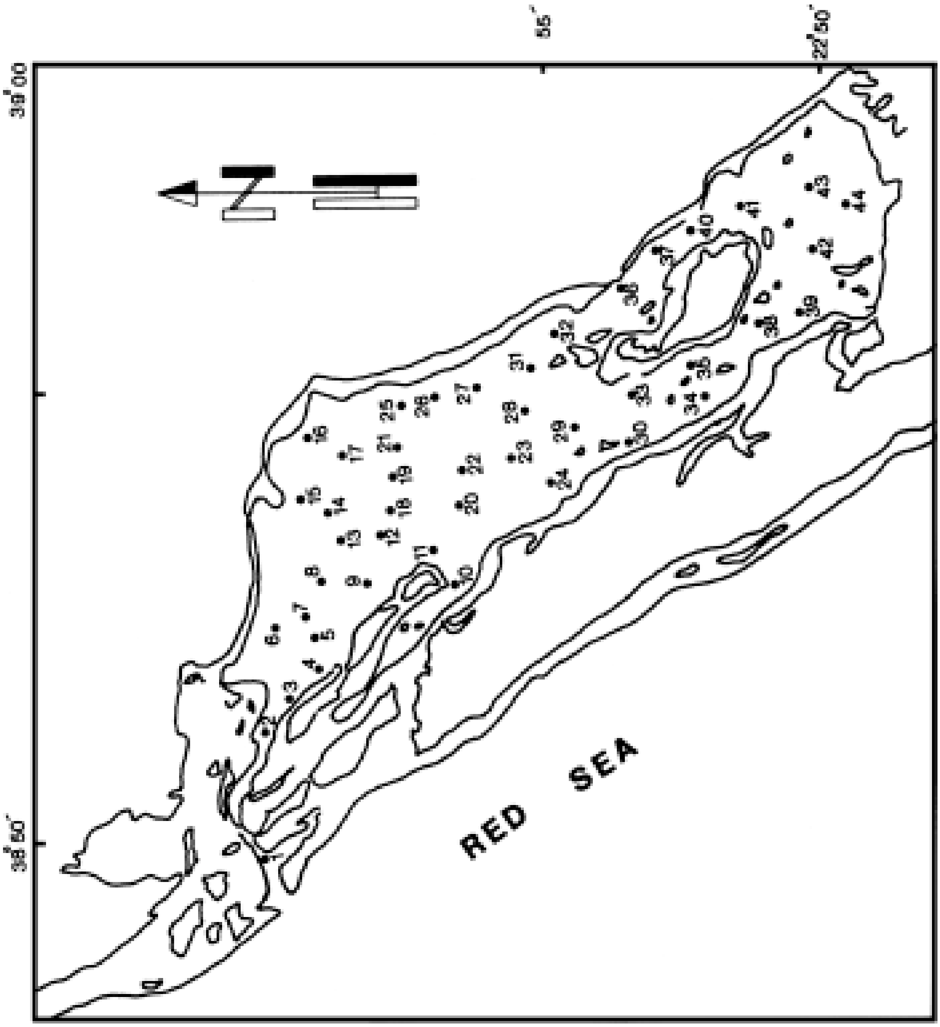

FIG. 1. Map showing the location of bottom sediments samples collected from Al-Kharrar Lagoon.

Al-Kharrar Lagoon is backed by a prominent escarpment which is nearly 1500 m high. The escarpment marks the split of the margins of both the Arabian and African shields and is the structural edge of the Red Sea rift area (Al-Sayari and Zotl 1978). Sharms of the Red Sea coast are thought to be channels formed by erosion in the Late Pleistocene and drowned by post-glacial sea level rise (Brown *et al.*, 1989). During the last glacial period sea level fell by at least 120 m (Braithwaite 1987) and the present day seasonal streams (Wadis) are often still connected to these earlier erosional features. While Rabaa (1980) interpreted these Sharms as erosional features formed in postwarm Wisconsin emergence. He also considered the coastal lagoons to be collapse structures resulting from the selective solution of Miocene evaporite beds underlying the younger succession.

The area of study is characterized by hot humid conditions with variable wind speed regime. The oceanic waves generally break at Al-Kassara reefal edge and then quietly enter the lagoon.

Numerous and different studies have been carried out on the beach zone of the western coast of Saudi Arabia to the north of Jeddah; (Behairy 1980, 1983; Behairy *et al.*, 1985; Durgaprasada Rao and Behairy1984, 1986; Gheit and About Ouf 1994). Unfortunately none of these researches has dealt with the bottom sediments of the lagoon itself. Behairy *et al.* (1991) studied only the evaporitic supratidal and intertidal sediments around the lagoon. The aim of this paper is to provide a background on the nature and composition of the bottom sediments of the lagoon and their conditions of sedimentation.

Samples and Methods

Forty-four bottom sediment samples have been collected from Al-Kharrar Lagoon with a grab sampler from depths of 5 to 10 m (Fig. 1). Each sample was air-dried and part of it was crushed into powder by agate mortar and used for bulk mineral analysis by X-ray diffraction using a Phillips X-ray diffractometer unit equipped with nickel-filtered Cu-k radiation source. The scanning range was between 24º and 60º 2 Θ to include peaks of detrital and carbonate minerals.

The textural composition of the sediments (gravel, sand and mud contents) have been determined using wet sieving analysis technique of Folk (1968). Carbonate content was determined by leaching the samples with cold diluted 10% hydrochloric acid. The weight of acid soluble material ($CaCO_3$) is expressed as a percentage of the total weight of sample. The heavy minerals in the very fine grained sand fraction (3-4 Phi) have been separated using tetrabromoethane (sp. gr. 2.85). Identification was made with the polorizing microscope and about 200 mineral grains of each fraction were counted in order to determine the relative frequency percentages. The clay fraction (< 2 μ) was separated from the mud fraction samples using the sedimentation technique (Folk 1968) to prepare oriented clay samples. Untreated, glycolated and heated samples at 550ºC were prepared before analysis (Brown 1972). The relative abundance of clay minerals was estimated semi-quantitatively using the peak height ratio method described by Brindley (1980).

Study of the carbonate minerals of the bottom sediments of the lagoon shed light on the environmental conditions under which they were deposited while the other sedimentological studies were used in the interpretation of paleogeography and provenance.

Results and Discussion

I – Texture

Bottom sediments samples were analyzed for gravel, sand, mud and carbonate contents. Data obtained are summarized in Table 1 and represented graphically in the ternary diagram of Folk (1968) shown in Fig. 2.

TABLE 1. Textural components and carbonate content of Al-Kharrar Lagoon bottom sediments.

Sample no.	Water depth (m)	Gravel %	Sand %	Mud %	Carbonate %
1	9.5	38	55	7	91.27
2	10	47	49	4	93.72
3	9	27	70	3	92.30
4	7.5	23	72	5	89.26
5	7.5	9	85	6	95.20
6	7.5	7	86	7	77.85
7	7	1	88	11	75.94
8	6.5	6	24	70	76.85
9	6.5	3	62	35	89.20
10	6.5	5	44	51	92.70
11	6.5	5	48	47	82.91
12	6	4	50	46	65.81
13	5	4	50	46	74.72
14	5	6	40	54	73.93
15	6	18	45	37	78.11
16	7	12	49	39	53.99
17	7	7	48	45	61.64
18	6	4	49	47	71.42
19	6.5	8	50	42	68.52
20	7	1	21	78	77.28
21	6.5	12	59	29	65.36
22	7	3	23	74	78.20
23	7	5	57	38	82.35
24	7	3	52	45	93.74
25	6	5	41	54	66.38
26	5	5	50	45	58.71

TABLE 1. Contd.

Sample no.	Water depth (m)	Gravel %	Sand %	Mud %	Carbonate %
27	5.5	12	59	29	61.24
28	6.5	15	2	83	75.31
29	6.5	6	29	65	90.50
30	6	5	36	59	91.73
31	6	8	22	70	42.47
32	6.5	1	8	91	38.68
33	6	5	22	73	87.51
34	6	3	21	76	84.85
35	5.5	4	18	78	53.87
36	6.5	0	2	98	29.73
37	6.5	0	7	93	32.21
38	6	0	3	97	41.12
39	5	0	9	91	46.36
40	7	0	2	98	27.29
41	7	2	27	71	30.11
42	7.5	0	2	98	32.17
43	6	0	1	99	28.57
44	6	0	3	97	20.97

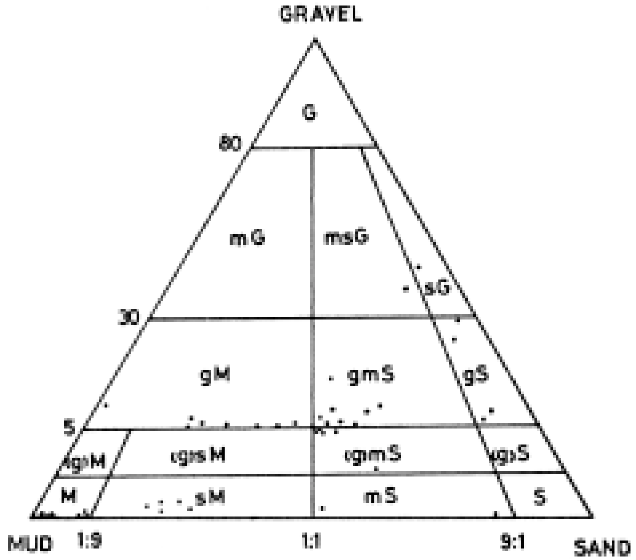

FIG. 2. Triangular diagram of gravel-sand-mud showing the textural composition of Al-Kharrar Lagoon bottom sediments (after Folk, 1968).

According to the different textural classes given by Folk (1968) it was found that most of the bottom sediments in Al-Kharrar lagoon have two distinct textural types namely; gravelly muddy sand prevailed in the northern part of the lagoon and sandy mud to mainly mud dominated in the southern border of the lagoon. Land derived materials have been entering the lagoon through active flash floods during the rainy periods. Carbonates, found in these sediments have values which vary between 20.97% and 95.20%. It was noticed that when carbonates decrease, sediments appear finer especially in the southern part of the lagoon.

II - Gross mineralogy

Identification of the bulk mineralogy in 17 samples is based on the tables of key lines in x-ray diffraction patterns for minerals after Pei-Yuan Chen (1977). The significant reflections used in the identification of mineral components found in Al-Kharrar Lagoon sediments are given in Table 2. Quantitative estimations of carbonate minerals are made following the technique given by Milliman (1974). Two representative x-ray diffraction patterns of samples 27 and 43 have been given in Fig. 3. The bulk mineralogy results obtained are summarized in Table 3 and represented graphically in Figs. 4 and 5.

TABLE 2. Reflections used for identification of total minerals present (after Pei-Yuan Chen 1977).

Minerals	2 Θ	d(A°)
Aragonite	26.2° - 27.2°	3.4 - 3.27
Calcite	29.37°	3.04
Mg-calcite	29.6° - 30.2°	2.99 - 2.95
Dolomite	30.94°	2.89
Quartz	26.3°	3.40
K-feldspar	26.9°	3.31
Plagioclase feldspar	27.8°	3.21
Halite	31.7° - 45.48°	2.82 - 1.99
Pyrite	56.33° - 33.05°	1.63 - 2.71

1 – Carbonate Minerals

Carbonate minerals are dominated by aragonite and high magnesian calcite with scarce calcite and dolomite. These results resemble those of sediments precipitated in the nearshore zone of the Red sea in the subtropical regions (Bahafzallah and El-Askary 1981, Durgaprasada Rao and Behairy 1984 and Behairy 1980). Dolomite found in the lagoon bottom sediments is considered to be of diagenetic origin. While calcite may have originated from erosion of the coastal reefal limestone terraces and other shall marine organisms. Halite occur in moderate amounts due to the evaporation and high colorisity of the lagoon water.

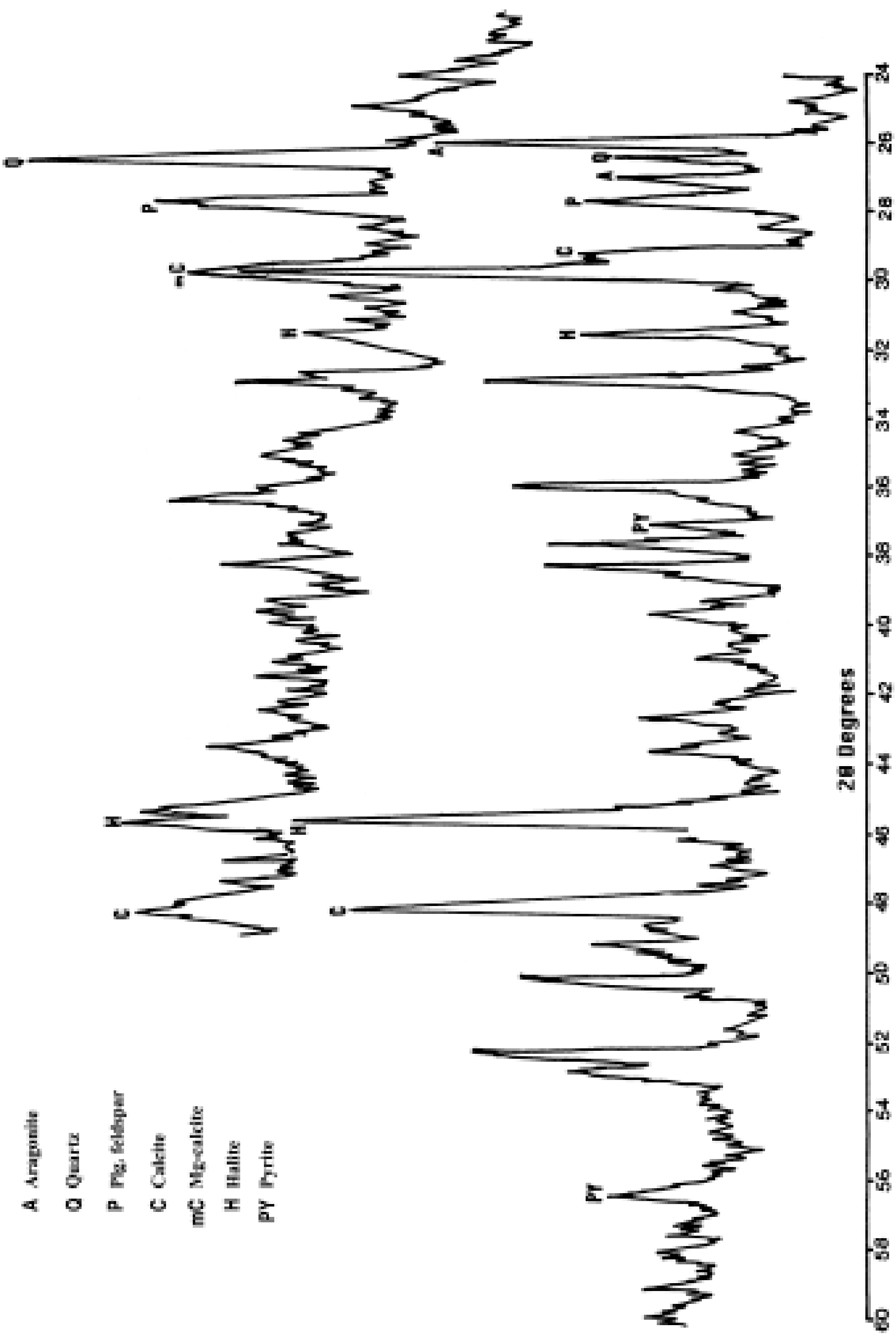

FIG. 3. Representative X-ray diffraction patterns of two bulk sediment samples of Al-Kharrar Lagoon.

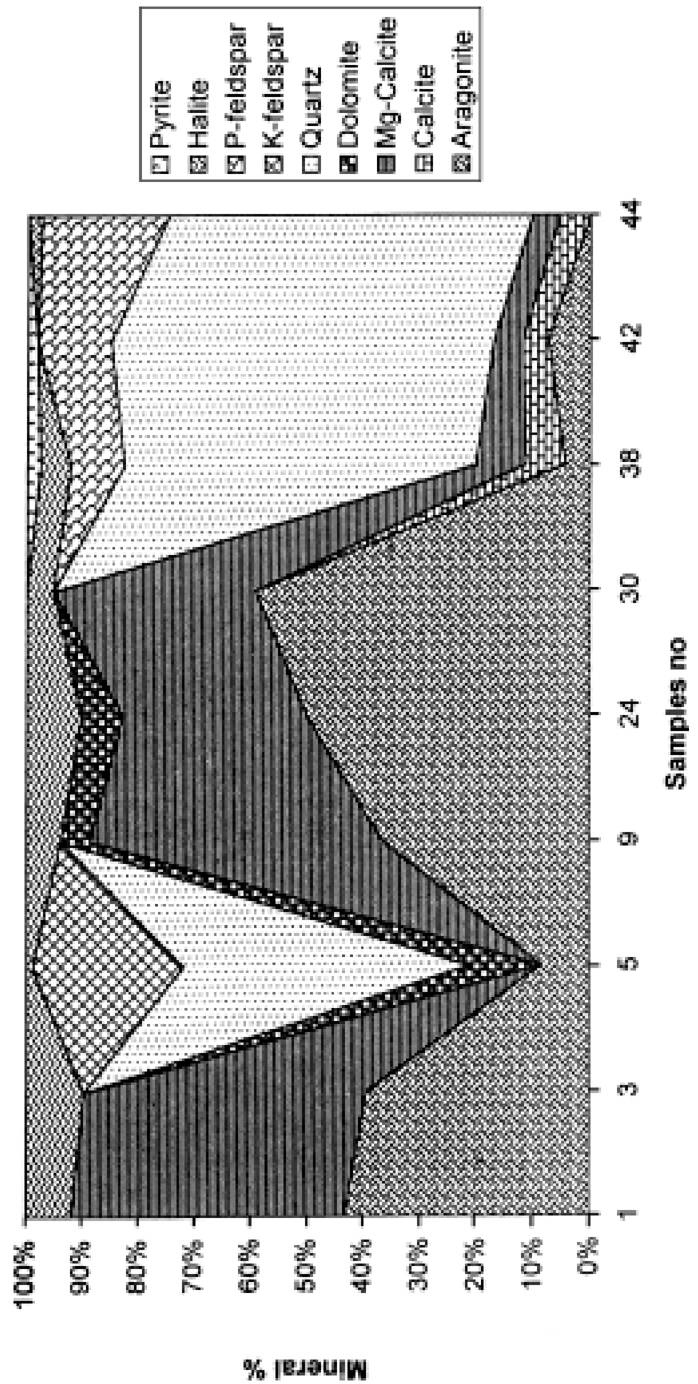

FIG. 4. Lateral variation in bulk mineral components along the western side of Al-Kharrar Lagoon.

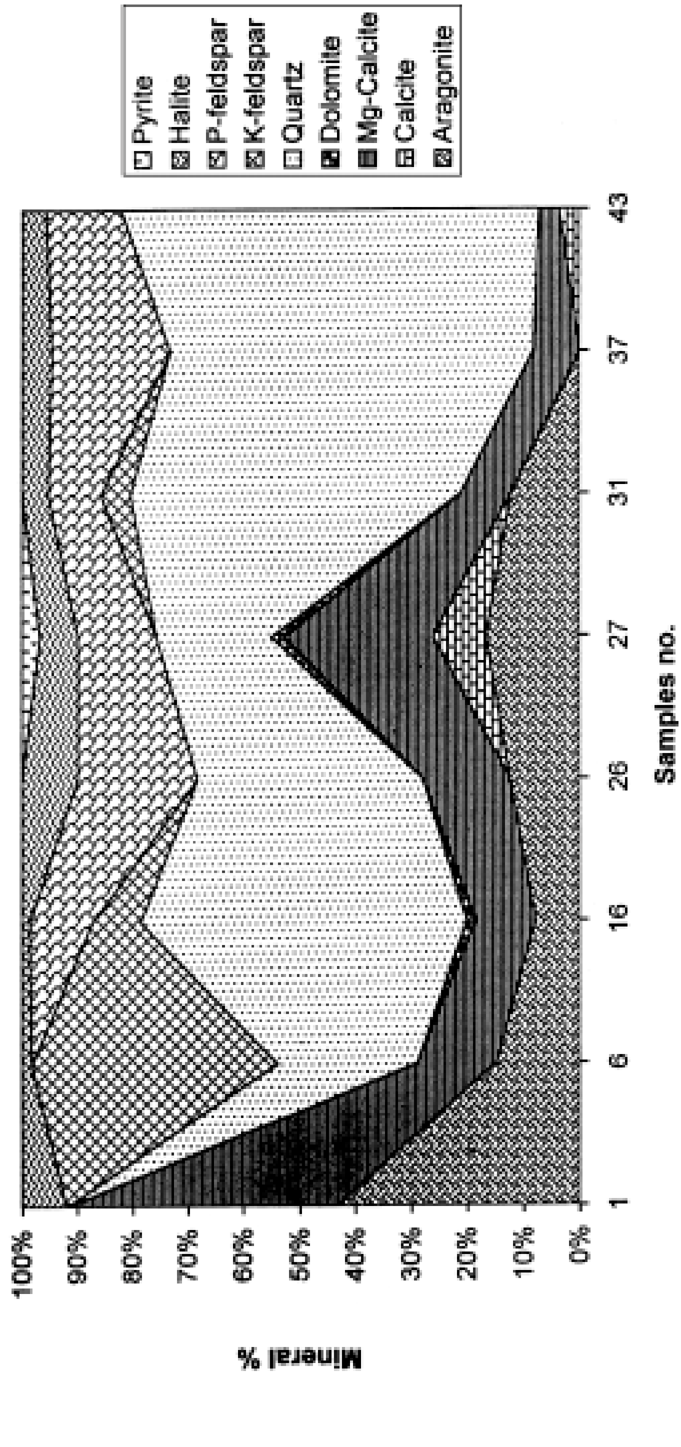

FIG. 5. Lateral variation in bulk mineral components along the eastern side of Al-Kharrar Lagoon.

2 – Detrital Minerals

The detrital minerals are dominated by quartz and plagioclase feldspar. Quartz values vary from 0.0% to 74.90%, while plagioclase feldspar occurs between 0.0% to 30.27% (Table 3).

Table 3. Gross mineralogy in the bottom sediments of Al-Kharrar Lagoon.

Station no.	Water depth (m)	Carbonate minerals				Detrital minerals			Evaporate minerals	Pyrite
		Aragonite	Calcite	Mg-calcite	Dolomite	Quartz	K-feldspar	P-feldspar	Halite	
1	9.5	43.26	0.00	48.63	0.00	0.00	0.00	0.00	8.11	0.00
3	9	39.44	0.00	50.29	0.00	0.00	0.00	0.00	10.36	0.00
5	7.5	8.56	0.00	0.00	12.64	50.68	26.94	0.00	1.17	0.00
6	7.5	14.82	0.00	14.10	0.00	24.95	44.28	0.00	1.85	0.00
9	6.5	36.70	0.00	51.94	5.16	0.00	0.00	0.00	6.20	0.00
10	6.5	29.10	0.00	25.60	0.00	21.70	0.00	18.70	4.90	0.00
14	5	65.00	0.00	6.56	1.54	15.87	0.00	9.87	1.16	0.00
16	7	7.90	0.00	10.53	1.54	58.52	8.78	11.34	1.39	0.00
24	7	50.24	0.00	32.62	7.35	0.00	0.00	0.00	9.79	0.00
26	5	12.39	0.00	15.49	0.00	40.38	0.00	21.60	10.14	0.00
27	5.5	16.59	9.53	26.82	2.12	20.59	0.00	14.12	6.94	3.29
30	6	59.24	0.00	35.92	0.00	0.00	0.00	0.00	4.84	0.00
31	6	12.15	0.00	8.90	0.00	59.33	5.42	9.41	4.79	0.00
34	6	35.61	5.90	22.40	0.00	0.00	0.00	30.27	5.82	0.00
37	6.5	0.00	0.00	8.38	0.00	66.22	0.00	21.87	5.53	0.00
38	6	4.49	6.93	8.85	0.00	62.45	0.00	9.41	5.47	2.40
39	5	11.72	0.00	16.26	0.00	67.90	0.00	0.00	4.12	0.00
42	7.5	7.59	4.41	5.10	0.00	68.05	0.00	13.10	0.00	1.75
43	6	0.00	3.68	3.53	0.00	74.90	0.00	13.62	4.27	0.00
44	6	0.00	5.40	4.88	0.00	64.50	0.00	22.66	2.56	0.00

The heavy minerals in the separated sand fraction occurred in very limited samples especially at the shallow eastern border of the lagoon. They are dominated by weathered minerals, opaques, augite, hornblende and epidote (Fig. 6). Zircon, chlorite and biotite occur in very minor amounts. They indicate derivation from metamorphic and igneous source rocks that suffered strong chemical weathering under humid climate. The clay minerals found in the lagoon and shown in Fig. 7 are dominated mainly by kaolinite and illite. However montmorillonite is recorded in very small amounts (Fig. 8). Kaolinite is

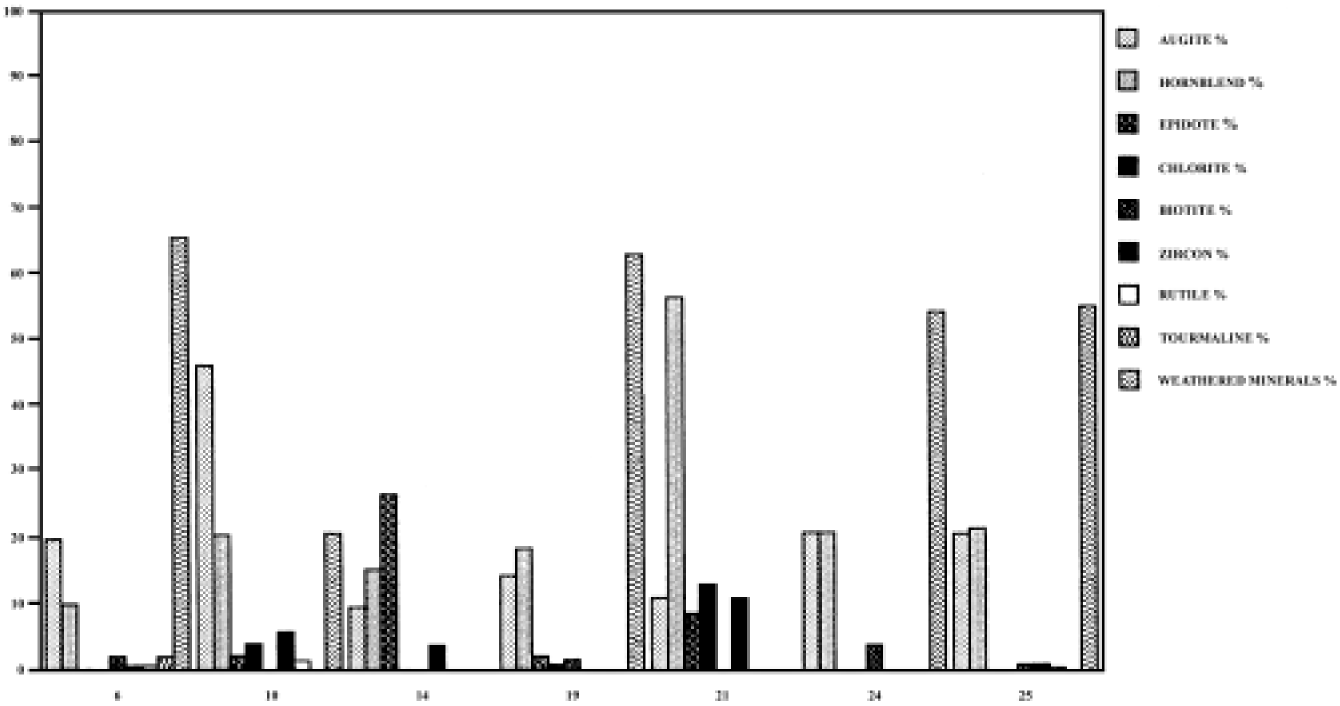

FIG. 6. Abundance of heavy minerals shown as bar graphs in the bottom sediments of Al-Kharrar Lagoon.

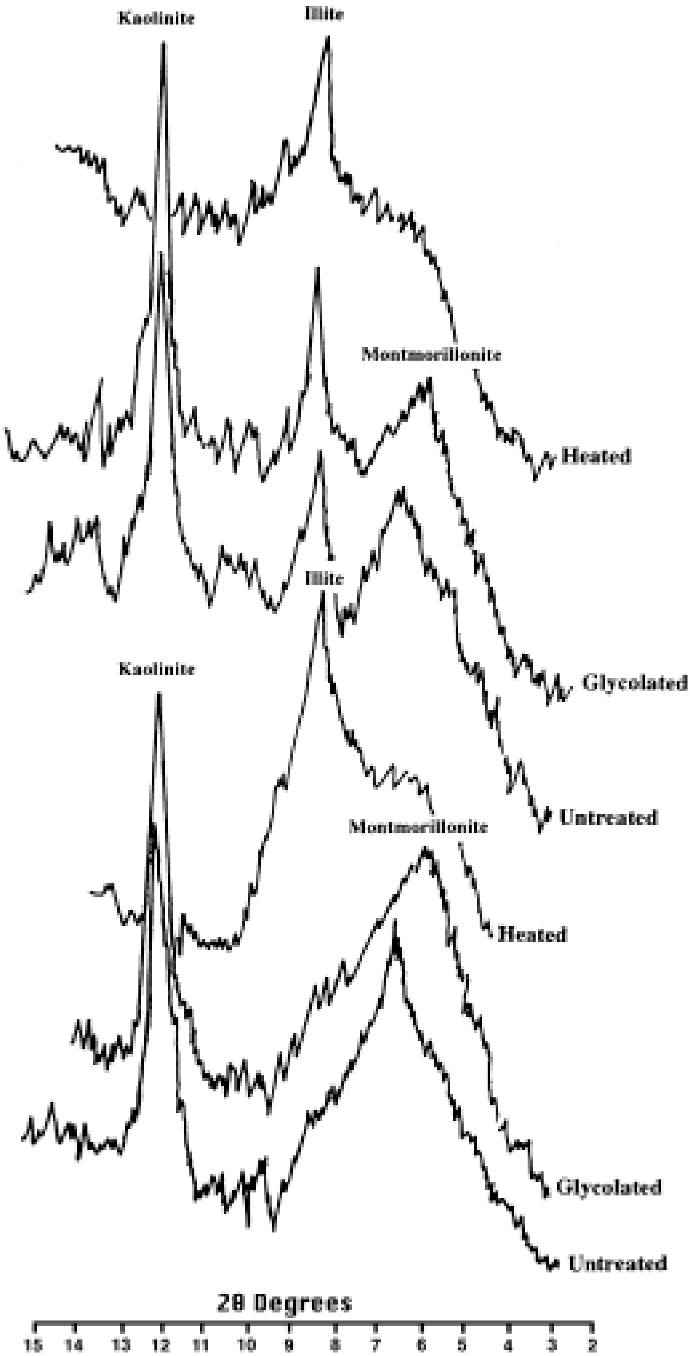

FIG. 7. X-ray diffraction patterns of clay fractions of two representative samples of Al-Kharrar Lagoon bottom sediments.

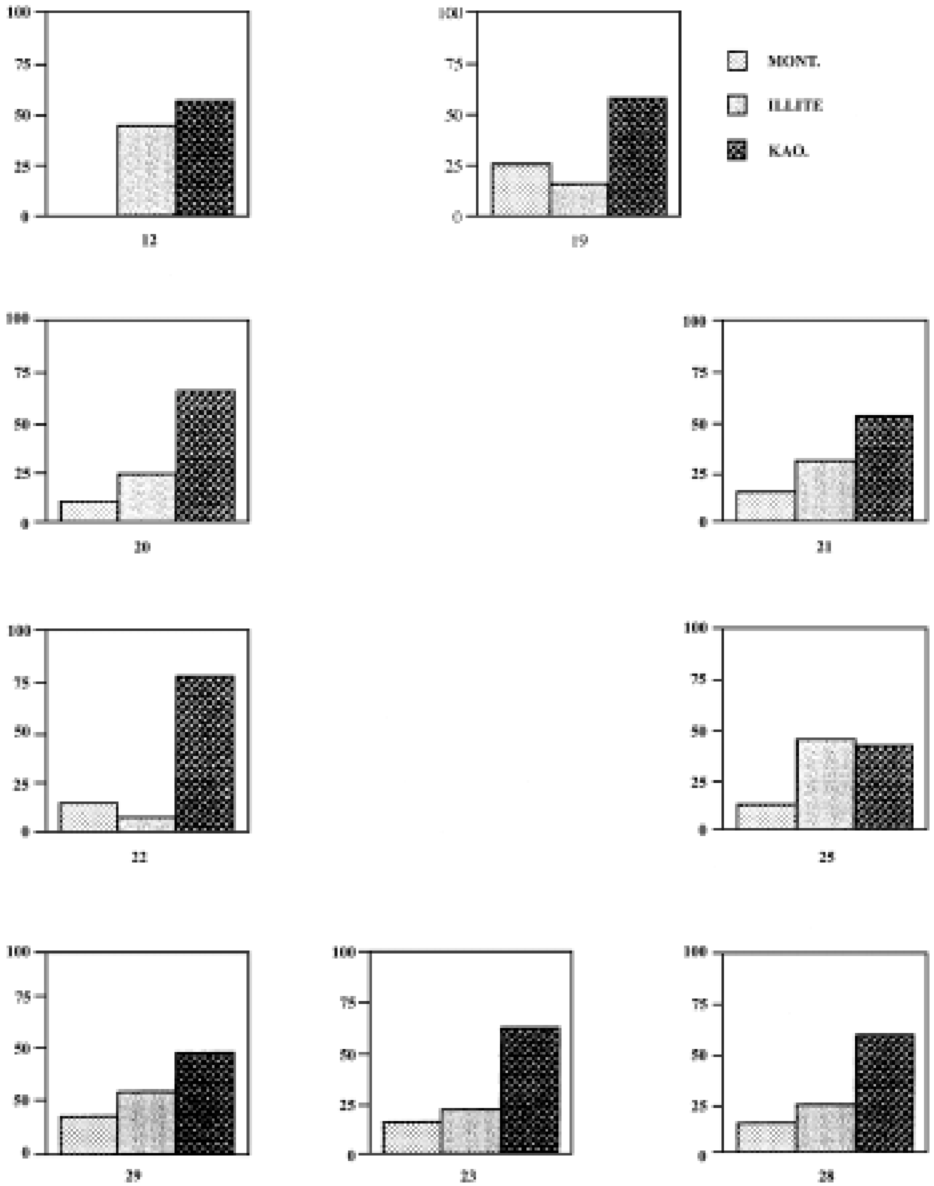

FIG. 8. Clay mineral abundance shown as bar graphs in the clay fraction of bottom sediments of Al-Kharrar Lagoon.

produced by strong weathering and soil formation under strong acid leaching conditions particularly in the subtropical and tropical regions (Millot, 1970). The association of illite with kaolinite is interesting. The strong tectonic activity associated the formation of the Red sea leads to erosion in up and down the continental source areas of high magnitude according to Singer (1984).

The recorded montmorillonite in poorly crystallized form and its association with plagioclase feldspar confirms weathering of basic to acidic igneous source rocks where Mg ions are liberated and the Mg-type montmorillonite formed. The heavy and clay minerals found in Al-Kharrar Lagoon sediments originated from Tertiary mountains bordering the eastern coastal plain of the Red Sea. The red soils commonly noticed in the eastern coastal plain bear evidence for the humid conditions.

The bulk mineral variations in the eastern and western sides of the lagoon are shown in Figs. 4 and 5 and can be summarized as follows:

1 – Occurrence of carbonate minerals increase in the western border of the lagoon.

2 – Carbonate minerals generally diminish towards the southern part of the lagoon.

3 – Detrital quartz and feldspars increase towards the southern end of the lagoon almost on the expense of carbonate minerals.

4 – Occurrence of K-feldspar is occasional; in the northern part of the lagoon.

5 – The behavior of halite is peculiar, it has an increasing trend towards the northern half of the lagoon.

A considerable difference between the eastern and western sides of the lagoon and also between the northern and southern ends are noticed. Detrital minerals are the predominant components in the eastern and southern borders, while carbonate minerals dominate in the northern and western borders of the lagoon. These abrupt changes in bulk mineralogy along the whole lagoon indicate the effect of land derived material from the tertiary mountains bordering the coastal plain, since the lagoon acts as a trap cutting the potential supply of material from both Red Sea and coastal region. Occasional flash floods across the ancient wadies connected with Al-Kharrar Lagoon on the southern border contribute the terrigenous sediments. However, aeolin transport plays a considerable role. According to the distribution of various sediment types and total mineralogical composition, it is possible to reconstruct the environmental conditions prevailing in the lagoon area. The lagoon sediments were deposited on a reefal limestone fracture basin with dominant subtropical to tropical climatic conditions. In general, the northern part of the lagoon is characterized by high energy conditions with dominant sandy texture composition. On the other hand, the lagoon is connected at it southern border with the ancient dry wadies which flash floods during rainy periods providing the lagoon by a high quantity of fine grained detrital materials and fresh water. The mixing of saline water with fresh water increases the deposition of suspended clay material through low energy conditions. The sedimentary cycle in the lagoon suggests a Red Sea marine and fresh water floods influences. Knowledge of the sediment texture and mineralogy can give insight into the environmental conditions under which lagoon sediments were deposited. The lagoon area was under the fluvial deposition during Late Pleistocene, when sea level dropped,while at Holocene, the lagoon became under the influence of the Red Sea transgression.

Conclusions

1 – The predominant type of sediment in Al-Kharrar Lagoon is gravelly muddy sand generally composed mainly of carbonate minerals in the northern part of the lagoon while becoming sandy mud and mud in the southern part with prevailing terrigenous sediments.

2 – Al-Kharrar Lagoon receives sea water and sediments from the northern tip connected with the open Red Sea through inlet and it is affected by the longshore currents with high aragonite and high Mg-calcite as shallow water carbonates. While the southern part of the lagoon received an ambiguous fresh water and finer clastic sediments through flash floods flowing in rainy periods in the lagoon till present. Thus, the sediment distribution in the lagoon reflects the hydrographic conditions therein.

3 – The precipitation of mud material in the lagoon depends on the mixing zones between saline and fresh water which seems to be high in the northern part of the lagoon were flacculation of mud material dominated.

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المفاهيم الترسيبية والظروف البيئية التي تم التعرف عليها من الرواسب القاعية لهور الخرار ، السهل الساحلي الشرقي للبحر الأحمر ، المملكة العربية السعودية – جـدة

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المستخلص . معظم هورات البحر الأحمر لم تحظ باهتمام كبير من ناحية دراستها من وجهة النظر الترسيبية ، يعتبر هور الخرار الواقع شمال مدينة جدة على السهل الساحلي الشرقي للبحر الأحمر هور شبه استوائي .

هذا البحث عبارة عن محاولة لدراسة التكوين النسيجي والمحتوى المعدني الكلي لرواسب قاع هور الخرار ، كما درست أيضًا ظروف الترسيب ، التغيرات السحنية والمصدر الصخري .

واستنادًا إلى نتائج الفحوصات الترسيبية والمعدنية تم التعرف على سحنتين رسوبيتين هما : سحنة كربونات ذات نسيج حبيبي خشن وهي سائدة في النصف الشمالي من الهور متأثرة بالتيارات الساحلية الطولية للبحر الأحمر من خلال مدخل الهور ، وسحنة قارية تبدو ذات نسيج حبيبي قاري ناعم وهي تميز نهاية الجزء الجنوبي من الهور معظم رواسبها نقلت عن طريق السيول المتدفقة من الأودية القديمة في فترات المواسم المطيرة .