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Sediment Distribution Pattern in the Al-Shoaiba Lagoon, Red Sea Coast of Saudi Arabia

H. A. Al-Washmi
Faculty of Marine Science, King Abdulaziz University
P.O. Box 80207, Jeddah 21589, Saudi Arabia

نموذج توزيع الرواسب فى هور الشعيبة

حمد بن عبد الله حمد الوشمي
كلية علوم البحار – جامعة الملك عبد العزيز
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هور الشعيبة يقع على الساحل الشرقى للبحر الأحمر وهو مغطي برمل ورمل طيني عضوي ذو مصدر حيواني. يعتبر الكوارتز المنقول بواسطة الرياح هو من أكثر المعادن شيوعاً للمكونات الفتاتية للرواسب المتواجدة على قاع الهور. وهناك مصدرين أساسيين ومصدر ثانوي آخر يمكن ملاحظتهما وهما، رواسب ذات مصادر حيوانية ورواسب ذات مصادر قادمة عن طريق الرياح. أما المصدر الثانوى الآخر فهو رواسب المتبخرات. التيارات المدية تلعب دور هاماً فى اعادة توزيع الرواسب عند فتحة الهور. الرواسب الناعمة عند فتحة الهور يعاد تعليقها فى عمود الماء عن طريق التيارات المدية وتنقل إلى داخل الهور بواسطة التيارات المدية على الرغم بأن الهور يعتبر ضحلاً الا أن التيارات التى تنشأ عن طريق الرياح والأمواج لا تؤثر فى عملية توزيع الرواسب داخل الهور ما عدا عند منطقة مدخل الهور. مياه البحر المالحة التى تدخل إلى الهور خلال المد العالي تتحرك بإتجاه شمال شرق مؤثرة على النسيج الرسوبي للهور. الاراجونيت والكلسايت العالى المغنسيوم هما المعدنيين السائدين يليهما معدن الكالسيت والدولوميت. اما الهاليت فأنه ينقل إلى الهور اثناء فترة تراجع الماء خلال المد المنخفض خاصة فى مناطق السبخة المحيطة بالهور. الاصداف المتكسرة والمرقطة بصبغات رصاصية إلى سوداء فيعتقد بأنها نشأت بسبب تواجدها فى بيئات مختزلة حيث ان تلك البيئات ساعدت فى نشوء معدن البيريت.

Key words: *aeolian quartz, Al-Shoaiba lagoon, authigenic pyrite, strong tidal currents.*

ABSTRACT

The Al-Shoaiba coastal lagoon located on the eastern side of the Red Sea is covered mostly with calcareous sand and muddy sand. Wind derived quartz is the most abundant detrital component in the surficial sediments of the lagoon. The lagoon is veneered with sediments of biogenic, aeolian and/or of evaporitic origin. Tidal, wind and wave generated currents play an important role in the redistribution of sediment at the mouth of the lagoon. The fine sediments at the mouth are resuspended by tidal currents and transported into the lagoon. Although the lagoon is very shallow the wind and wave generated currents have little impact on the redistribution of sediment except at the entrance. The tidal current moves in the northeastern direction resulting in the winnowing of the fine sediment, leaving the coarser material as lag deposits. Carbonate is abundant in the form of aragonite and high-Mg calcite with subordinate calcite and dolomite. Halite is transported to the lagoon during ebbing from the surrounding low-lying sabkhas. The presence of gray to blackly freckled shell fragments and the presence of authigenic pyrite may be taken as an evidence for reducing condition in some parts of the lagoon.

Introduction

The entire Red Sea coast of Saudi Arabia is indented with coastal inlets. These coastal inlets known as lagoons vary greatly in size. They are believed to be erosional features formed in postwarm Wisconsin emergence [1]. In the Red Sea the vigorously growing coral, the presence of fringing and barrier reefs play a very vital role in the very high production of reefal sediments and carbonates. A number of studies have been carried out on the lagoons and the associated sabkhas of the Red Sea, for example [2] and [3] studied the sediment of the Al-Kharrar lagoon whereas [4] and [5] investigated the Al-Kharrar sabkhas, and [6] worked on the sedimentological and mineralogical aspects of Sharm Obhur. The mineralogical composition of coastal sabkhas of the Red Sea and aeolian material in the coastal areas north of Jeddah have been researched in [7,8]. The nature and composition of shore-zone deposits between Jeddah and Yanbu have been investigated in [9] whereas, only a limited number of studies but none on the sediment concerning the Al-Shoaiba coastal lagoon have been conducted [10]. The objective of this paper is to study the sediments of Al-Shoaiba lagoon and their environment of deposition.

Materials and Methods

Field Description

The Al-Shoaiba lagoon is located approximately 100 km south of Jeddah city on the eastern coast of the Red Sea (Figure 1). The lagoon is connected to the Red Sea through a narrow channel with a maximum depth of 6 meters. Tidal, wind and wave generated currents are amongst the most important factors affecting the distribution of sediments at the mouth of the lagoon, where the water depth is shallow. The southeastern fringes of the Al-Shoaiba lagoon are bounded by sabkhas and mangrove stands. Most of the lagoon area is low-lying except at the southern end of the lagoon, which is relatively elevated. The lagoon is not connected to any wadis (seasonal streams) and no fluvial input is observed in the lagoonal area. Most of the sediments are indigenous carbonates with admixtures of aeolian quartz and other terrigenous materials including feldspars in small amounts.

The rainfall over the Red Sea and its coasts is extremely low; the rain is mostly in the form of showers of short spells often associated with thunderstorms and occasionally with dust storms. The scarcity of rainfall over the Red Sea area results in the excess of evaporation as well as high salinity with minimal seasonal variation. Most of the Red Sea area is subjected to the influence of regular and seasonally reversible winds.The northern part of the Red Sea is dominated by northwesterly wind, with speeds between 7-12 km/hr [9,11]. However, the southern half is subjected to seasonal reversible winds. From April to September the winds blow from the NNW but from October to March the winds are SSE. Tidal range is very low (20 30 cm) but the water during high tide inundates the adjoining sabkhas. The prevailing north and northwesterly winds influence the movement of lagoon water to the adjacent sabkhas, especially during storms, whereas, the low tidal range affects the sabkhas only as a thin sheet of water.

Experimental

A total of 53 sediment samples used in this study were collected on three different cruises (Figure 2). The surficial sediments were recovered using a Petersen grab sampler on board *RB Muntasir*. Position fixing was carried out by GPS-Magellan (Global Positioning System). Air-dried sediment samples were subjected to particle size analysis on ≥ 63 µm and mud fractions using standard sieving, according to the method adopted by Folk [12]. Calcium carbonate in sediments was determined using a calcimeter. Bulk mineralogical identification was carried out using a Phillips X-ray diffractometer incorporating a PW 1130 generator, a PW 1050 Goniometer unit with a PW 1965 detector and PM8220 chart recorder. Instrumental settings employed included nickel-filtered Cu-ka radiation 35KV; 25mA; with a scanning speed of $1^\circ\ 2\theta$/min and with an angle range of 2°- $40^\circ 2\theta$. Semi-quantitative estimation of the bulk minerals was made by the method of Bush [13]. Composition of sand fractions was studied under a binocular microscope.

Results

1. Grain size

The results of sieving analysis are given in Table 1 and illustrated in Figures 3 and 4. The sediment ranges in size between gravel and mud. Sand is the dominant size fraction and ranges between 20 % (station 42) and 99% (station 52) and averaging 78 %. Mud fraction ranges between 0 % (stations 45, 52 and 53) and 79 % (station 42) averaging 18 %. Gravel size fraction ranges between 0 % (station 35, 37, 39, 40, 41, 46 and 48) averaging 3 %.

2. Calcium Carbonate

Calcium carbonate ranges between 43 % (station 28) and 89 % (station 1), averaging about 74 %. The highest value of calcium carbonate is present at the entrance and at one of the mangrove clusters, whereas, the lowest values are associated with the other two clusters where calcium carbonate ranges between 40 and 60%. However, most of the lagoon is veneered with carbonates ranging between 60 and 80% (Figure 5).

3. Mineralogy

Bulk mineralogy was performed on 18 representative samples and identified according to the procedures adopted by Pei-Yuan Chen [14]. Semi-quantative estimations of carbonate minerals were made after Milliman [15]. X-ray data indicate that carbonate minerals are the major component in the lagoonal sediments (Table 2 and Figures 6a,b).

4. Composition of Sand Fraction

Sand fractions are dominated by shells, shell debris, and quartz. Biogenic material constitutes more than 95 % in the lagoon with subordinate detrital material. Microscopic examination showed that the bulk of the detrital materials are aeolian quartz, with subordinate feldspars, and occasionally dolomite. Aeolian quartz are iron-stained and owe their source to the adjoining sand dunes.

Discussion

The Al-Shoaiba lagoon is veneered with a wide range of sediment texture ranging from gravel to mud. This wide range is caused by the varying energy levels in different environments of deposition within the lagoon. The tidal currents at the entrance of the lagoon are generally affected by the force and direction of wind. They may attain a maximum velocity of up to 80 cm/sec at times. This is clearly reflected in the sediment texture at the entrance where a tongue of gravel-rich muddy sand is observed, running in a northerly direction following the path of the tidal current. Relatively finer sediments resuspended by tidal, wind and wave generated currents at the entrance, are transported inside the lagoon and deposited in quiescent environment (Figure 3). The northwestern area of the lagoon is relatively calm where muddy sand dominates. Along the southwestern fringes of the lagoon medium sand is dominant because of the influence of wind generated waves and shallow water depth that does not allow the fine material to settle down. However, gravelly sand is found to be present in the northwestern area adjacent to one of the mangrove clusters where finer materials are not trapped by the roots of the mangrove trees as observed in other areas where the roots play a vital role in trapping fine sediment [16]. The tidal generated current resuspends the finer material at the mangrove stand. The resuspended materials are then transported to relatively deeper water (5-6 meters) by northwesterly wind generated currents and settle out of suspension in calmer conditions. This is also confirmed by the presence of sandy mud texture in the vicinity of this particular (northwestern) mangrove stand (Figure 3). In general sand dominates at shallow depths in the north and southwestern fringes of the lagoon. The coarse texture (sand) results from the to and fro movement of water in the beach like environment. Mud dominates the relatively deeper water where the effect of water movement is minimal (Figure 4).

Since there is no river flowing into the lagoon and scarce rainfall, the lagoon receives very little or no terrigenous material through wadis (seasonal streams). The surrounding sand dunes are the main provenance for the detrital sand in the lagoon. This sand is transported by the prevailing north-westerly wind. Carbonate sediments at the mouth of the lagoon are mainly detrital in origin. They are formed due to mechanical weathering of coral reef, mollucs and carbonate rocks within the lagoon. The mechanical weathering is caused by strong tidal currents and wave action at the entrance of the lagoonal. Similar findings have been reported in the Al-Kharrar coastal Lagoon (Rasul, et al., 2002).

The high percentage of carbonate is the result of strong tidal currents that removes the fine sediment leaving the coarse carbonate material as lag deposits particularly at the mouth of the lagoon. The source of the carbonate is mostly from the biogenic components of the Red Sea. Broken shell fragments contribute significantly to the carbonate content of the Al-Shoaiba lagoon.

Carbonate mineral aragonite and detrital mineral quartz are the most abundant minerals followed by high Mg-calcite and feldspars. Carbonate minerals calcite and dolomite, evaporite mineral halite and minor amount of pyrite are also present. The dominance of aragonite and high Mg-calcite and scarce calcite and dolomite is diagnostic of the Red Sea coastal sediments located in the subtropical region [17,18]. It is known from previous work that primary aragonite is produced from coral, biogenic fragments e.g. *Halmimeda sp.*, and inorganic carbonate precipitates whereas, Mg-calcite is produced from reefal sediments, coralline algae and mollucs [19,20]. Dolomite could possibly be derived diagenetically through the interaction between previously precipitated calcium carbonates and concentrated marine brines rich in magnesium [21], whereas calcite is contributed to the lagoon by the erosion of reefal limestone exposure especially at the entrance of the lagoon where limestone terraces are present, and by marine organism [2].

The presence of halite in the sediment is the result of high evaporation and the hypersaline water where salinity reaches as high as 52 ‰. The southeastern end of the lagoon extends into a flat coastal plain that is slightly inundated by the water during high tide. The air temperature as high as 50° C in the sabkha areas thus help in the rapid evaporation of the water and in turn initiating the precipitation of evaporite minerals for e.g. halite and gypsum. Thin crusts and sand-sized halite crystals also result from the evaporation of saline water in the sabkha areas especially in the south and eastern side of the lagoon. Halite found in shallow water in the eastern side (station 28, 30,31 and 32) and western side (station 49, 50, 51 and 52) of the Al-Shoaiba lagoon is believed to be transported from the sabkha area during ebbing (low tide). The hypersaline lagoon with very little water contribution by means of rainfall fails to dilute the lagoon water. This condition therefore enhances the formation and preservation of halite in the shallow water of the lagoon and in the adjoining sabkha areas. Crystals of halite and occasional gypsum are found to be abundant in the low-lying sabkhas particularly in the south-southeastern areas.

Some calcareous materials are found to be stained black (station 42, 46 and 47) and on analysis they were found to contain pyrite (Table 2). These stations have either muddy sand or sandy mud texture and are relatively deeper stations with minimal effect of current. Staining by pyrite is regarded as the end product of anaerobic bacterial activity. Once the sediment is buried under the pile of sediment a reducing environment may develop due to the consumption of oxygen and organic matter by the bacteria. Therefore the presence of pyrite could be the result of a reducing environment in the areas where calcareous materials are stained black. Similar staining of calcareous is found to be present in the Indus continental shelf [22], the Arabian Gulf [23], the Bahamas [24], and coastal sabkhas of the Red Sea coast [25].

Sand dunes in desert regions of the Middle East are important contributors of pitted quartz to the marine environment [3]. The quartz are mostly aeolian, transported to the lagoon by the dominant northwesterly wind. Occasional dust storm, strong winds and mostly dry conditions prevalent in the study area helps in the uplifting of fine quartz and its transportation to the lagoon. Dune sands along the fringes of the Al-Shoaiba lagoon are rich in iron-stained quartz and a major contributor to the surficial sediments of the lagoon.

Conclusion

The grain size data indicate that physical processes play a minor role in most of the study area except at the entrance where tidal current seemed to play a significant role in the redistribution of sediment; the effect of which is observed in the coarser sediment texture. The strong tidal current is responsible for the sediment transport in and out of the inlet. In general, sediments are calcareous rich resulting from the break down of coral reefs, coralline algae, molluscan shells, forams, sponges and bryzoans. The distribution of iron-stained quartz is controlled by the atmospheric dust brought in by the shamal (wind) to the depositional environment. The low-lying sabkhas contribute halite to the lagoon during ebbing, only at the periphery and in shallow water, fringing the lagoon. The presence of pyrite at some stations in relatively deeper and calmer conditions is due to the reducing environment.

Table 1: Sediment type and carbonate content in the surficial sediments of the Al-Shoaiba coastal lagoon

St. #	Gravel (%)	Sand (%)	Mud (%)	Textural Class	$CaCO_3$ (%)
1	12	87	1	gravelly sand	89
2	3	96	1	sand	82
3	1	98	1	sand	81
4	12	87	1	gravelly sand	87
5	1	98	1	sand	82
6	1	98	1	sand	84
7	7	81	12	gravelly muddy sand	84
8	9	81	10	gravelly muddy sand	81
9	3	96	1	sand	81
10	1	98	1	sand	82
11	7	70	23	gravelly muddy sand	81
12	1	60	39	muddy sand	81
13	7	79	14	gravelly muddy sand	83
14	1	98	1	sand	84
15	1	98	1	sand	85
16	8	76	16	gravelly muddy sand	86
17	9	79	12	gravelly muddy sand	85
18	1	98	1	sand	81
19	7	80	13	gravelly muddy sand	85
20	2	94	3	sand	64
21	1	82	17	muddy sand	78
22	1	85	14	muddy sand	76
23	1	98	1	sand	58
24	2	72	26	muddy sand	64
25	1	76	23	muddy sand	44
26	1	74	25	muddy sand	65
27	1	78	21	muddy sand	64
28	1	60	39	muddy sand	43
29	2	64	34	muddy sand	69
30	1	98	1	sand	79
31	1	98	1	sand	78
32	2	97	1	sand	77
33	1	89	10	muddy sand	54
34	1	56	43	muddy sand	63
35	0	58	42	muddy sand	64
36	1	65	34	muddy sand	56
37	0	68	32	muddy sand	70
38	1	57	42	muddy sand	68
39	0	98	2	sand	58
40	0	62	38	muddy sand	58
41	0	65	35	muddy sand	69
42	1	20	79	sandy mud	68
43	1	21	78	sandy mud	73
44	24	75	1	gravelly sand	83
45	13	87	0	gravelly sand	84
46	0	33	67	sandy mud	67
47	8	91	1	gravelly sand	76
48	0	60	40	muddy sand	75
49	1	59	40	muddy sand	70
50	4	96	0	sand	76
51	1	87	12	muddy sand	73
52	1	99	0	sand	76
53	2	98	0	sand	76

Table 2: Mineralogy of the surficial sediments of the Al-Shoaiba coastal lagoon

Station	Aragonite (%)	High Mg-calcite (%)	Calcite (%)	Dolomite (%)	Quartz (%)	Feldspar (P) (K) (%)	Halite (%)	Pyrite (%)
11	42	38	1	0	7	12	0	0
19	44	37	4	0	8	7	0	0
20	37	0	42	0	18	3	0	0
23	20	41	13	0	6	20	0	0
27	22	34	14	2	19	9	0	0
28	20	33	14	0	21	9	3	0
29	24	32	12	2	22	5	0	3
30	14	11	21	0	44	8	2	0
31	11	7	14	6	44	10	8	0
32	18	11	16	1	42	9	3	0
41	44	33	0	0	19	0	0	4
42	42	32	2	0	20	0	0	4
45	34	18	0	0	40	7	0	1
46	22	24	0	2	33	13	0	6
49	28	18	2	0	39	11	2	0
50	47	34	7	1	36	13	7	0
51	40	29	4	0	19	6	2	0
52	39	33	16	0	9	3	1	0

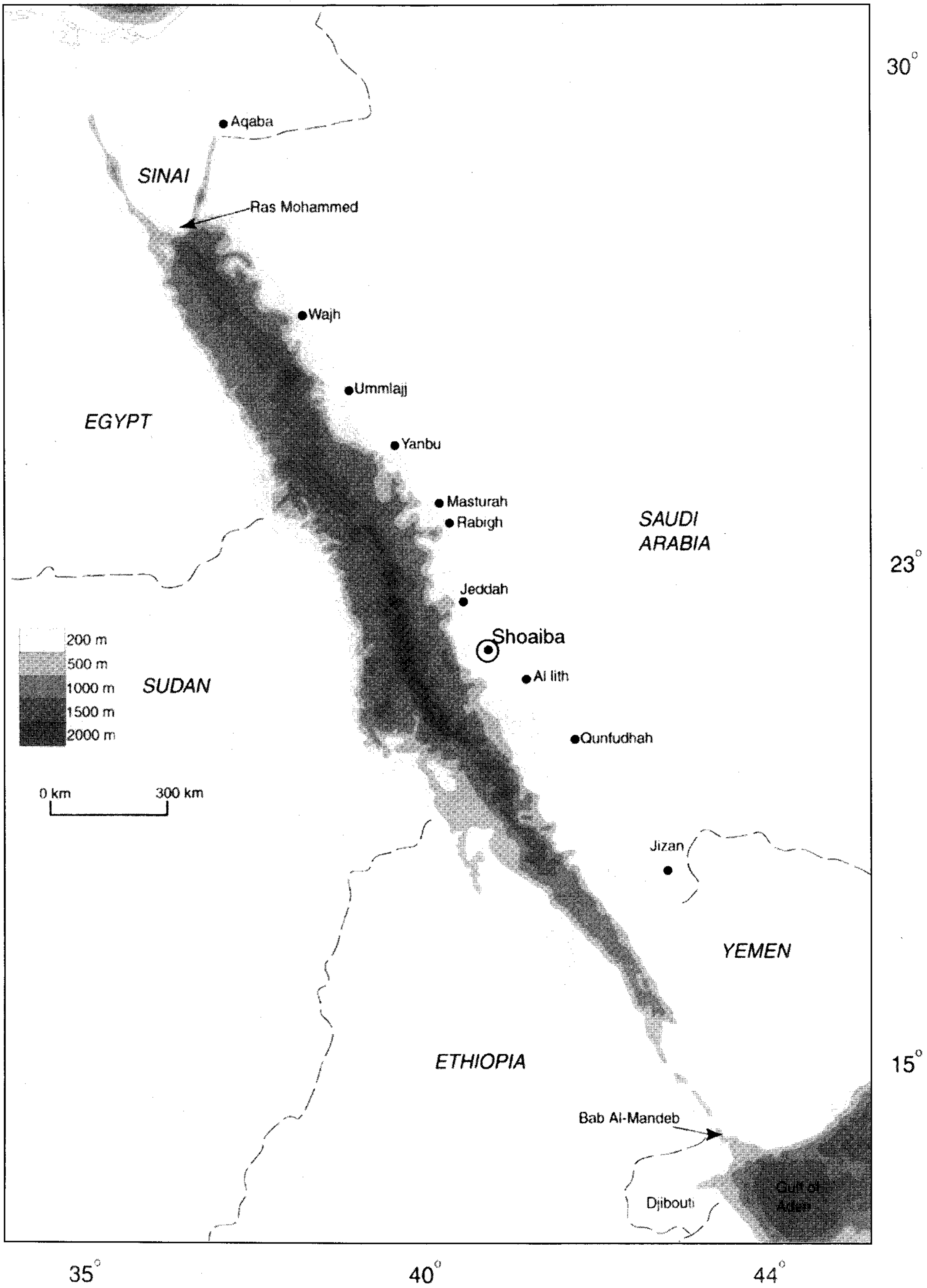

Figure 1: The location of Al-Shoaiba coastal lagoon southeastern Red Sea coast of Saudi Arabia.

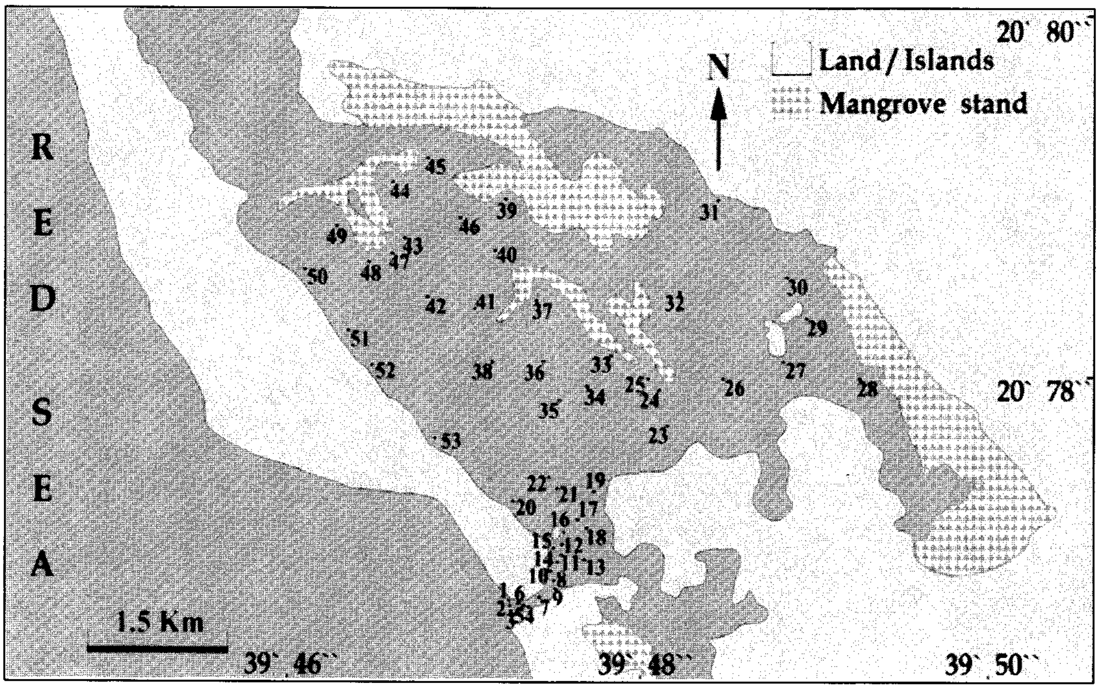

Figure 2: Map showing sampling sites in the Al-Shoaiba coastal lagoon, Red Sea coast of Saudi Arabia

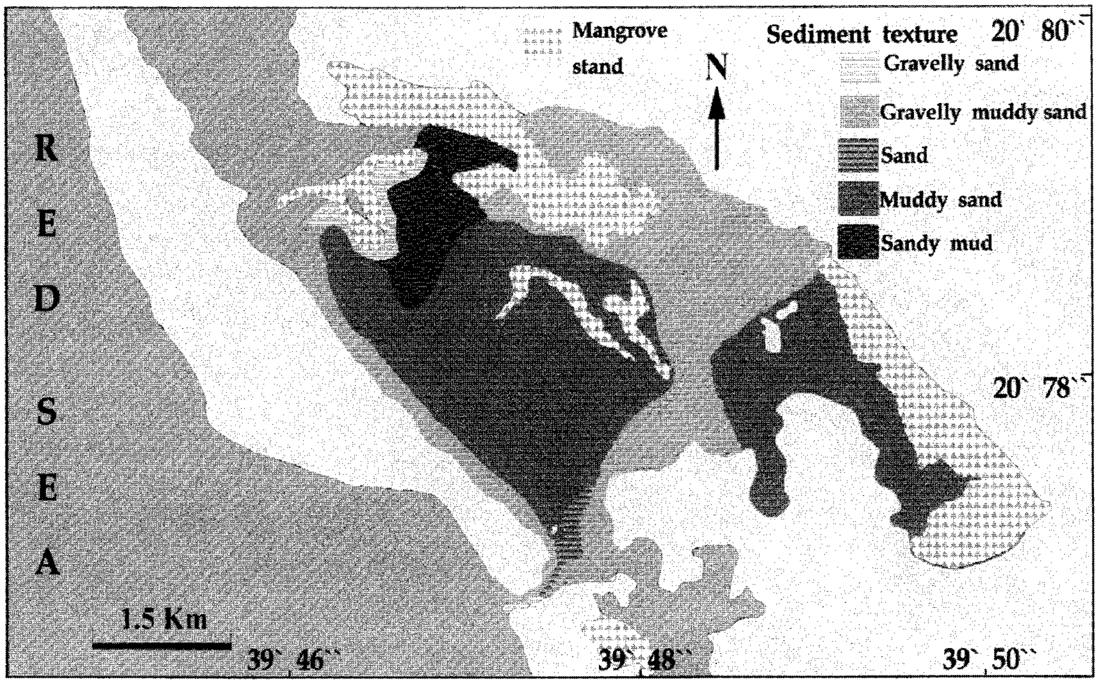

Figure 3: Sediment distribution map of the study area.

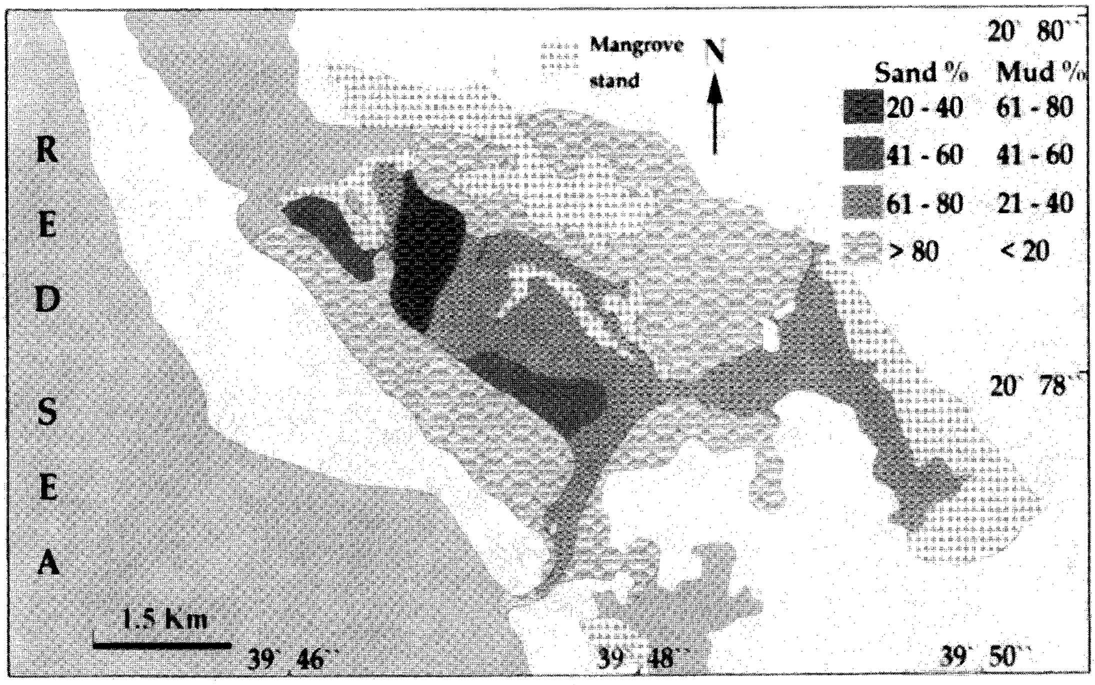

Figure 4: Distribution of sand and mud in the study area.

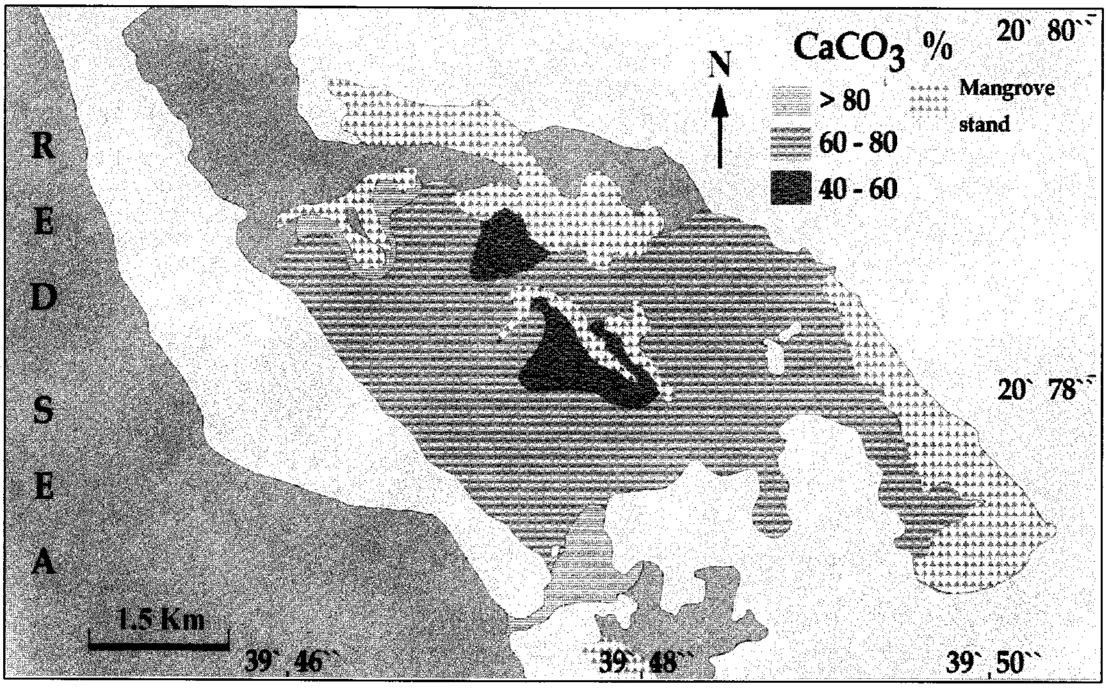

Figure 5: Carbonate content in the surficial sediments of the Al-Shoaiba lagoon.

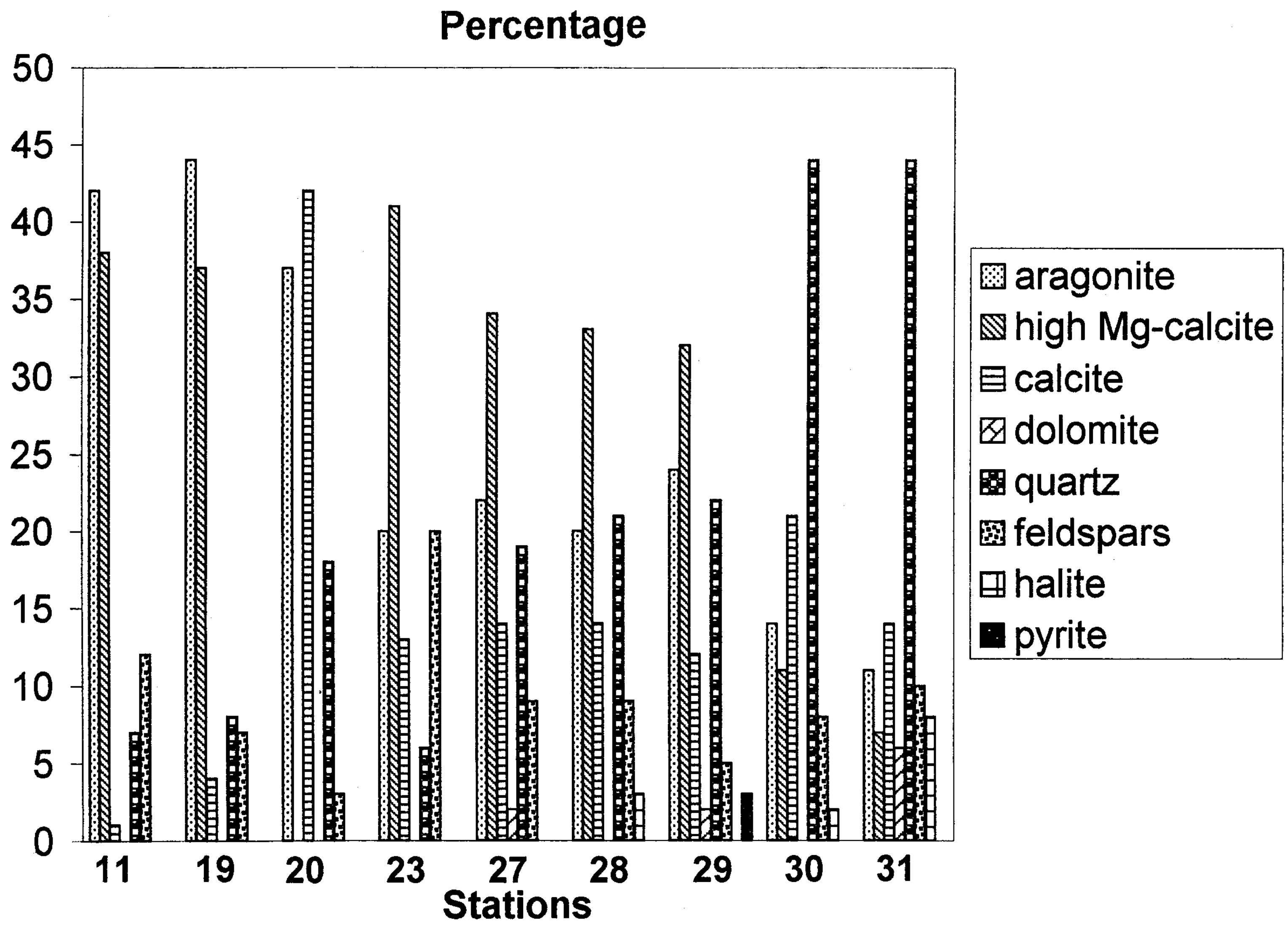

Figure 6a: Distribution of carbonate, detrital and evaporite minerals in the surficial sediments at some selected stations in the Al-Shoaiba lagoon.

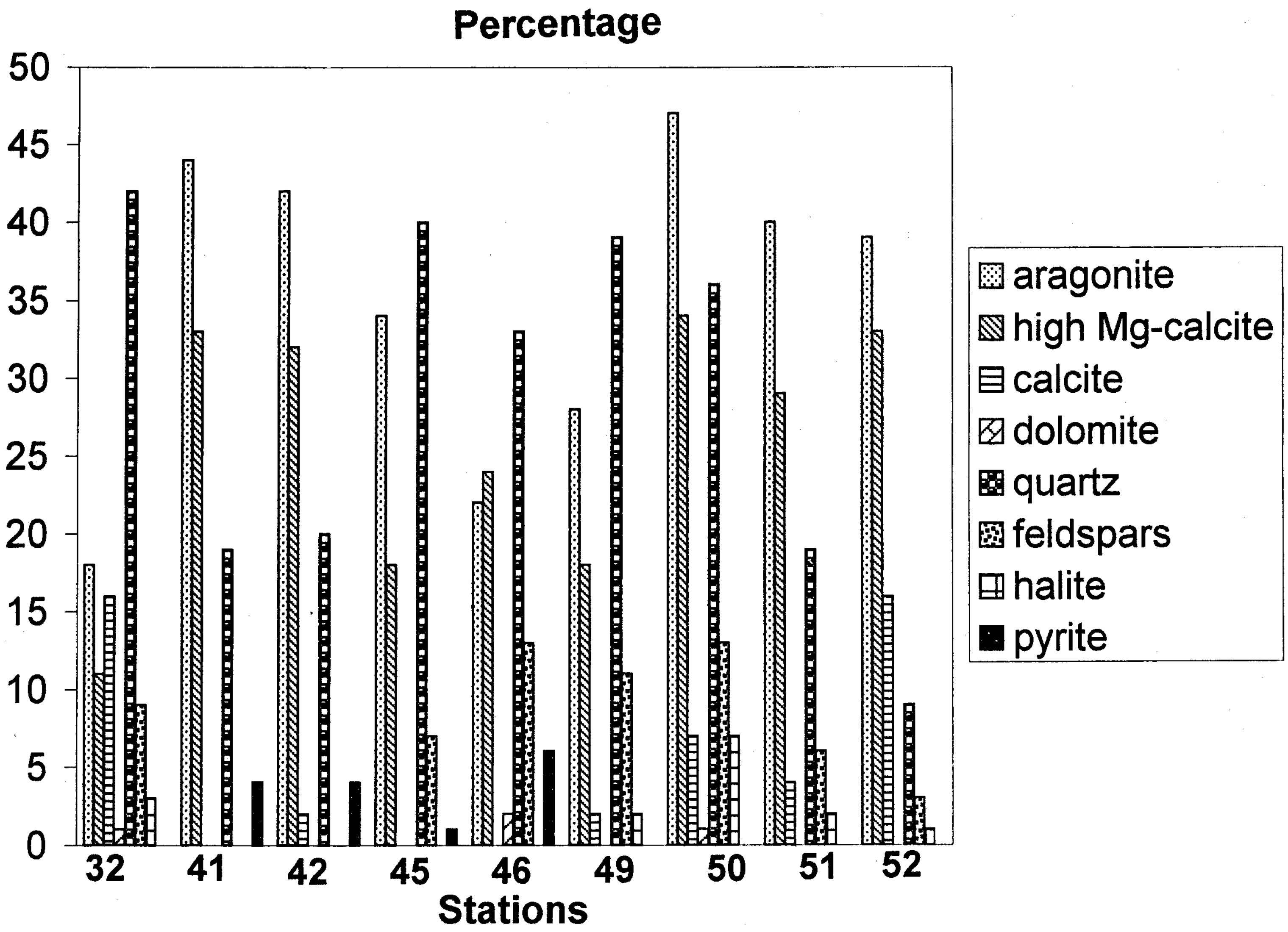

Figure 6b: Distribution of carbonate, detrital and evaporite minerals in the surficial sediments at some selected stations in the Al-Shoaiba lagoon.

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