

**THE RELATIONSHIP BETWEEN GRAIN SIZE AND CARBONATE
MINERALS IN REEFAL SEDIMENT OFF JEDDAH CITY, RED
SEA, SAUDI ARABIA**

BY

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ABSTRACT

The carbonate sediments off Jeddah City, Saudi Arabia are of biogenic origin and are contributed by coral debris, molluscan shells, coralline algae and foraminifera. The relationship between sediment grain size and its carbonate minerals is studied and discussed. The sediments were analyzed for mean grain size, calcium, magnesium, strontium, and their content of carbonate minerals. The study showed that there is a strong relation between mean grain size of the sediment and its carbonate minerals. Aragonite is strongly correlated with fine sediments. High-magnesian calcite is inversely correlated with both aragonite and fine sediments. Low-magnesian calcite showed no distinct distribution pattern. The aragonite fine sediments may be derived by inorganic/organic precipitation of lime mud. The high-magnesian calcite coarse sediments are contributed by algal debris and foraminifer shells. Low-magnesian calcite is detrital in origin; it is most probably derived from the Pleistocene sediments of the coastal plain.

INTRODUCTION

Although carbonate sedimentation along the Red Sea coast of Saudi Arabia has been examined by many workers (e.g. Behairy and Jaubert, 1983; Durgaprasada Rao and Behairy, 1984; Behairy, 1988; Geith and Abou Ouf, 1996; Rifaat, 1996), most studies concerned with carbonate mineral distributions in near shore environment have been devoted to the qualitative determination of carbonate minerals and their metal composition. On the other hand, Kennedy and Smith (1977) studied the relation of dolomite and calcite in sediments from two alpine lakes. They found out that dolomite decreased and calcite increased with decreasing grain size. The carbonate sediments of the alpine lakes are predominantly detrital (Kennedy and Smith, 1977). This study was undertaken to determine if the carbonate minerals are differentially distributed in sediments of a near shore fringing reef environment near Jeddah city, and how the occurrences of those minerals relate to the sediment grain size distribution.

SEDIMENTS AND SEDIMENTARY ENVIRONMENT OF THE STUDY AREA

The nearshore bottom sediments off the study area composed mainly of carbonate detritus of the adjacent corals together with coralline algae, molluscan shell fragments, foraminifers and others. 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 0.3m (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 to 5.6 mg/l (Behairy & Jaubert, 1983). The surface currents trend to the Northwest following a course parallel to the coast.

MATERIAL AND METHODS

The area of study lies north of Jeddah City at a distance of about 10 km (Fig. 1). Forty-six beach and bottom sediments samples, along a profile perpendicular to the coast, were collected using a grab sampler for bottom sediments and with a spoon for beach sediments. The location of sediment samples and the morphology of the fringing reef are shown in figure (2). The sediments, that are almost sand, were analysed for mean grain size using the method mentioned in Folk (1974). Representative subsamples were washed with deionized distilled water, air dried and ground in an agate mortar to pass the 0.063mm (4phi) mesh sieve. Representative subsamples were attacked with 1N HCl to dissolve the carbonate materials following the methods mentioned in Robinson (1980).

The metals (calcium, magnesium, and strontium) 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). The metals calcium, magnesium and strontium are determined to verify the quantitative x-ray mineralogical determination procedure.

The sediment samples were powdered and mounted on aluminium holders and analyzed on a Phillips X-Ray Diffractometer. Nickel filtered Cu radiation was used with settings at 30 MA, 40 KV and a chart speed of half degree per minute. The calcite peaks were checked by running the charts at a speed of quarter degree per minute. Quantitative estimations of the carbonate minerals were made using the method given in Milliman (1974). Mole percent of magnesium carbonate in the high magnesian calcite was measured from the standard curve of Goldsmith and Graf (1958)

STATISTICAL ANALYSIS

The results of mean grain size, chemical and mineralogical analyses sediments were processed statistically. The R-Mode Factor Analysis is applied to extract the factors controlling the relation of mean size and carbonate mineralogy in the sediments. The method depends on summarizing the information within the original data matrix to convert them into a more simple form that could be interpreted. The data have been standardized, and the

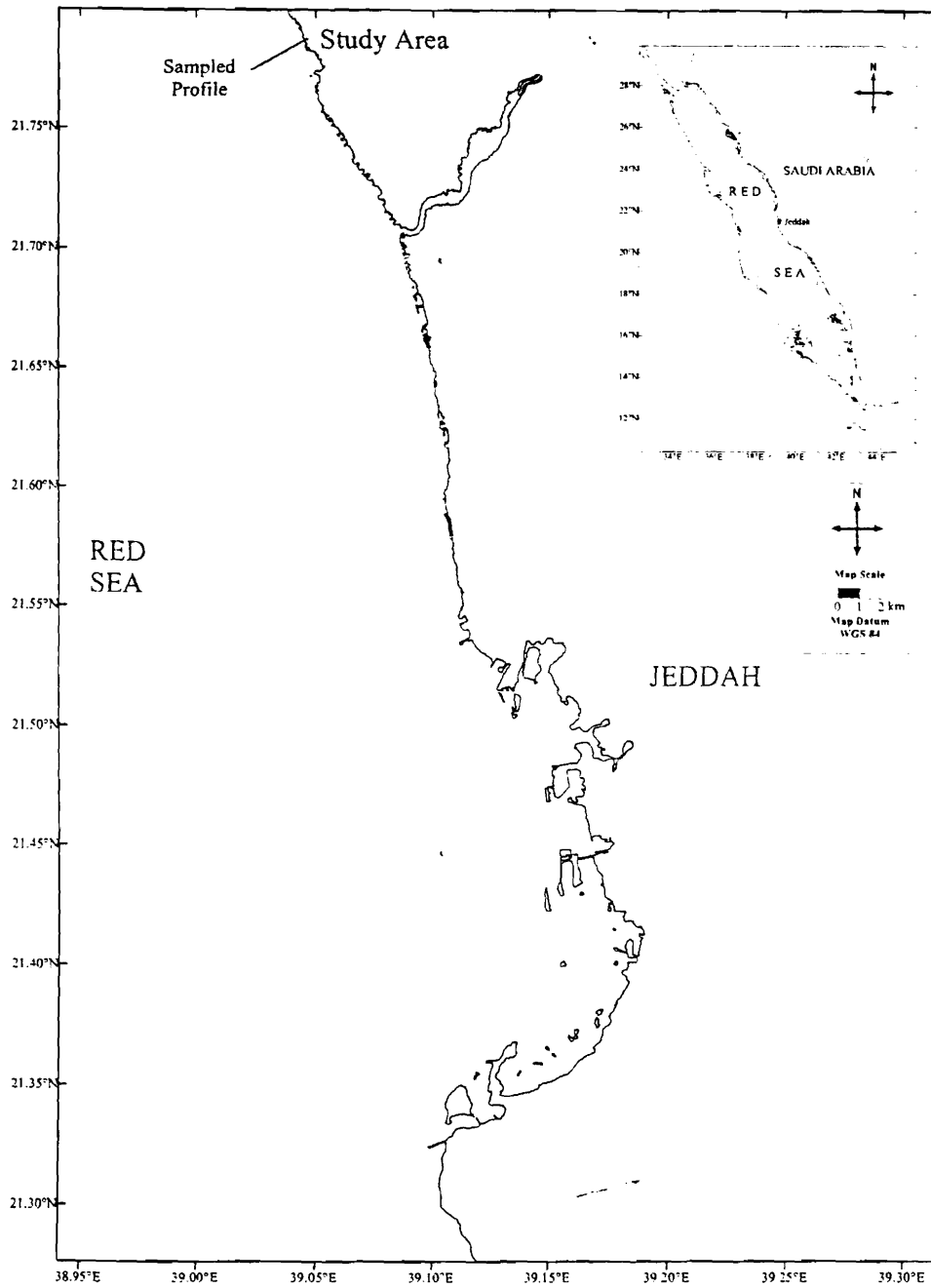


Figure (1) Area of study and location of the sampled profile.

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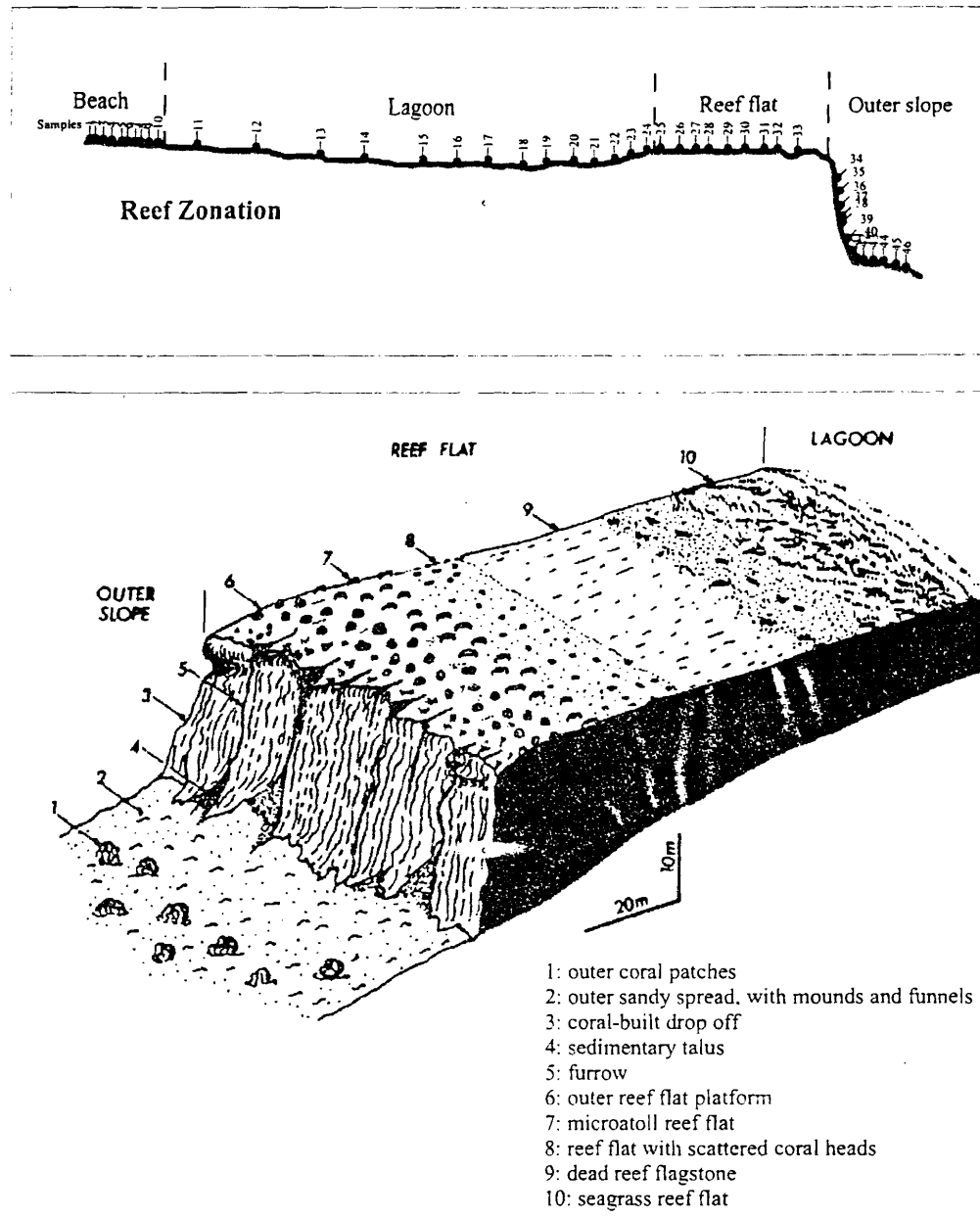


Figure (2) Upper: cross section and location of sediment samples.
 Lower: the fringing reef: morphology and zonation of the reef flat and outer slope off Jeddah (after Behairy and Jaubert, 1983).

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 (Davis, 1973).

RESULTS AND DISCUSSION

The mean grain size in the study area ranges between -1.87ϕ (granules) and 4.51ϕ (coarse silt). The sediments are mainly carbonate from biogenic origin and can be defined into two types in relation to the physiography of the reef system (Behairy and Jaubert, 1983). The barrier reef flats are dominated by coarse sands to granules, well sorted and symmetrically skewed. The outermost and inner reefs are fine to coarse sand, well to moderately sorted and symmetrically to positively skewed.

The X-ray mineralogical analysis revealed that the major carbonate minerals in the area of study are aragonite, high magnesian calcite and low magnesian calcite with traces of calcite, quartz and feldspar as also noted by Behairy (1988) and Durgaprasada Rao and Behairy (1984). In the carbonate sediments of the study area, aragonite ranges between 31% and 70%, high-magnesian calcite ranges between 20% and 70% and low-magnesian calcite ranges between 2% and 12%. Calcium ranges between 30.5% and 34.7%, magnesium ranges between 0.97% and 2.4% and strontium ranges between 0.35% and 0.62% (Table 1). The association of aragonite with strontium, high-magnesian calcite with magnesium and low-magnesian calcite with calcium indicates that the quantitative determination of the respective carbonate minerals is correct.

The statistical analysis of data showed that the grain size, chemical and mineralogical contents of sediments are controlled by two factors:

Factor 1

This factor accounts for about 56% of the total variance among variables. It represents the inverse relationship of (aragonite, mean size, strontium)-(high magnesian calcite, magnesium) associations and characterized by high positive loadings on aragonite, strontium, mean size and high negative loadings on magnesium and high magnesian calcite (Fig. 3, Table 2). The factor shows that

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Table (1): Mean grain size, X-Ray mineralogical and chemical composition of sediment samples.

Sample	Mz	Arag %	HMCa %	LMCa %	Ca %	Mg %	Sr %
1	-0.05	31	64	5	33.1	1.90	0.45
2	0.74	49	49	2	32.1	1.80	0.47
3	-1.87	35	63	2	30.5	2.40	0.35
4	-0.52	42	56	2	33.3	2.20	0.41
5	0.30	49	49	2	33.1	2.10	0.46
6	0.77	59	39	2	33.0	1.70	0.48
7	0.68	59	39	2	32.5	1.70	0.43
8	0.92	55	43	2	33.2	1.70	0.50
9	1.24	54	44	4	33.8	1.30	0.54
10	1.13	57	39	4	32.6	1.60	0.50
11	2.97	69	24	7	32.4	1.50	0.54
12	1.28	74	22	4	33.3	0.97	0.62
13	4.51	65	30	5	32.9	1.50	0.54
14	3.31	74	24	2	33.0	1.10	0.61
15	3.28	69	27	4	33.3	1.20	0.54
16	1.46	64	32	4	33.8	1.40	0.55
17	0.43	70	20	10	34.7	1.40	0.53
18	1.54	66	32	2	34.6	1.20	0.57
19	1.25	64	34	2	34.5	1.20	0.53
20	-0.01	54	42	4	33.8	1.50	0.47
21	1.91	54	44	2	33.7	1.70	0.50
22	-0.07	44	44	12	34.4	1.80	0.56
23	-0.52	44	70	4	34.6	1.90	0.45
24	0.85	45	52	3	32.5	1.70	0.48
25	0.55	47	51	2	32.1	1.80	0.47
26	0.32	49	49	2	33.6	1.70	0.48
27	-0.08	42	54	4	33.4	2.00	0.43
28	0.33	38	60	2	33.6	1.80	0.47
29	1.05	54	44	2	33.4	1.50	0.51
30	2.76	52	46	2	33.8	1.60	0.51
31	1.49	55	43	2	34.0	1.30	0.55
32	3.28	53	45	2	33.8	1.20	0.59
33	2.02	57	39	4	34.6	1.40	0.56
34	1.60	49	49	2	34.5	1.50	0.54
35	1.01	74	24	2	34.4	0.98	0.57
36	0.15	61	36	2	33.9	1.10	0.51
37	1.60	50	48	2	33.3	1.50	0.51
38	2.67	45	53	2	33.6	1.70	0.50
39	0.68	39	59	2	32.9	1.80	0.45
40	1.12	39	59	2	34.1	1.70	0.46
41	1.19	35	63	2	32.9	2.00	0.43
42	0.28	57	39	4	34.1	1.80	0.44
43	0.93	55	43	2	34.1	1.30	0.46
44	0.45	44	53	3	34.3	1.30	0.51
45	0.29	39	59	2	33.5	1.60	0.48
46	-1.53	44	49	7	33.7	1.40	0.51
Mean	1.04	53	44	3	33.5	1.58	0.50

Mz=Mean grain size LMCa %=Low magnesian calcite Sr %=Strontium
 Arag %=Aragonite Ca %=Calcium HMCa %=High magnesian calcite
 Mg %=Magnesium

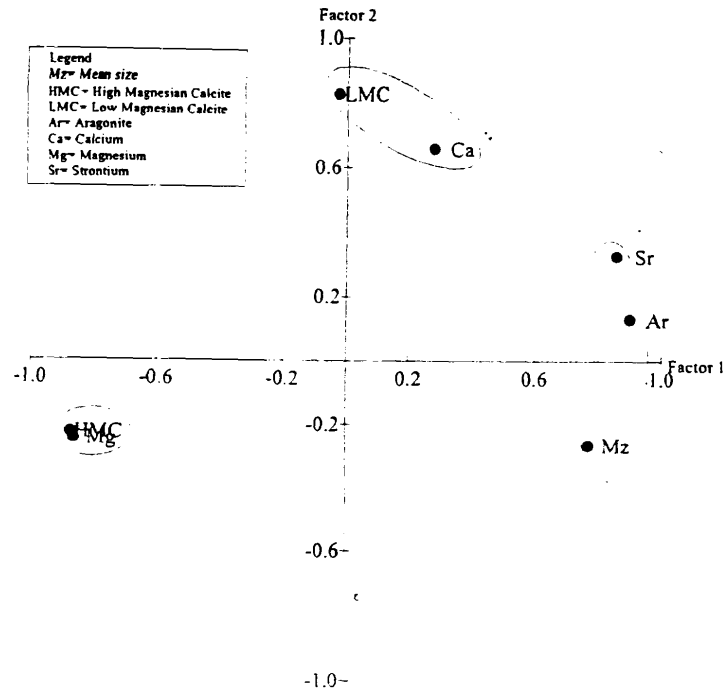


Figure (3) Plot of the extracted factors from table (2).

Table (2) Factor Analysis of the variables determined in sediments.

Variable	Factor1	Factor2
Aragonite	0.90	0.13
Calcium%	0.28	0.66
High Magnesian Calcite%	-0.87	-0.23
Low Magnesian Calcite%	-0.03	0.83
Magnesium%	-0.86	-0.25
Mean grain size	0.77	-0.27
Strontium%	0.85	0.33
Eigenvalue	3.93	1.19
Percent of Variance	56.10	17.00
Cummulative Percent of	56.10	73.10

Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.64

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aragonite, which is associated with strontium, is present in the fine fractions of the carbonate sediment. High magnesian calcite is strongly associated with magnesium and they are inversely associated with the (aragonite-mean size-strontium) group. The inverse relationship of high magnesian calcite association with the aragonite association displays the effect of mean size where the first is dominating the coarse fraction of the sediment and the later is predominant in the fine sediments.

Factor 2

This factor accounts for about 73% of the total cumulative variance among variables and it represents the association of calcium and low-magnesian calcite (Fig. 3, Table 2). The lack of association of low-magnesian calcite with mean size shows that low-magnesian calcite is randomly distributed among the size fractions of the sediments.

The carbonate sediments of the study are essentially skeletal sands composed of *Halimeda* plates, mollusks, coral reef debris, algal grains and benthic foraminifera Montaggioni *et al.* (1986). Earlier investigations (Milliman, 1974; Burkani, 1983) have shown that *Halimeda*, mollusk and corals contribute to aragonite whereas coralline algae and foraminifera contribute to high magnesian calcite. This implies that aragonite should be associated with the coarse sediments. On the other hand, Durgaprasada Rao and Behairy (1984) reported that there was no indication of reworking in the carbonate sediments off Jeddah. Thus, association of aragonite with fine sediments in the study area indicates that aragonite is contributed by precipitation of lime mud by either inorganic or organic processes. The subtropical nature of the environment of deposition in the area of study may lead to the precipitation of lime mud. Many authors reported the precipitation of inorganic aragonite (Evamy, 1973; Kinsman, 1969; Stoffers and Ross, 1979). The association of the high-magnesian calcite with coarse sediments indicates that the algal grains and foraminifer shells did not subject to reworking. The low-magnesian calcite shows no definite distribution patterns and might have been originated from either the Pleistocene limestone in the coastal plain or certain type of calcite-secreting foraminifera (Behairy and Jaubert, 1983).

CONCLUSION

It has been shown that there is a strong relation between mean grain size of the sediment and its carbonate mineralogy. The sediments of the area of study consist of biogenic carbonate and are composed of aragonite, high-magnesian calcite and low-magnesian calcite in varying proportions. The aragonite mineral is associated with fine carbonate sediments and may be derived by inorganic or organic precipitation. High-magnesian calcite is associated with coarse carbonate sediments and is contributed by algal debris and foraminifer shells that are not reworked. Low-magnesian calcite is minor and showed no distinct distribution pattern and may be originated from either the Pleistocene limestone in the coastal plain or certain type of calcite-secreting foraminifera.

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