

Composition And Characteristic Of The Surficial Sediments In The Southern Corniche Of Jeddah, Red Sea Coast

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Received: Feb 1, 2017, Revised : 15 Feb 2017, Accepted: Feb 20, 2017, Published: 1 March 2017

DOI:10.24273/jgeet.2017.2.1.19

Abstract

This work discusses the composition and characteristic of the surficial sediments in the southern corniche of Jeddah, Saudi Red Sea coast, in an attempt to infer the surficial distribution pattern of minerals and provenance of sediments. Twenty-six superficial sediments samples were collected from backreef and forereef areas and were analyzed for grain size, CaCO₃ content, and mineralogy. The textural of grain size range from gravel to mud fraction. The mud-dominated substrates (<63 μm) occur generally in the back-reef area near the shoreline (sheltered area) and in the lagoon. Gravel rich-sediments are mostly found in forereef regions. The highest content of aragonite and Mg-calcite occur in the forereef area, probably because to suitability the forereef region for chemical and biochemical precipitation of these minerals. High Mg-calcite and Dolomite are low in both the regions. The pyrite occurs in lagoon; this indicates the reductive conditions in this part. However, on the contrary the percentage of carbonate minerals were low in the backreef-flat area, which could be attributed to the supply of non-carbonate terrigenous materials. The terrigenous material contains quartz, k-feldspar, plagioclase and amphibole minerals and are dominant in backreef-flat area with averages of 12.7%, 7.13%, 2.93% and 0.65%, respectively. Their abundance could be attributed to the supply of terrigenous materials by Aeolian deposits and intermittent Wadis.

Keywords: *Carbonate minerals, Red Sea, Saudi Arabia, southern Corniche and coral reef.*

1. Introduction

The southern Corniche of Jeddah (SCJ) is located south of Jeddah City on the western side of the Saudi Arabian Red Sea coast (Fig. 1). It is situated in arid and hot a climate with scarce rainfall and no perennial river runoff. The shallow water environment of the SCJ are areas of extensive carbonate production and accumulation as indicated by the occurrence of many reefal and calcareous deposits. The shallow water carbonate deposits comprise mainly of biogenic sand enriched in calcareous algae, coral debris, skeletons remain of molluscs, and foraminiferal tests (Bahafzallah and El-Askary, 1981; Durgaprasada Rao and Behairy, 1984, 1986; Basaham, 2009; Al-Dubai, 2011; Bantan and Abu-Zied, 2014). Chemical and biochemical carbonate deposits also take place in the coastal hypersaline shallow areas (Winter et al., 1983; Ellis and Milliman, 1985; Basaham, 2009). Wright and Burchette (1996) reported that carbonate deposits are very frequent and consist of biogenic carbonate (detrital bioclastics and non-detrital calcareous organisms), peloids, coated grains (e.g., ooids), aggregates, lithified clastics and matrix (mud-grade carbonate).

Other constituents of the bottom sediments of the SCJ consist of terrigenous sediment. They are limited and conveyed by aeolian processes from an adjacent area that are covered by old alluvium and fan deposits derived from the nearby metamorphosed sediments and basic volcanics of the Jeddah Group (El-Sabrouti, 1983). Durgaprasada Rao and Behairy (1982) mentioned that aeolian transport is a major supplier with a maximum of 0.06 g m⁻² day⁻¹ of the modern non-biogenic nearshore sediments of the Saudi Red Sea coast. Moreover, terrigenous sediments are supplied by an intermittent wadis (ephemeral rivers) in the southern part of the SCJ, especially during the rainy seasons (Morcos, 1970). However, influx from the wadis has little importance since most of the sediments transported by wadis occasional not reach directly to the shoreline and may remain trapped in the neighboring coastal plains. Terrigenous particles are also introduced by tidal movements (Phleger, 1969) or by wave erosion of old reefal limestone terraces that occupying the coastal plain (Durgaprasada and Behairy, 1982).

Mineralogy and sedimentation processes of the coastal sediments of Jeddah coast were studied by many authors (Behairy, 1980; Bahafzallah and El-Askary, 1981; Durgaprasada Rao and Behairy, 1982; El-Sabrouti, 1983; Behairy and El-Sayed 1984;

Durgaprasada Rao et al., 1987; Basaham, 1998, 2004; El-Sayed et al., 2002; Bantan and Rasul, 2003; Bantan, 2006; Rifaat et al., 2007). None of these studies have focused on conducting a comparison between the characteristics and composition of modern sediments of the forereef and backreef regions of the SCJ from a mineralogical point of view.

Therefore, the present study is intended to investigate of characteristics and distribution of minerals pattern in the bottom sediments of the forereef and backreef regions of the SCJ.

2. Materials and methods

2.1. Study area and site characteristics

The The southern Corniche of Jeddah (SCJ) is located ~10 km south of Jeddah City on the eastern side of the Saudi Arabian Red Sea coast (Fig. 1). It extends to a length of 20 km south of the Jeddah City. The present study deals only with the marine coastal (backreef) area of the SCJ that occurs between Jazirt Ghurab and Al-Sarum Guard Station, which is located between latitudes 21° 10' to 21° 20' N and longitudes 39° 10' to 39° 06' E (Fig. 1). It occupies a total area of approximately 43 km² with length of 19.5 km and extends into the sea of ~1.5 km wide. It is divided by the breaker zone (coral reef crest) into back-reef region (a narrow coastal strip) including tidal flats and Ghurab lagoon. The width of back-reef area varies considerably but with an average of 500 m. The bottom topography (bathymetry) of the study area is variable due to the dominance of coral reef communities (Fig. 1). Water depth of the back-reef area varies from 0.0 (shoreline) to 2 m, whereas water depth of the fore-reef area reaches 60 m. After the reef crest (breaker zone), the sea bottom descends rapidly reaching maximum depths (60m) in the study area (Fig. 1). The central part of SCJ, especially at Al-Budhai area is covered by mangrove trees (Fig. 1). The eastern side is bordered by old reefal limestone terraces (0.5-1m in height), covering a vast area from the shore to about 10 km inland (Basaham, 2004). These terraces were probably formed during the latest Pleistocene high sea level stand (Skipwith, 1973). This old reefal limestone overlies a bed of conglomerate with argillaceous cement, which is in turn underlain by basalts of the trap series (El-Sabrouti, 1983).

2.2. Samples and techniques of study

This work is based on data from 26 superficial sediments samples. They were collected from the backreef and forereef of the SCJ, using a stainless steel Van Veen grab sampler (HYDRO BIOS KIEL) on board of fishing boat and by hand in the shallower areas. The coordinates of the sediment samples (Fig. 1) were assigned by Geographic Position System (GPS).

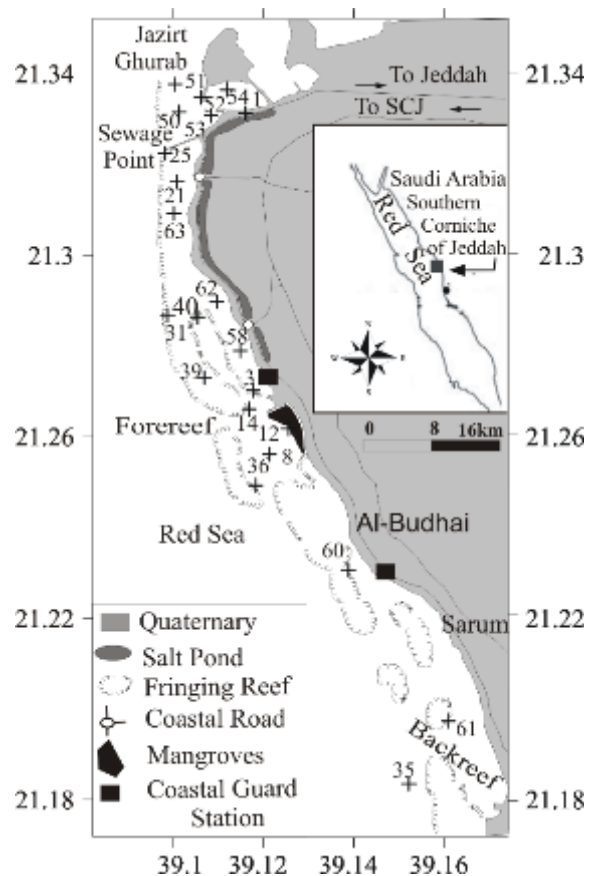


Fig. 1. Map of the study area

The mineralogy was determined in the bulk powdered sub-samples that less than 0.063 mm by X-ray diffraction (XRD) using a Shimadzu 6000 X-ray generator. The sub-samples were placed on glass holders and scanned from 2 to 60° 2θ at a speed of 2°/minute using a Cu-K α₁ radiation tube, Ni filter and a voltage of 30 kV and 20 mA. The relative percentages of the various minerals in powdered sub-samples were determined by measuring the heights of the main reflections according of Milliman (1974) and Tucker (1988). Graphic grain size parameters were determined according to Folk's classification (Folk, 1980) after mechanical sieving of backreef and forereef sediments. Calcium carbonate (CaCO₃) concentrations were determined by treating a known weight of each sub-sample with an appropriate volume of cold dilute hydrochloric acid (1M HCl) using a Calcimeter (WIKA) with an accuracy of ± 0.25%.

2.3 Sediment grain size

The raw weights for each grain-size class were converted to weight percent for each sub-sample and classification to four sizes mud (silt and clay), coarse sand, fine sand and gravel. The median, standard error, standard deviation and mean of the grain size for each sub-sample were calculated using SPSS v.11.5/2002 for (Windows-based software). Contour maps were plotted for the

sediments and minerals using Remote Sensing (IMAGINE 8.7), ArcGIS 9 and SURFER v.8 (Golden Software). Triangle diagram of distribution of gravel, sand and mud were plotted using Golden Software Grapher 5 Software.

3. Results

Sediment characteristics and substrate types

The coarse sand fraction (150 μm to 2 mm) predominates in the northern part of the studied area, representing about 53% of the total sediment fraction (Fig. 2). The fine sand fraction (63-150 μm) predominates in the lagoon and the southern part of the studied areas, representing about 25% of the total sediment fraction (Fig. 2). The mud-dominated substrates (<63 μm) occur generally in the back-reef area near the shoreline (sheltered area) and in the lagoon, representing about 5% of the total sediment fraction (Fig.2). However, gravel rich-sediments are mostly found in forereef regions such as that of Al-Budhai area with an average of 17% (Fig. 2).

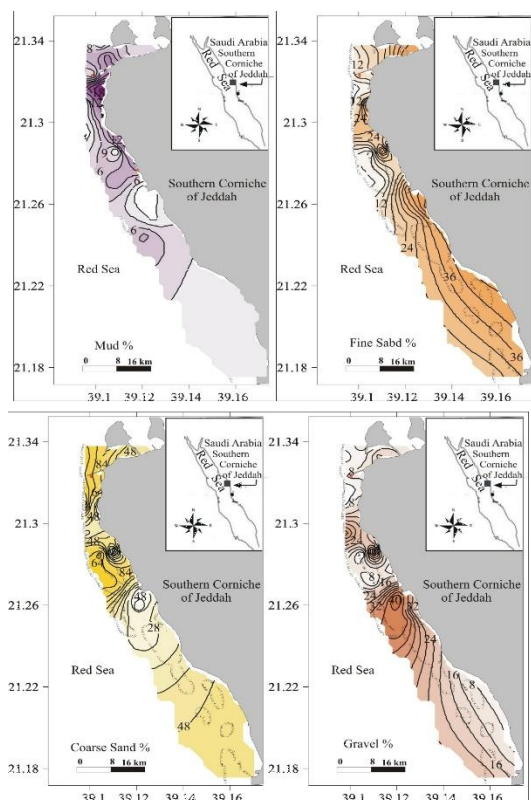


Fig. 2. Relative abundance distribution of mud, sand and gravel sediments in the studied area of the SCJ.

In general, the sand and gravel sediments dominate studied part of the SCJ. Microscopic studies indicate that the sand sediment (>63 μm) is composed mainly of bioclastic materials, such as foraminiferal tests, ostracod carapaces, pelecypod and gastropod shells, sponges, tubes of polychaetes, corals debris and coralline algae. Lithic particles of sand are relatively few. The bottom sediments of the lagoon and those occurring near the sewage outlet are characterized by having grey to blackish colors. According to Folk's classification method

(Folk, 1980), seven textural classes are identified (Fig. 3). Most of the samples are generally vary between sand to gravelly sand, while few samples were muddy sand. Overall, the backreef zone of the SCJ is generally flat and covered by thin layer of soft sediments overlying hard substrates.

3.1 Calcium carbonate

The bottom sediments of the SCJ consist mainly of calcium carbonate (CaCO_3). Their contents vary from 59 to 99%, with a mean value of 84.5%. The high content of CaCO_3 occurs in forereef area, immediately along reefal limestone called "Al-Kasarah", reaching value up to 99% (Figs. 4). While the low content (59%) of CaCO_3 occurs in the lagoon (Fig. 4). The calcium carbonate in the bottom sediments of the Al-Budhai area ranges from 73 to 94%. The highest value of CaCO_3 in the bottom surface sediments of the SCJ is usually linked with the coarse-grained sediments (Fig. 4).

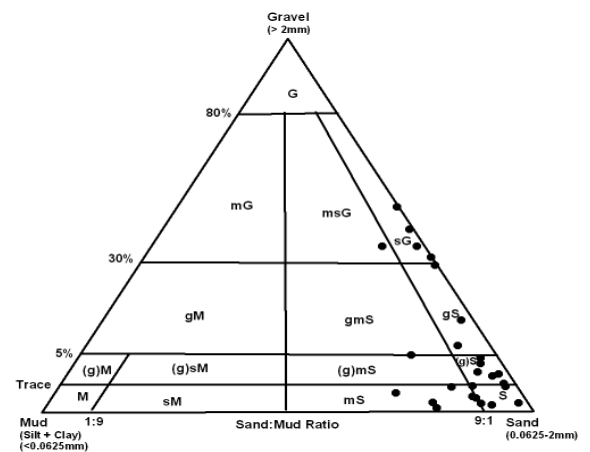


Fig. 3. Gravel, Sand and Mud (Clay plus Silt) triangle diagram for the Southern Corniche sediments of Jeddah.

3.2 Mineral composition

The mineralogy of the studied sediment samples from the forereef and backreef-flat region of the SCJ is characterized by the existence of carbonates minerals (e.g., aragonite, Mg-calcite, calcite and dolomite), plagioclase, amphibole, K-feldspar, quartz, pyrite and halite (Table 1). Overall, carbonate minerals represent more than 70% of the bottom surface sediments.

Samples from the forereef area show higher aragonite and higher Mg-calcite content than the samples from the backreef-flat. The average percentage of aragonite ranges from 37.47 to 79.85%, and the highest percentage of aragonite occur in the forereef part and decreases towards the shoreline of the studied area. Mg-calcite content varies from 9.69% to 32.96% with an average of 18.31%. Dolomite occurs in considerable amounts; especially in the surface sediment samples which collected from backreef-flat. However, dolomite and calcite occur in minor content, especially in the samples collected from backreef-flat and shoreline,

with averages of 0.87 and 1.08%, respectively (Table 1).

The non-carbonate mineralogy of the bulk surface bottom sediments is dominated by terrigenous quartz K-feldspar, plagioclase and amphibole minerals. They occur in considerable amount, especially in the surface sediment samples which collected from backreef-flat and shoreline (Table 1). It is apparent that quartz and K-feldspar are more in abundance in the backreef-flat part and shoreline, especially in Al-Budhai area (Fig. 5) with average amounts of 12.71% and 7.13% respectively;

while plagioclase and amphibole minerals are abundant along the northern part of the studied area.

Halite occurs in considerable amounts in most of the studied samples, it constitutes about 4.42% of the whole sediments of the SCJ. In some samples, pyrite is present in lesser amounts, especially in the northern part in Ghurab lagoon. It forms 0.34% of the bulk mineralogy of the samples. Therefore, it can be noted that the SCJ sediments are composed mainly of aragonite, Mg-calcite, quartz and K-feldspar.

Tabel 1
Mineralogy and their relative concentration (in %) of the sediment samples from SCJ

| S no. | Carbonate minerals | | | | Detrital minerals | | | | Evaporate mineral | Pyrite % |
|----------------|--------------------|-------------|--------------|-------------|-------------------|--------------|---------------|-------------|-------------------|-------------|
| | Aragonite % | Calcite % | Mg-calcite % | Dolomite % | Quartz % | K-Feldspar % | Plagioclase % | Amphibole % | Halite % | |
| 1 | 45.31 | 3.49 | 9.92 | - | 18.50 | 5.36 | 9.92 | 2.95 | | - |
| 3 | 53.44 | - | 13.99 | - | 16.28 | 8.91 | 2.80 | - | 4.58 | - |
| 8 | 61.15 | - | 17.29 | 2.51 | 7.27 | 9.77 | 2.01 | - | - | - |
| 12 | 50.76 | 2.72 | 10.27 | - | 21.45 | 8.16 | 3.02 | - | 3.63 | - |
| 14 | 44.62 | - | 15.75 | - | 25.72 | 9.45 | - | 1.84 | 2.62 | - |
| 21 | 60.53 | - | 20.57 | 2.15 | 3.83 | 7.18 | - | - | 5.74 | - |
| 25 | 43.35 | - | 21.01 | - | 20.74 | 10.64 | - | - | 4.26 | - |
| 31 | 56.46 | - | 26.84 | 2.03 | 4.30 | 5.82 | - | - | 4.56 | - |
| 33 | 46.15 | - | 22.56 | - | 19.49 | 8.72 | - | - | 3.08 | - |
| 35 | 79.85 | - | 13.93 | - | - | 6.22 | - | - | - | - |
| 36 | 38.02 | - | 25.75 | - | 29.94 | 6.29 | - | - | - | - |
| 39 | 59.37 | - | 31.12 | - | - | 5.19 | - | - | 4.32 | - |
| 40 | 63.59 | - | 26.12 | 2.37 | - | 7.92 | - | - | - | - |
| 46 | 54.47 | - | 32.96 | 1.68 | - | 5.31 | - | - | 5.59 | - |
| 47 | 54.99 | - | 32.74 | 2.05 | - | 5.12 | - | - | 5.12 | - |
| 50 | 51.53 | 4.34 | 16.58 | - | 16.58 | 6.38 | - | - | 4.59 | - |
| 51a | 64.41 | 2.76 | 14.29 | - | - | 6.27 | 8.02 | - | 4.26 | - |
| 52 | 48.92 | - | 13.01 | 1.93 | 19.52 | 6.02 | 5.30 | - | 5.30 | - |
| 53 | 39.23 | - | 10.17 | 1.69 | 20.34 | 9.44 | 2.91 | - | 7.26 | 8.96 |
| 54 | 46.15 | 2.56 | 9.69 | 1.99 | 17.38 | 7.41 | 5.13 | 3.13 | 6.55 | - |
| 56 | 65.23 | - | 20.98 | - | - | 6.61 | 2.30 | - | 4.89 | - |
| 58 | 37.47 | 3.47 | 12.90 | - | 22.33 | 8.68 | 6.20 | 3.47 | 5.46 | - |
| 60 | 39.62 | 3.83 | 12.30 | 2.46 | 16.12 | 6.56 | 4.37 | - | 14.75 | - |
| 61 | 47.78 | 1.97 | 14.04 | 1.72 | 22.41 | 6.90 | 3.45 | - | 1.72 | - |
| 62 | 43.51 | - | 14.50 | - | 18.07 | 4.83 | 11.45 | 2.29 | 5.34 | - |
| 63 | 44.44 | 2.85 | 16.81 | - | 10.26 | 6.27 | 9.40 | 3.13 | 6.84 | - |
| Average | 51.55 | 1.08 | 18.31 | 0.87 | 12.71 | 7.13 | 2.93 | 0.65 | 4.42 | 0.34 |

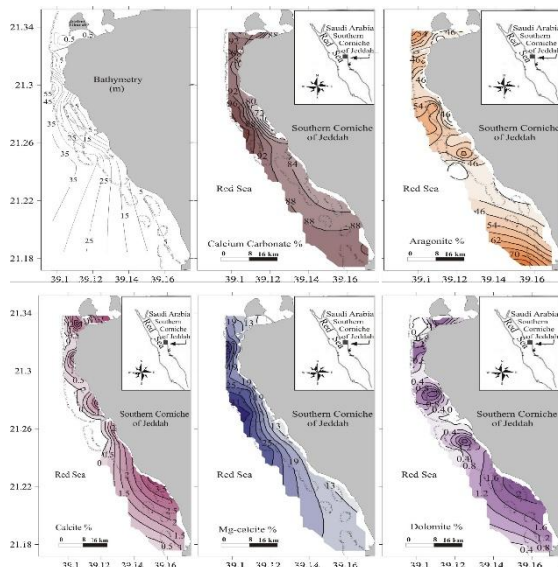


Figure 4. Bathymetry, Distribution of calcium carbonate (CaCO₃).

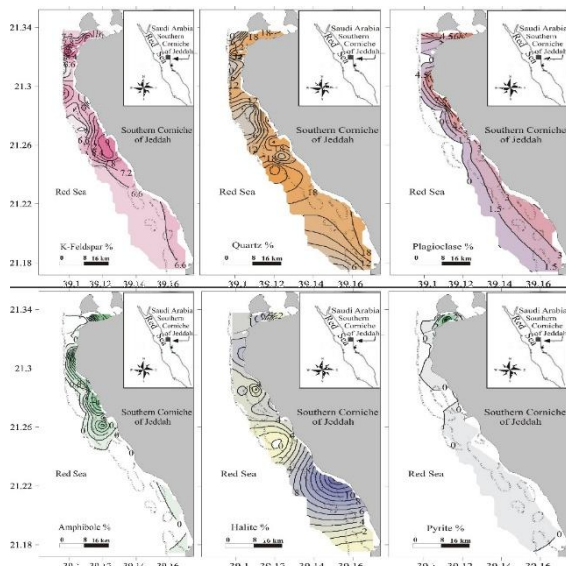


Figure 5. Distribution of Mineralogy in the studied bottom sediments of the SCJ.

4. Discussion and Conclusions

The studied area of the SCJ can be divided into two major zones, namely: (1) The backreef-flat zone, which is considered as sheltered-low energy zone and (2) the forereef zone, which is considered as an open sea. The superficial sediments of the backreef-flat of SCJ are muddy sand and consist mainly of carbonate and terrigenous minerals. Carbonate minerals are represented by Mg-calcite, calcite, aragonite, and dolomite, while terrigenous mineral is represented by quartz, K-feldspar, plagioclase and amphibole. Moreover, the presence of halite and pyrite minerals in sediments of the backreef -flat zone is also noticed.

The mineralogy of the backreef-flat zone shows significant variations in their distribution and compositions, in the northern part of the studied area especially in lagoon, it contains some pyrite minerals that could be attributed to the occurrence of reducing conditions in this lagoon due to dominance of organic matters.

Terrigenous materials in backreef-flat are dominated by quartz and K-feldspar and low abundance of plagioclase and amphibole; these minerals could be attributed to the nature of the source rocks, such as igneous and volcanic basalts rocks, which formed the bordering mountains of the Red Sea, and apparently transported to backreef-flat area by intermittent wadi stream and wind. Many studies indicated that these minerals are intimately associated with terrigenous deposition and introduced to sea-marginal flat environments in the Red Sea by winds (Sneh and Friedman, 1985 and Phleger, 1969). Wadi Fatima is dry intermittent stream and flows during the rainy season in the main wadi and the southern part of the SCJ. The abundance and supplies of the terrigenous materials in the backreef-flat area could be responsible for the low abundance of aragonite and Mg-calcite. This low average carbonate minerals in backreef-flat are probably due to dilution by terrigenous input which transported by wind and seasonal freshwater discharge to the coastal area (Khalaf and Ala, 1980). However, this dilution by the terrigenous material gradually decreases towards the forereef region. Moreover, inorganic precipitation of carbonate deposits (carbonate minerals) in seawater is inhibited by the presence of dissolved organic and inorganic chemicals (Suess 1973; Rushdi et al. 1992). The relative abundance of the halite was close to the shoreline; especially in shallow water sheltered area could be attributed to high rates of evaporation, and very low precipitation and runoff. The concentration of pyrite mineral in backreef-flat area, especially in Ghurab lagoon could be attributed to the early diagenetic processes that occur as response to the reducing environmental conditions. Basaham (1998) reported that pyrite in the surface sediments of Al-Arbaeen lagoon was a product of early diagenetic reactions in highly reducing environment.

The recent superficial sediments in forereef area of the SCJ are gravely sand and consist mainly of carbonate materials, while the terrigenous matters (e.g., quartz, K-feldspar, plagioclase and amphibole) are rare in this region. The high value of aragonite and high magnesium calcite in forereef zone sediments could be attributed to high degree of saturation of seawater with respect to calcium carbonate (Rushdi et al., 1992). It is noted that aragonite and Mg-calcite formed the majority among other carbonate minerals in forereef region, where it has been shown that aragonite is kinetically favored to precipitate in a solution with magnesium-to-calcium concentration ratio more

than 4 such as in seawater (Kitano 1964; Rushdi 1993; Rushdi et al. 1992).

Based on the previous discussion, it is suggested that the mineralogical compositions of surface sediments of the SCJ are derived from the following sources: Fluvial deposits which discharged in the southern part of the SCJ by Wadi Fatima, chemical and biochemical precipitation from the sea water, and eroded the reefal terraces on the shoreline and the reef crest (breaker zone). The low value of aragonite and Mg-calcite in backreef-flat sediments could be attributed to supply of the terrigenous materials. On other hand, the abundance of aragonite and Mg-calcite in forereef area, probably due to the high levels of seawater saturation with respect calcium carbonate and the decline of the terrigenous inputs.

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