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Microtextures on Quartz Grain Surfaces in the Beach Sediments of Southern Hodeidah, Red Sea Coast, Yemen

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ABSTRACT: Surface features of quartz grains on the Al-Haymah and Moushij beaches of the coastal area in the southern Red Sea of Yemen were analyzed by a scanning electron microscope (SEM) to deduce the provenance and depositional environment of sediments. The microtextures on quartz grains were classified into mechanical, chemical, and mechanical/chemical origins. The quartz grains from the two beach areas were rounded to subrounded in shape. Rounded quartz grains with a combination of bulbous and broken edges indicated a recycled provenance. Mechanical features such as V-shaped marks and straight and curved scratches revealed the combination of fluvial and high-energy subaqueous beach environments, whereas aeolian grains are mainly marked by crescentic percussion marks, elongated depressions, and upturned plates.

Chemical features such as solution pits, silica globules, trapped diatoms, and adhering particles in quartz grains indicated a diagenetic environment and silica re-precipitation in a coastal environment. In general, the microtextures identified on quartz grains reveal that sediments are influenced by wind, fluvial, and subaqueous marine environments and are derived from nearby and distal sources.

Contents

1. Introduction

Many researchers have emphasized that microtextures on quartz grain surfaces can be used to identify different sedimentary environments and modes of transport mechanisms [1-9].

The microtextures of quartz sand grains can provide valuable information about the various processes acting on grains during transportation and after deposition [10, 11]. Hence, the surface textural study of quartz grains is considered to reflect the sedimentary history of quartz: parent rock, transportation process, provenance, and depositional environment [9, 12–15].

The Tihama coastal plain, which stretches along Yemen's Red Sea coast and is around 500 km long and 30-60 km wide, occupies an area of about 10% of the total country area [16]. It is characterized by a relatively flat topography gently sloping toward the sea and is occasionally dissected by several wadis. It is also characterized by the occurrence of alluvial fans, derived from the highlands about 60 km to the east, aeolian and coastal dunes, siliciclastic beach sands, sabkhas, and muddy mangrove shorelines [17]. There are seasonal surface streams discharging into the Red Sea, although flash floods are a widespread phenomenon following torrential rains. However, they reach the sea only during rainfalls with a large number of sediments. In some places, groundwater seepage supports coastal wetlands [18].

The sedimentological and geochemical composition of the recent sediments from the Al-Khowkhah and Al-Mokha beach areas was investigated by [19] to infer provenance and identify their relationship to the natural and anthropogenic processes occurring in that area. They concluded that the beach sediments of Al-Khowkhah were derived largely from the igneous and volcanic rocks outcropping to the east of the studied area. [4] utilized microtextures on quartz grains from the Al-Khowkhah and Al-Mokha coastal areas to the south of Al-Hodeidah, to clarify the relationship between the various recent sedimentary environments. However, none of these studies utilized microtextures on quartz grains from the Al-Khowkhah beach area of southern Hodeidah to examine sediment provenance.

In this study, the microtextures on quartz grains collected from beaches (Al-Haymah and Moushij) in southern Hodeidah will be discussed to deduce the provenance and depositional environment of sediments based on the type of microtextures on quartz grains.

2. Geological Setting

Moushij and Al-Haymah areas are located at 13°40′N, 43°13′E and 13°55′N, 43°20′E, within the Tihamah coastal plain (Fig. 1), which is characterized by a hot and dry climate with only about 50 mm of rain fairly well distributed throughout the year. The prevailing wind, in general, is almost NNW and SSE [20]. The plain of the study area is almost flat and covered by Pleistocene and recent sediments, mainly composed of aeolian sand and gravels, which are derived mainly from the eastern Red Sea mountainous escarpment composed of basic (basalt, andesite, and andesitic pyroclastics) and acidic (dacite and rhyolite) volcanic rocks as well as granitic rocks specifically of tertiary age. The surface of the mountainous escarpment is dissected by means of several developed drainage channels (wadis), flowing westward toward the Red Sea and disappearing sometimes in the Tihama plain (*e.g.*, wadi Nakhlah and wadi Irfan) (Fig. 1).

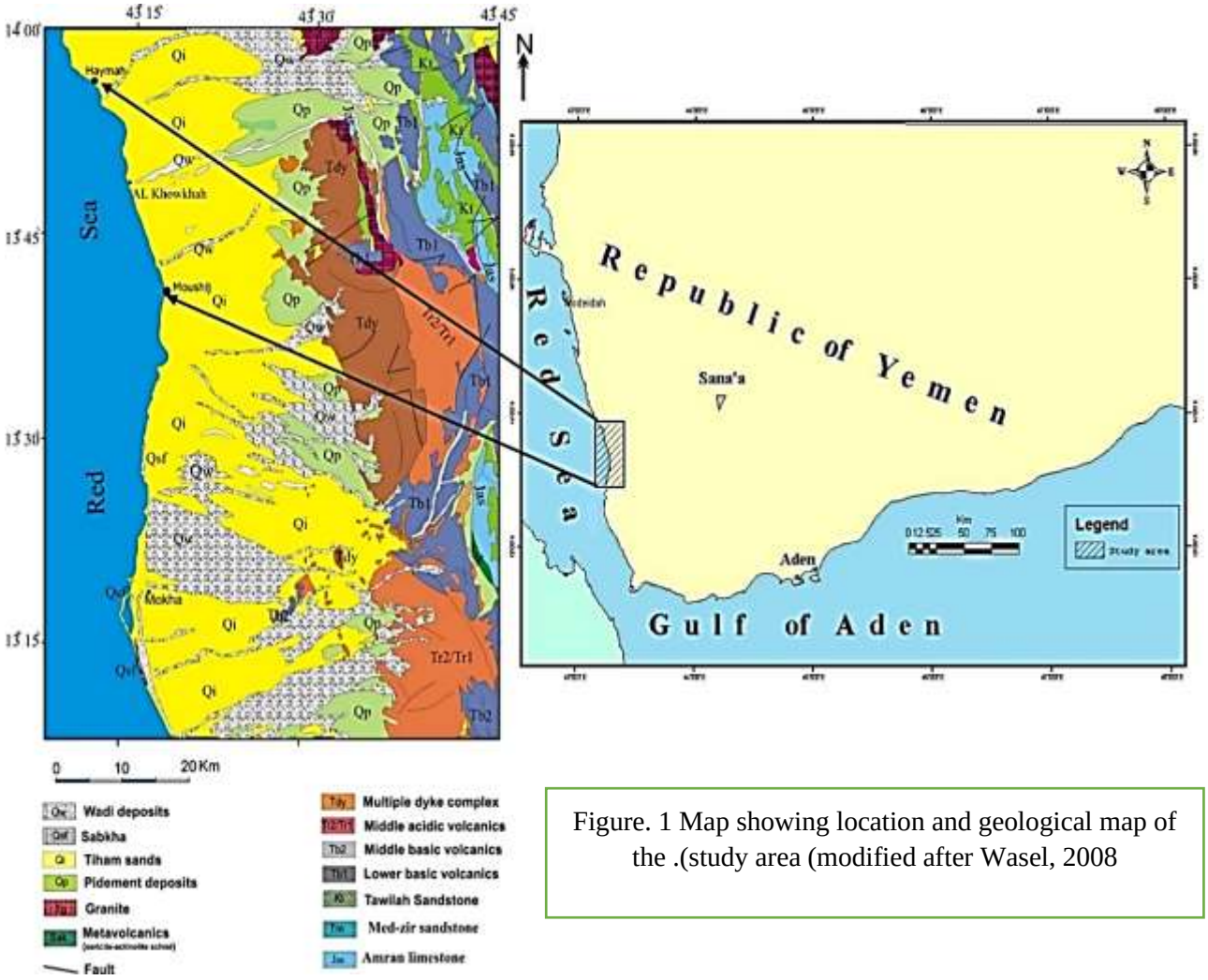

Figure. 1 Map showing location and geological map of the .(study area (modified after Wasel, 2008

3. Material and Methods

Twelve beach samples from the two locations (Moushij and Al-Haymah) were collected to study the quartz grain surface features using SEM. Six sediment samples were collected from each location. Approximately 10 g of each sample was treated with HCl 30% to remove the carbonate coatings and iron oxides and washed with deionized water. Then, the organic matter was removed by treatment with H_2O_2 30% and washed with deionized water until clear quartz grains were obtained. The cleaned grains were oven-dried at 60°C.

Sand grains (200–400-µm in size) were picked randomly from each sample using a binocular microscope. Fifteen grains from each sample were selected for the present study, which is considered sufficient to represent the variability present in a single sample [1, 22]. Diagnostic features were identified and photographed using a JEOL-JSM-5400LV scanning electron microscope at the Assiut University of Egypt.

4. Results

Microtextures on quartz grain surfaces

The quartz grain surface features of the Al-Haymah and Moushij beach samples are summarized in Table 1. The microtextures are classified as mechanical, chemical, and mechanical/chemical based on their modes of origin. The chemical mode of origin is divided into dissolution and precipitation origins. In the present study, twenty-five microtextures on the quartz grains are identified and classified into three groups according to their mode of origin. Sixteen microtextures of them are of

mechanical origin; six microtextures are of chemical dissolution/precipitation origin; and three microtextures are of combined mechanical and chemical origin (Figs. 2 and 3).

Table 1. Microtexture Features and Their Abundance on Quartz Grains from Al-Haymah and Moushij Beaches of the Red Sea Coast, Yemen

Microtexture features	Al-Haymah beach	Moushij beach
Mechanical origin		
Rounded grains	**A**	**C**
Subrounded	**P**	**S**
Parallel striations	**AB**	**S**
Curved grooves	**S**	**S**
Conchoidal fractures	**S**	**P**
Straight steps	**AB**	**P**
Arcuate steps	**S**	**P**
Straight scratches	**P**	**S**
Curved scratches	**P**	**AB**
Crescentic percussion marks	**C**	**C**
V-shaped marks	**C**	**P**
Upturned plates	**P**	**C**
Bulbous edges	**S**	**S**
Abrasion fatigue	**AB**	**AB**
Meandering ridges	**S**	**S**
Impact scars	**S**	**AB**
Mechanical/Chemical origin		
Adhering particles	**S**	**P**
Elongated depressions	**S**	**S**
Low relief	**C**	**S**
Chemical origin - Dissolution		
Oriented etch pits	**C**	**C**
Solution pits	**C**	**C**
Scaling	**P**	**AB**
Chemical origin - Precipitation		
Silica globules	**S**	**C**
Silica flower	**S**	**S**
Trapped diatoms	**AB**	**C**

A = Abundant (>75%); C = Common (50-75%); P = Present (25-50%); S = Sparse (5-25%); AB = Absent.

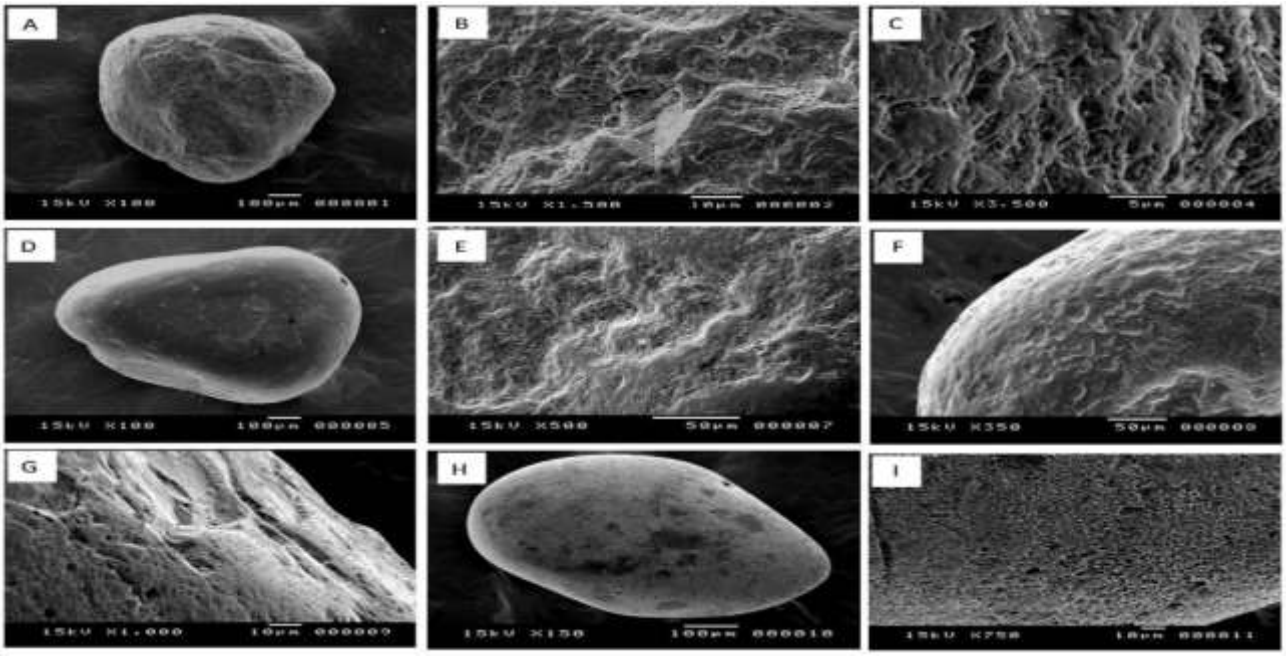

Fig. 2: Microtextures were identified on the quartz grains by SEM from the Al-Haymah beach area, Yemen. A: general view of the quartz grain displaying round and elongated in its lower part with a bulbous edge and small crescent-shaped marks with chemically weathered surfaces. B: V-shaped patterns, solution pits, upturned plates, crescentic percussion marks, and adhering particles. C: V-shaped pits, dish-shaped depressions and silica globules over chemical etch**.** D: general view of the quartz grain showing subrounded with a bulbous edge, crescentic percussion marks and small pits. E: meandering ridges, V-shaped pits, upturned plates, curved scratches and adhering particles. F: quartz grain edge shows edge rounding, straight and curved scratches and crescentic percussion marks. G: quartz grain exhibiting curved grooves, small pits, dish-shaped depressions and conchoidal fractures. H: quartz grain displaying rounded and subrounded edges with a bulbous edge and parallel striations. I: precipitation of silica globules and flowers.

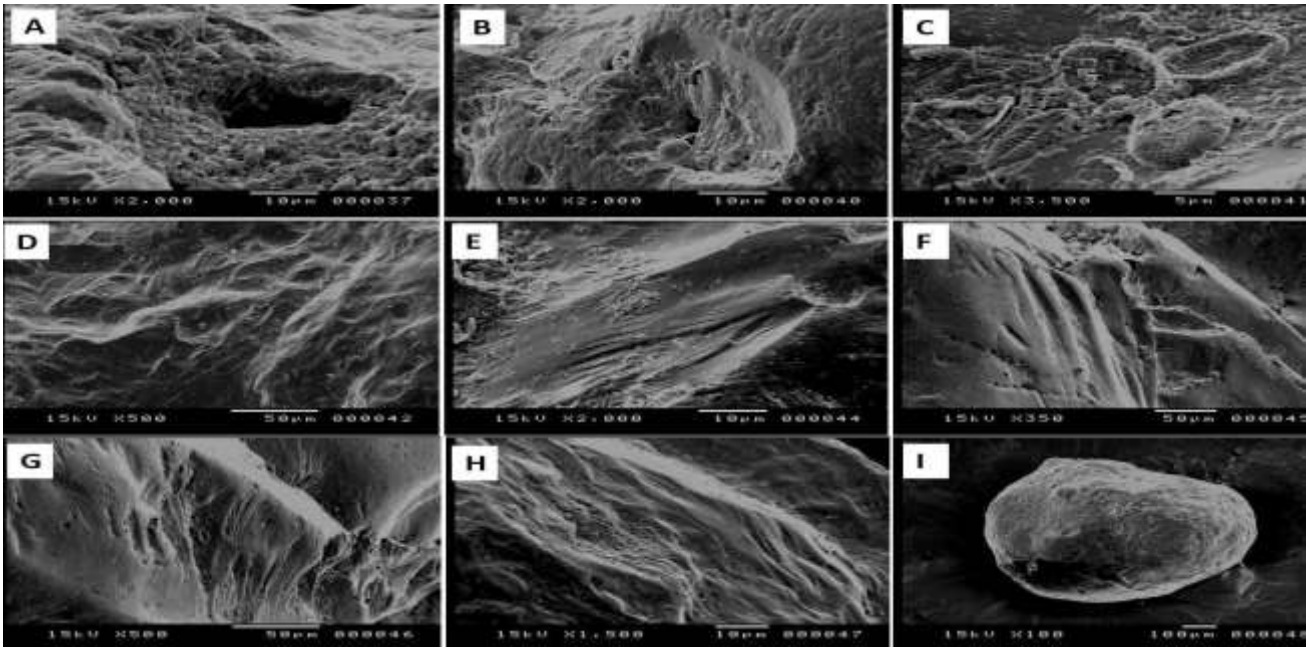

Fig. 3: Microtextures were identified on the quartz grains by SEM from the Moushij beach area, Yemen. A: Silica precipitation in the form of upturned plates, associated with silica globules. B: V-shaped patterns, dish-shaped depressions with silica globules. C: Numerous diatoms are observed on the quartz grain in association with silica globules. D: Upturned plates, dish-shaped depressions with precipitation of silica globules and curved grooves. E: Conchoidal fractures, V-shaped patterns, dish-shaped depressions, and straight steps. F: Smooth grain surfaces, straight steps, pits, and dish-shaped depressions G: Straight and arcuate steps in association with silica precipitation. H: Upturned plates and precipitation of silica. I: Quartz grain showing a subrounded outline and surface abrasion, crescent-shaped marks with some V-shaped patterns.

Mechanical origin

The dominant microtextures of mechanical origin include rounded and sub-rounded outlines, crescentic percussion marks, V-shaped marks, upturned plates, conchoidal fractures, straight and arcuate steps, and straight and curved scratches (Figs. 2 and 3).

The surface features of mechanical origin show rounded and sub-rounded quartz grains. The rounded type was abundant on quartz grains from Al-Haymah and common on Moushij beach grains (Figs. 2a, d, f, h, and 3a). Crescentic percussion marks are common on quartz grains (Figs. 2a, b, f and 3a, c, e); V-shaped marks are common on quartz grains from Al-Haymah and moderately present in Moushij samples (Figs. 2b, c, g, and 3a, c). Upturned plates are present and common on quartz grains (Figs. 2b and 3e, i); conchoidal fracture and straight and arcuate steps are sparse and present on quartz grains (Figs. 2g and 3g, h); straight and curved scratches are present and sparse on quartz grains (Figs. 2a, e, f, g and 3f, g, h); bulbous edges and meandering ridges are sparse in both beaches (Fig. 2a, d, e).

Chemical origin

Microtextures on quartz grains resulting from chemical dissolution/precipitation processes were identified in all the quartz grains (Table 1). Microtextures of chemical origin in Al-Haymah and Moushij include solution pits, etched surfaces, silica globules, and silica flowers (Figs. 2c, i and 3b, c, d).

Mechanical/chemical origin

The distribution of combined mechanical and chemical microtextures of quartz grains from beach samples of Al-Haymah and Moushij exhibits varied relief, such as low relief, adhering particles, and elongated depressions (Table 1). Low relief is common and moderately present on quartz grains, respectively, from beach samples of Al-Haymah and Moushij, (Figs. 2d, h, and 3a). Adhering particles are sparsely distributed in Al-Haymah and moderately present in Moushij beach samples (Figs. 2b, e and 3b, e, f). Elongated depressions are sparsely distributed on the quartz grains on both beaches (Figs. 2c, g and 3c, e, h).

5. Discussion

Microtextures on quartz grains from Al-Haymah and Moushij beaches display diverse categories and are showing similarities in some of the microtextures on quartz grains (Table 1). The roundness of the quartz grains mostly depends on their residence time in a specific environment, grain stability, and mode of transport [23, 24]. Rounded quartz grains with bulbous edges are diagnostic of aeolian transport [23, 25]. In an aeolian environment, wind action tends to produce rounded to well-rounded quartz grains, low relief with dish-formed depressions, upturned plates, and arcuate and round surface features [26]. For this reason, rounded grains with low relief may have been derived through onshore delivery in coastal environments or because of the effect of aeolian transport [23]. In addition, elongated depressions were noted on some grains. Their formation is attributed to high-energetic aeolian transport [2, 27]. However, the rounded to subrounded grain outline may reflect the original grain shape generated by the parent rock. The grain outline is related to both the transportation process and the original grain shape of the source rock [25]. Such features were commonly confirmed by the geological setting of the sampling area, which contained rounded quartz grains that originated from igneous and sedimentary rocks outcropping to the east of the study area.

Crescentic percussion marks are another observed mechanical feature that shows crescentic pits on surface grains and may result from the collision of the grains during transportation. The presence of crescentic percussion marks on the surface of the quartz

grains may be used to indicate an aeolian environment [28].

V-shaped patterns, straight scratches, and curved scratches are present on many quartz grains from Al-Haymah and Moushij. These features are characteristics of moderate to high-energy subaqueous conditions, as proposed by [28], and mainly happen on quartz grains from the beach, and fluvial and deltaic environments [22]. According to environmental differentiation, mechanical features, including V-shaped ones, are common and characteristic features of subaqueous environments and result from grain-to-grain impact during transport, whereas aeolian environments are especially marked by upturned plates and crescentic percussion marks [29].

The quartz grains from Al-Haymah and Moushij exhibit different orientations of V-shaped patterns, which is a characteristic feature of a mechanical origin. V-shaped patterns of mechanical origin mainly originate in subaqueous mediums with high-energy conditions. Many quartz grains from Moushij show upturned plates, but they are sparsely distributed on the quartz grains from Al-Haymah. These features were developed in an aeolian environment.

The microtextures of chemical origin, such as solution pits, silica globules, and trapped diatoms, probably originated due to dissolution and precipitation activities during diagenetic processes within the depositional environment, which are characteristics of intertidal and subaqueous environments. Silica globules are identified only in quartz grains of the Moushij, especially on broken surfaces, which represent saturated water with silica in a low-energy aqueous environment. Diatoms on quartz grains are indicators of silica reprecipitation or silica biogenic globules. According to [5, 30], these features of chemical precipitation concern tropical and intertidal zone water saturated with silica.

The results mentioned above stated that the microtextures identified in quartz grains reveal that sediments are influenced by wind, fluvial, and coastal environments and are derived from nearby and distal sources.

6. Conclusion

A scanning electron microscope investigation of quartz grains in the studied beach sediments of the coastal area in the southern Red Sea of Yemen indicates the presence of mechanical, mechanical/chemical, and chemical features. From the relative frequency distribution of the various surface features on quartz sand grains from the sediment studies, it was noticed that mechanical features are prevalent, followed by chemical features. The mechanical features comprise upturned plates, meandering ridges, mechanical V-shaped pits, conchoidal fractures, and oriented cleavage-like plates.

Rounded to well-rounded quartz grains have low relief with dish-shaped depressions, mechanically upturned plates, and arcuate and circular surface features, proposing that these grains were subjected to shoreface environments and/or aeolian processes. In addition to high-energy subaqueous conditions, which are mainly characteristic of the fluvial environment.

The chemical precipitation features, such as silica globules, in addition to the presence of diatoms on the quartz grains of the beach, support the process of chemical precipitation in a high-silica environment.

Overall, microtextures of the quartz surfaces of samples collected from Al-Haymah and Moushij confirm that the main rock source materials (which are igneous rocks with minor metamorphic and sedimentary rocks) and the depositional environments, such as marine, aeolian, and fluvial, were almost similar. These findings indicate that the surface texture of the studied quartz grains depends on the geologic

source, transportation process, and depositional environment.

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