Microtextures of Quartz Grain Surface from Recent Sedimentary Environments along Al-Khowkhah-Al-Mokha Coastal Area, Southern Red Sea, Yemen

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Abstract. Scanning electron microscopy (SEM) analyses of quartz grains from Recent sedimentary environments such as beach, coastal dunes, sabkha and wadi deposits in the Al-Khowkhah and Al-Mukha coastal area along southern Red Sea, Yemen, revealed variations in surface textures. Results of this study reveals the existence of distinguished surface features that reflect the effect of mechanical and chemical actions on the quartz grains.

Quartz grains of beach, coastal dune and wadi deposits show significant abundance of both mechanical and chemical surface features developed during transportation of the grains in the subaqueous and aeolian environments, respectively. In contrast, quartz grains of sabkha are characterized by the dominance of chemical surface features. Among these chemical surface features, those originated from silica dissolution are considerably more numerous than those due to silica precipitation.

Relative proportions of various surface features recorded on quartz grains from different environments indicate a considerable overlapping among the identified surface features in the examined quartz grains of coastal sediments and wadi deposits.

Keywords: Microtextures; Quartz grains; Coastal sediments; Red Sea; Yemen.

Introduction

Quartz grains microtextures have been studied by several workers. Krinsley and his co-workers have done extensive studies on the surfaces

Surface textures of quartz sand grains have been used to identify the sources and genesis of various detrital sediments (Krinsley et al., 1973; Ly, 1978; Frihy and Stanley, 1987, and Ambre et al., 2005).

The microtextures provide useful information regarding the various processes acting on the grains during transportation and after deposition (Krinsley and Funnell, 1965; Doornkamp and Krinsley, 1971; Moral-Cardona et al., 1996, 1997; Mahaney, 1998, and Newsome and Ladd, 1999) and the criteria for distinguishing the mechanical and chemical features and their implications have been well established (Krinsley and Donahue, 1968; Whalley and Krinsley, 1974; Al-Saleh and Khalaf, 1982; Rahman and Ahmed, 1996, and AL-Hurban and Gharib, 2004). Hence, the surface textural study on quartz grains is considered as a powerful tool in the identification of provenance, processes of transport and diagenetic history of the detrital sediments (Krinsley et al., 1973; Madhavaraju and Ramasamy, 1999; Abu-Zeid et al., 2001; Madhavaraju et al., 2004, 2006; Armstrong et al., 2005; Kasper-Zubillaga and Faustinos-Morales, 2007, and Madhavaraju, et. al., 2009).

The aim of this study is determine the surface feature characteristics of quartz sand grains sampled from the recent coastal sediments and the wadi deposits in the southern Red Sea coastal areas of Yemen. The occurrence, proportions and overlapping of chemical and mechanical surface features are used to interpret the environmental conditions under which these recent sediments were formed.

**Study Area**

The Yemen coastline, 730 km long, is located at the southern part of the Arabian Peninsula on the Red Sea that extends from the strait of Bab Al-Mandab to the northern border of Yemen named Yemen Tihama plain. The study area is bounded between Al-Khowkhah in the north and Al-Mukha at the south and extends for about 60 km along the shoreline.
and lies between latitude 13° 15’ and 13° 50’N and longitude 43° 14’ and 43° 20’ E (Fig. 1).

Fig. 1. Location map of the study area along Yemen coastline.

The coastal plain is characterized by relatively low-relief topography with very gentle slope towards the sea, and occasionally several wadis dissect the coastal area. About 75% of the Red Sea coastline consists of loose sediments. The backshore of the coastline is mostly covered by recent sediments of sabkhas and salt marshes. Based on their textures these sediments are formed in a coastal environment (beach sands, coastal dunes and coastal sabkhas) or represent wadi deposits (Wasel, 2008).

Beach and nearshore sand deposits are the dominant recent sediments in the Red Sea coast of Yemen. They are composed of poorly-sorted mixture of sand, silt and clay (Wasel, 2008). Coastal dunes of the tidal area cover a narrow area depending upon sand supply and climate. This tidal sediment is composed of quartz sand occasionally mixed with some shells and shell fragments. The isolated coastal sabkha is widespread in the supratidal area; they vary in width and extend to about 2 km in length. They are characterized by marine transgression and...
evaporitic condition. Therefore, sabkha sediments signify continental and adjacent marine origin. Wadi deposits are composed mainly of sand, gravel and mud. These deposits are almost flat and covered by scattered vegetation (Wasel, 2008).

Methods

Ten samples have been collected from the coastal area in the southern Red Sea of Yemen (Fig. 1). These samples were chosen to represent various types of recent environments. Two samples from the wadi; two samples from the coastal dune; two samples from the coastal sabkha and four samples from the beach. The procedures used for cleaning quartz sand grains for SEM examination are those described by Krinsley and Doornkamp (1973). The medium grained sand fraction was selected from each sample to study the surface textures. Monocrystalline quartz grains were picked from each of the study samples with the use of a binocular microscope (Delgado, 1999, and Alekseeva, 2005). Fifteen grains were selected at random from each sample and mounted on metal specimen stubs, were coated with a gold-palladium alloy. Grains were visually examined using (model JEOL-JSM-5400LV) scanning electron microscope at Assiut University of Egypt.

Results and Discussion

In general, Investigations of the surface textures of quartz grains from the different types of recent sediments of the study area revealed the effects of mechanical and chemical action on the studied quartz grains. Mechanical features are mainly V-shaped and crescent-like pits, dish-shaped depressions, upturned plates, straight and curved grooves, striation and stepped cleavage planes.

Chemical features are manifested on quartz grain surfaces by solution and precipitation mechanisms. These result into the formation of triangular etching pits, irregular solution pits, crystal overgrowth and smooth precipitation surfaces. Study of the relative frequency distribution of various surface features recorded on the quartz grains showed that each type of sediment is characterized by an abundance of certain surface features, in addition to other main features, summarized in Table 1 and their graphic representation is shown in Fig. 2.
Table 1. Identified microtextures, and their abundance, on quartz grains of the recent sediments along southern Red Sea, Yemen.

<table>
<thead>
<tr>
<th>Surface features</th>
<th>Coastal sediments</th>
<th>Wadi deposits</th>
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<tbody>
<tr>
<td></td>
<td>Beach sand</td>
<td>Coastal dune</td>
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<tr>
<td>Mechanical origin</td>
<td></td>
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<tr>
<td>Conchoidal fractures</td>
<td>17</td>
<td>33</td>
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<tr>
<td>V-shaped pit</td>
<td>50</td>
<td>25</td>
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<tr>
<td>Crescent-like Pit</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Smooth abraded surface</td>
<td>26</td>
<td>50</td>
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<tr>
<td>Dish-shaped depressions</td>
<td>30</td>
<td>55</td>
</tr>
<tr>
<td>Striations</td>
<td>40</td>
<td>52</td>
</tr>
<tr>
<td>Upturned plates</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Meandering</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>Subangular outline</td>
<td>42</td>
<td>15</td>
</tr>
<tr>
<td>Rounded outline</td>
<td>10</td>
<td>25</td>
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<tr>
<td>Chemical origin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triangular etching pits</td>
<td>52</td>
<td>4</td>
</tr>
<tr>
<td>Precipitation of silica</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Deep grooves</td>
<td>40</td>
<td>10</td>
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</tbody>
</table>

Fig. 2. The frequency of various types of microtextures observed on the quartz grains from Sedimentary Environmental of study area. CF: Conchoidal fractures, V: V-shaped patterns, P: Pitted, SA: Smooth abraded surface, DD: Dish-shaped depressions, S: Striations, UP: Upturned plates, M: Meandering, SO: Subangular outline, RO: Rounded outline, TE: Triangular etching pits, PS: Precipitation of silica, DG: Deep grooves.
Coastal Sediments

Most of the studied beach quartz grains are rounded to subrounded (Fig. 3A). The surface features of these grains are mainly represented by mechanical V- shaped impact pits, rounded and pitted grooves, surface and edges roughness and upturned plates (Fig. 3B).

Graded arcs which are characteristic of aeolian origin were also noticed on the surfaces of the quartz grains (Fig. 3C); they occur in concentric series with the arcs graduated in size. Each arc series forms a fan-shaped pattern. The graded arcs are a sub-variety of the conchoidal breakage blocks may be due to grinding collision in a fluvial environment. However, they are much less common than either the conchoidal blocks or the meandering ridges formed by grinding collision (Krinsley and Donahue, 1968, and Cater 1984).

The observed meandering ridges are suggested to be formed during grain to grain collision in an aeolian environment (Krinsley and Takahashi, 1962a, and Moral-Cordona et al., 1997). They were observed in a few of the investigated quartz grains (Fig. 3D). Some quartz grains show chemical precipitation features such as silica globules, and trapped diatoms (Fig. 3E and 3F) which suggest that these grains were derived from the silica saturated environments of intertidal zones (Madhavaraju et al., 2009).

Such surface features may reflect the effects of both subaqueous and aeolian origin. The subaqueous origin is supported by the presence of V-shaped pits and rounded and pitted grooves (Krinsley and Doornkamp, 1973), whereas the aeolian effects are related to the presence of upturned plates. The presence of aeolian features in such beach sediments may suggest that some aeolian sands were reworked by waves and tides to form these beach sand deposits. Most of the mechanical impact features are quite common and generally reflect medium to high energy nearshore environments. Also the roughness of surfaces and edges of some of the quartz grains in Fig. 2A might reflect differential chemical weathering that may be related to differences in chemical resistance within the grains (Krinsley and Doornkamp, 1973).
Fig. 3. Surface features of quartz sand grains from beach environment as observed by SEM.
A) Rounded outline and surface abrasion with some V-shaped pits. B) Upturned plates in association with V-impact pits. C) Arcuate and straight steps in association with silica precipitation. D) Meandering ridges, associated with scattered pits. E) Pits grooves, arc steps and silica globules associated with diatoms. F) Numerous diatoms are observed on the quartz grain in association with silica globules.

In the coastal dunes, quartz grains are rounded to subrounded and mainly characterized by surface and edges roughness (Fig. 4A). They are mainly characterized by dish-shaped depressions, striations, conchoidal fractures, upturned plates, stepped cleavage planes and V-shaped pits (Fig. 4B). One of the most important features that characterize quartz grains of the coastal dunes is silica precipitation (Fig. 4C). The V-shaped pits similar to those present on the surface of quartz grains of the beach sands are also common (Fig. 4D). This is probably a relict from some subaqueous environments. The presence of such features also indicates
the possibility of grain transportation from marine environment because of their closeness to the seawater.

Fig. 4. Surface features of quartz sand grains from coastal dune as observed by SEM. A) Subrounded quartz grain that shows small conchoidal fractures. B) Straight and arcuate steps and V-shaped pits. C) Upturned plates in association with V-impact pits, solution and precipitation. D) dish-shaped depressions and V-shaped pits.

The surface features of quartz grains from coastal sabkha deposits are mainly characterized by chemical features rather than features of mechanical origin. They are characterized by triangular etching pits (Fig. 5A, B and D). These textures usually indicate a high energy chemical environment (Krinsley and Doornkamp, 1973). Deep etching grooves (Fig. 5B) are frequently present as result of chemical processes, in particular, silica solution. It was also noticed that the surfaces of the quartz grains from the sabkha deposits display silica precipitation features, for instance irregular plates and cavity filling as well as silica plastering (Fig. 5B) where excess silica is pressed over quartz grain surface in non-oriented pattern. This may be explained by the movement of grains across one another under high pressure (Krinsley and Doornkamp, 1973).
Etching and precipitation of silica on surface grain (Fig. 5C), precipitation of silica on triangular etching pits (Fig. 5D) are also noticed. The most diagenetic features of this environment are the triangular etch depressions where chemical etching along planes of weakness occur extensively. This texture usually indicates a high energy environment. Solution (etching) and precipitation are mostly developed in the recent nearsurface diagenetic environment. The increasing rate of evaporation and the existence of saline brine generally increase the pH which affects the quartz grains and influence the development of chemical features (Udayaganesan et al., 2011). Abd-Alla (1991) found the dominance of chemical features on the surface of quartz grains in the Mediterranean coast of sabkha deposits. The types and frequency of chemical features of quartz grains from sabkha deposits suggest that the grains have been subjected to high energy chemical dissolution.

**Wadi Deposits**

Quartz grains from wadi deposits are commonly characterized by mechanical features and minor chemical features. Mechanical surface features of quartz grains are mainly represented by conchoidal fractures, upturned plates, mechanical V- pits and pitted grooves (Fig. 6A-D). Upturned plates (Fig. 6C), which are usually developed by mechanical action, have been enhanced by silica precipitation on these grains tends to give them a dull surface, characteristic of desert dune sand grains (Kuenen and Perdok, 1962).

From the preceding discussion it is clear that the coastal and wadi sediments are characterized by the prevalence of mechanical features rather than chemical one. The Mechanical features may reflect the effect of both subaqueous and aeolian origins. The subaqueous origin is supported by the presence of V- shaped pits, conchoidal fractures, pitted grooves and straight or pitted grooves (Krinsley and Doornkamp, 1973), whereas the aeolian effects are related to the presence of upturned plates, meandering ridges and graded arcs. The presence of aeolian features in such beach sediments which are probably relict from aeolian environments may suggest that some aeolian sands were reworked by waves and tidal currents to form these beach sand deposits. Alternatively, some of such beach sands were subjected to transportation
by winds following their deposition. On the other hand, chemical features are intensely imprinted on some of our studied sand grains showing two clear phases of both dissolution and precipitation features; comprising irregular solution pits, etched cavities and smoothed surfaces. The dissolution and precipitation features observed in the studied quartz grains have been considered by several authors to be related to diagenetic processes, e.g. (Krinsley and Doornkamp, 1973).

Fig. 5. Surface features of quartz sand grains from sabkha deposit as observed by SEM. A) Medium relief with chemically weathered surfaces. B) Upturned scattered silica plastering associated with triangular solution pits and irregular plates. C) Precipitation of silica on grain surface. D) Precipitation of silica on triangular etched pits.

In hot and arid conditions which prevail along Red Sea, evaporation of pore water in these sediments during diurnal tidal cycles may have led to high concentration of dissolved salts and rising the pH values. Under such conditions, silica dissolution altered some of the quartz surfaces, that it may be redeposited when suitable microenvironmental conditions are available (Krinsley and Doornkamp, 1973).
Fig. 6. Surface features of quartz sand grains from wadi deposit as observed by SEM. A) dish-shaped depressions associated with conchoidal fractures and deep pits modified by silica solution. B) Upturned plates in association with V-impact pits. C) Upturned plates and meandering ridges. D) Straight steps, associated with scattered pits.

Conclusions

Examination of quartz grain surfaces from four recent environments along the coastal area in the southern Red Sea of Yemen reveals the occurrence of mechanical and chemical surface features. From the relative frequency distribution of the various surface features on the quartz sand grains from the sediments studies, it is noticed that mechanical features are prevalent in wadi deposits, coastal dune sands, and beach and nearshore sands. Chemical features are mostly confined to coastal sabkha deposits. Mechanically formed grooves are predominant feature followed by impact V-marks and conchoidal fractures. Rounding of the grains and smoothening of the edges indicate high energy zone. Etch V-shaped and solution pits are dominant features followed by precipitation of chemical processes. Evaporation and exposure of quartz grains in the dry intervals increase the pH which subsequently led to the
etching process. In addition, the presence of diatoms on the quartz grains of the beach supports the process of chemical precipitation in a high-silica environment.

Mechanical and chemical surface features of quartz grains from the study recent sediments along the coastal area in the southern Red Sea of Yemen and associated environments show overlap similarity as would be expected in fluvial- coastal marine system where sediment is readily recycled between markedly different environments.

Relative frequency distribution study highlighting the proportions of mechanical and chemical features, however, shows that there are sufficient differences in the assemblages of textures to distinguish the aeolian-dominated environment (wadi deposits and coastal dune sands) from the subaqueous environment beach sands and nearshore sands from the chemical active- dominated ones coastal sabkha deposits.

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Reference


النسيج السطحي على حبيبات الكوارتز من البيئات الرسوبية الحديثة في المنطقة الساحلية الممتدة بين الخوخة والمخاء، البحر الأحمر، اليمن

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المستخلص. يتناول البحث دراسة النسيج السطحي لحبيبات الكوارتز الممثلة لرواسب البيئات الساحلية الحديثة باستخدام الميكروسكوب الماسيح الإلكتروني، وأوضحت النتائج تأثير الفعل الميكانيكي والكيميائي على حبيبات الكوارتز.

أثبتت الدراسة أن النسيج السطحي لحبيبات الكوارتز في ترسيات الأودية ورواسب الكثبان الساحلية الشاطئية تأثرت بكل من العوامل الميكانيكية والكيميائية والتي تشكلت خلال نقل الحبيبات في البيئات تحت المائية والهوية. بينما أظهرت حبيبات الكوارتز لرواسب السبخات سيادة العوامل الكيميائية التي تعود لتحلل السيليكا.