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Microtextures and trapped diatoms on quartz grain surfaces in the Acapulco Beach, Mexican Pacific: An insight into palaeoenvironment

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ABSTRACT

In this study, we report Scanning Electron Microscopy (SEM) images of quartz grains in the Acapulco beach, Mexican Pacific. The morphology of quartz grains is angular, sub-angular, sub-rounded, rounded, and well-rounded. The variations in the morphology of quartz grains are indicating both nearby and distance sources. The rounded and well-rounded grains support for a long transport distance and a distal source. Microtextures of mechanical and chemical origins are identified in quartz grains. The mechanical features include, bulbous edges (ble), elongated depression (ed), parallel striations, crater, meandering ridges (mr), arcuate steps, conchoidal fractures (cf), v-shaped marks (v-s), and broken grain. These mechanical features indicate the combination of fluvial, aeolian, and subaqueous environments. The conchoidal fractures are characteristic of crystalline rocks. Arcuate steps and meandering ridges are indicating a high wave energy. The striations on grain surfaces are due to collision between two grains, probably during an aeolian transport.

The chemical features include adhered particles (ap), solution pit (sp), silica globule, crystal overgrowth (crg), precipitation, and trapped diatoms. The solution pits and precipitation are indicating the diagenetic processes in a silica saturated coastal environment. A few grains are associated with both mechanical and chemical features, suggesting a dual environment, probably littoral and marine. Trapped diatoms identified in quartz grains are *Cocconeis guttata* and *coccolith*.

Keywords: SEM, sand grains, microtextures, beach sediments, active margin. Pacific Ocean

INTRODUCTION

Microtextures of quartz grains are one of the widely applied techniques to infer the palaeoenvironment of a particular region (Machado et al. 2016; Ramos-Vázquez et al., 2023; Saha and Sinha, 2023). Although microtextures on quartz grains are influenced by the medium of transport, their types are distinct for the fluvial, littoral, and aeolian environments. Hence, the combination of different features in a single quartz grain is reliable to predict the paleoenvironment (Costa et al., 2019; Darshan et al., 2022). In general, the microtextures in quartz grains are due to grain-to-grain collision during transport, either by wind or water, and their types are varying, depends on the energy in the depositional environment or medium of transport. In fact, rounded and angular quartz grains indicate long and short transport distance, respectively (Mathur et al. 2009; Armstrong-Altrin, 2020). Several authors documented that conchoidal fractures, arcuate steps, striations, and linear fractures are typical of mechanical origin. Similarly, other studies grouped solution pits, adhered particles, and trapped diatoms on quartz grain surfaces into chemical origin. On the other hand, a quartz grain dominated by both chemical and mechanical origin are subjected to a heterogenous provenance. Hence, differentiating the microtexture types on quartz grain surface by SEM is a powerful tool to predict the palaeoenvironment (Madhavaraju et al. 2021; Passchier et al., 2021).

In Mexico, a very few authors studied the microtextures of quartz grains recovered from the coastal sediments. Some of them are briefly discussed below: Madhavaraju et al. (2021)

analyzed the sand grains in the Gulf of California beach and Ramos-Vázquez (2023) described various types of microtextures of quartz grains in the Puerto Chiapas beach, Mexican Pacific. Others discussed the morphology of sands grains recovered from dunes, along the Mexican Pacific coast (Kasper-Zubillaga 2009; Mejía-Ledezma et al., 2020). Recently, Ramos-Vázquez and Armstrong-Altrin (2021a, b) and Armstrong-Altrin et al. (2021, 2022), studied the palaeoenvironment of the Gulf of Mexico coastal region, based on the surface features of quartz grains obtained by SEM images. However, studies on quartz grain surface features from the Mexican Pacific coast is very little. In this study, we report the microtextures of quartz grains recovered in the Acapulco beach sediments in the Mexican Pacific coast, Mexico. The objective of this study to identify the microtextures and to infer the palaeoenvironment.

STUDY AREA

The Acapulco beach (16°50´22.52" N and 99°51´03.12" W) is in the Guerrero State, Mexican Pacific coast, southern part of Mexico (Fig. 1). About 10 sediment samples were collected in the Acapulco beach and ~ 20-30 quartz grains were selected for SEM study. In the Guerrero Stata rocks are dominated by: (1) granites and granitoids of Early Paleocene; (2) volcanic rocks of intermediate to acid composition, mostly of Early Tertiary age; (3) sedimentary rocks of Mesozoic to Tertiary ages; and (4) Quaternary alluvium. Sediments in the Acapulo beach are supposed to derive from the Guerrero terrane (Verma et al., 2017, 2020). The Guerrero terrane is associated with Late Jurassic to Early Cretaceous igneous and sedimentary rocks considered to be developed in an intra-oceanic setting (Ortega-Gutiérrez, et al., 2004). The major rivers that discharge relatively near to Acapulco beach is Cihuatlán. A warm humid climate prevails with an average annual maximum temperature of 28°C and a minimum of 22°C, whereas during summer raining with a variation from 2 to 15mm (CONANP, 2003).

METHODOLOGY

SCANNING ELECTRON MICROSCOPY - SEM

Quartz grains were picked from 10 sediment samples (~ 2 kg each) under the binocular microscope. The quartz grains were treated with 5% diluted hydrochloric acid solution to remove soluble carbonates. The grains were dried at 50° C and were coated with thin gold film (Armstrong-Altrin and Natalhy-Pineda, 2014). The JEOL JSM6360LV - SEM equipped with secondary electron detector is used to infer microtextures, which is located at Instituto de Ciencias del Mar y Limnología (ICML), Universidad Nacional Autónoma de México (UNAM).

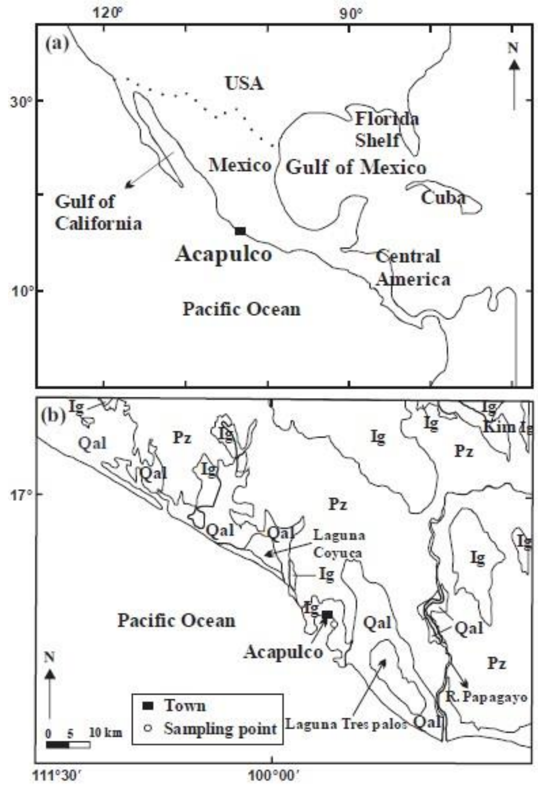

Fig. 1 Simplified geological map of the study area showing sample location (Modified after Armstrong-Altrin, 2009; CONANP, 2003). (a) Map showing location of the Acapulco beach, Mexico; (b) Volcanic and sedimentary units are: Ig = intrusive igneous rocks; Ige = extrusive igneous rocks (andesite); Jss = sedimentary rocks (lower Jurassic); Mi = intrusive rocks (Mesozoic); Pz = metamorphic rocks (Proterozoic); Qal = alluvium (Quaternary); Tiv = volcanic rocks (lower Tertiary); Tivc = volcanoclastic rocks (lower Tertiary); Tm = marine rocks (Tertiary; sandstone, mudstone); To = sandstone and limestone (Oligocene); Tsc = clastic rocks (upper Tertiary).

RESULTS

The different types of microtextures identified by SEM are shown in Figures 2 and 3. Based on their origin the microtextures are classified as Mechanical (Fig. 2) and Chemical types (Fig. 3). The morphology of quartz grains in the Acapulco beach are classified as angular (Fig. 2A), sub-angular (Fig. 2B), sub-rounded (Fig. 2C), rounded (Fig. 2D and E), and well-rounded (Fig. 2F and G).

MECHANICAL ORIGIN

The microtextures of mechanical origin identified in the quartz grains are listed below: well-rounded grains with bulbous edges (Fig. 2F and G) (ble), elongated depression (ed) (Fig. 2H), parallel striations (2I, J, K, and L), crater (2L), meandering ridges (mr) (Fig. 2M), arcuate steps (Fig. 2M), conchoidal fractures (cf) (Fig. 2N, O, and P), v-shaped marks (v-s) (Fig. 2P, Q, R, and S), and broken grain (Fig. 2T).

CHEMICAL ORIGIN

Microtextures of chemical origin includes, adhered particles (ap) (Fig. 3A, B, and C), solution pits (sp) (Fig. 3B, C, D, E, F, and G), silica globule (Fig. 3 H), crystal overgrowth (crg) (Fig. 3H, I, J, and L), precipitation (Fig. 3K and L), and trapped diatoms (Fig. 3 L, M, N, O, and P).

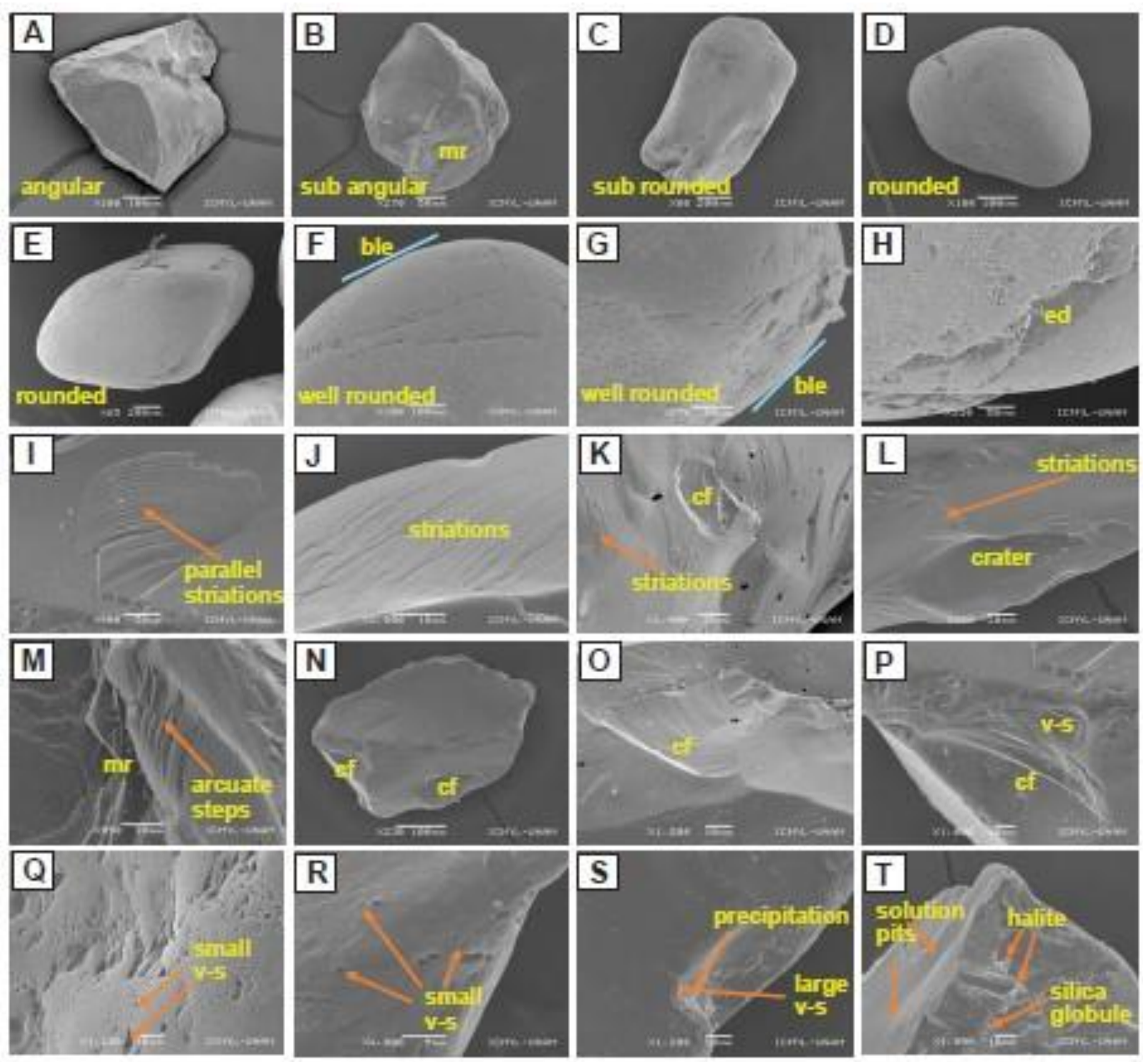

Fig. 2 Surface microtextures on quartz grains identified by SEM from the Acapulco beach, Mexican Pacific: (A) angular grain; (B) sub-angular grain; (C) sub-rounded grain; (D) rounded grain; (E) rounded; (F and G) well-rounded grains with bulbous edges (ble); (H) elongated depression (ed); (I, J, K, and L) parallel striations; (L) crater; (M) meandering ridges (mr); (M) arcuate steps; (N, O, and P) conchoidal fractures (cf); (P, Q, R, and S) v-shaped marks (v-s); (T) broken grain with chemical features

DISCUSSION

PALEOENVIRONMENTAL IMPLICATIONS

MECHANICAL FEATURES

The mechanical features identified in the Acapulco beach sands are indicating a high energy coastal environment. Rounded and sub-rounded grains are due to abrasion between two grains during transport, especially indicating a longer transport distance. The rounded grains with bulbous edges are indicating an aeolian transport and rolling of grains during saltation (Costa et al. 2013; Ramos-Vázquez and Armstrong-Altrin, 2019, 2020; Yhasnar et al., 2023). On the other hand, angular and broken quartz grains are indicating a short littoral transport. The combination of angular and well-rounded grains is revealing both proximal and distal sources. The parallel (Fig. 2I) and sub-parallel striations (Fig. 2J and L) on quartz grain surfaces are due to a collision between two grains during transport, either by wind or littoral transport. Meandering ridges and arcuate steps are indicating a grain to grain collision during saltation or suspension in a subaqueous coastal marine environment (Hossain et al., 2014; 2020). Similarly, meandering ridges are also indicating a long-distance transport of quartz grains in a fluvial environment (Madhavaraju et al., 2022). Meandering ridges may convert easily to elongated depressions due to large scale abrasion (Fig. 2H). A rare feature crater (Fig. 2L) identified in a quartz grain is indicating an impact between two grains with high energy, probably during wind transport. Later the impact point in a quartz grain is polished due to abrasion by wave action in a coastal environment. The conchoidal fractures are widely varying in size, i.e. small (Fig. 2K and N) and large (Fig. 2L and P). Few authors reported that large size conchoidal fractures with depressions of about 20-250 µm in size may indicate a glaciofluvial origin as well as a crystalline source (Mejía-Ledezma et al. 2020; Armstrong-Altrin et al., 2021). Similarly, v-s are triangular shaped pits, which are also common in the analyzed quartz grains and are varying widely in their size and frequency. Some of the v-s are large in size and are less in number (Fig. 2S). However, relative to large v-s, small size v-s are abundant and its distribution is high in a single grain (Fig. 2Q, and R; Fig. 3C). The origin of v-s is due to gouging and a mechanical collision between two grains. In general, v-s are suggesting a high energy subaqueous environment. However, other studies documented that v-s in quartz grains are suggesting both glaciofluvial and fluvial transport (Madhavaraju et al., 2009; Hossain et al., 2020). In summary, this study reveals the combination of microtextures derived by both wind and littoral transport.

CHEMICAL FEATURES

Chemical features are abundant in the quartz grains from the Acapulco beach. Adhering particles on grain surfaces are common, which are mostly fragmented rock pieces or other particles such as algae, microplastics, foraminifer, etc. (Fig. 3A and C). Adhering particles are highly reliable to infer the diagenetic characteristics of a particular depositional environment, i.e. shallow or deep water, marine or fresh water, and glacial or eolian (Bónová et al. 2020). Solution pits on quartz grains are varying widely in their size and shape, which are circular, sub-circular, and irregular in shapes (Fig. 3F), some of them are bigger in size, greater than 15 µm (Fig. 3G). In addition, few solution pits identified are smaller in size, similar to raindrop prints (Fig. 3C). Solution pits (Fig. 3B, C, D, E, F, and G) and precipitation (Fig. 3K and L) are indicating different stages of a diagenetic environment or chemical action in a marine environment, where water is saturated with silica. In fact, sea water acidification can also increase the intensity of solution activity in a marine environment. The frequency of solution pits is depending on the availability of silica solution and their time of stay in a particular marine environment. Similarly, the intensity of solution and precipitation in a marine environment is depending on the acidity of sea water, grain hardness and corrosion strength. The diagenetic features are relatively less in heavy minerals, such as magnetite, ilmenite, and zircon (Armstrong-Altrin, 2020). On the other hand, crystal overgrowth in quartz grains is frequently observed in many grains (Fig. 3H, I, J, and L), indicating an in-situ precipitation and an aquatic diagenetic environment. Crystal overgrowth in quartz grains are generally represented by halite crystals (Fig. I and J), but occasionally are associated with silica globules, due to silica precipitation (Fig. 3H).

In addition to chemical features, trapped diatoms are identified in many grains, which are well preserved and indicating a nutrient rich sea water (Fig. 3L, M, N, O, and P). An elliptically shaped diatom called *Cocconeis guttata* (Hustedt and Aleem 1951) is identified in a quartz grain surface, in a well-preserved form (Fig. 3O). It is interesting to note that the distribution of *Cocconeis guttata* was recorded from the coastal waters of England (Hustedt and Aleem 1951) and France (Riaux-Gobin, 1991). In 2003, it was recorded for the first time from the shallow coastal waters of the Gulf of Matías, southwestern Atlantic

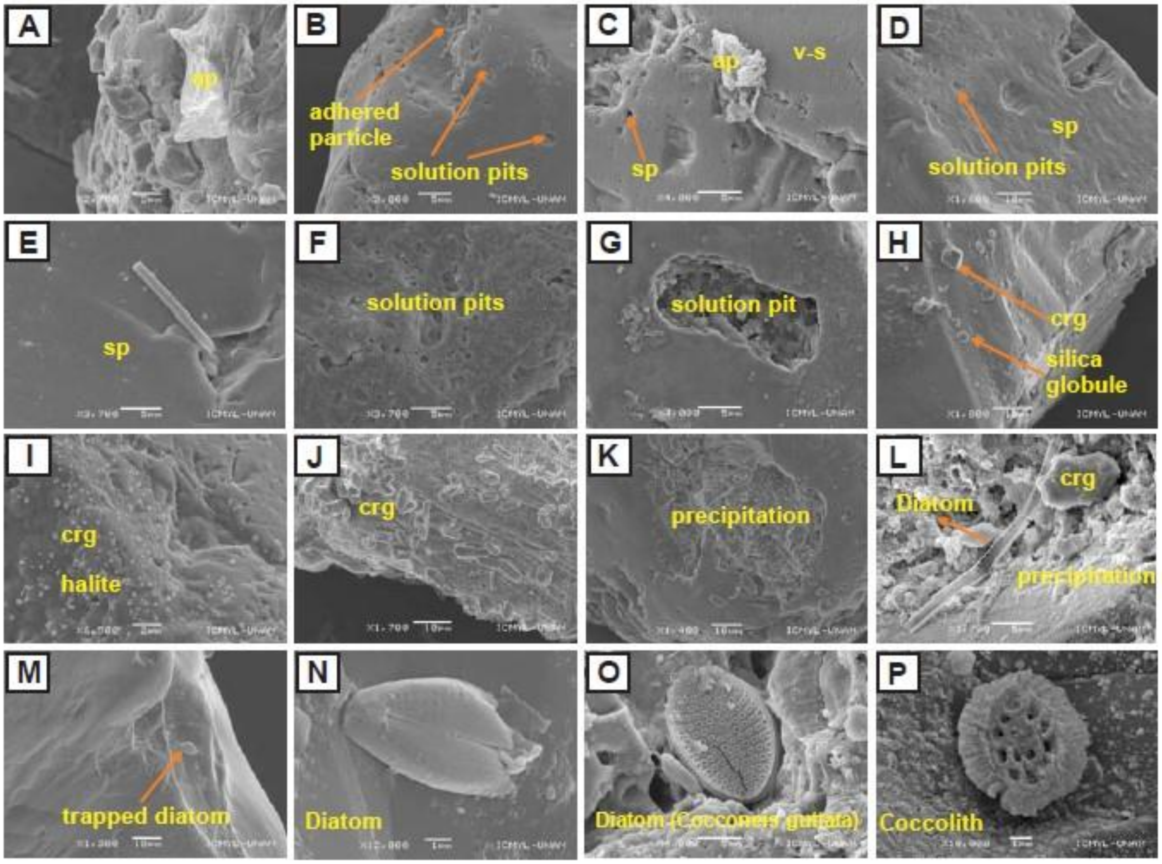

Fig. 3 Microtextures on quartz grain surfaces in the Acapulco beach, Mexican Pacific: **(A, B, and C)** adhered particles (ap); **(B, C, D, E, F, and G)** solution pits (sp); **(H)** silica globule (sg); **(H, I, J, and L)** crystal overgrowth (crg); **(3K and L)** precipitation; **(L)** diatom; **(M)** diatom; **(N)** enlarged view of previous image; **(O)** Diatom *Cocconeis guttata*; **(P)** Coccolith.

Ocean (Sar et al., 2003). Similarly, a fragmented disc shaped *coccolith* is identified (Fig. 3P), which is a single-celled organism, part of the phytoplankton, mostly 5-20 µm in diameter. *Coccoliths* form the part of calcite oozes, which are utilized in other studies to reconstruct the past climate (Arundhathy et al., 2021). Few quartz grains are with both mechanical and chemical features: 1) a broken grain with silica globule, halite, and solution pit (Fig. 2T) and 2) solution pits, adhering particles, and v-s (Fig. 3C), which are indicating a dual environment.

CONCLUSIONS

The morphology of quartz grains varies from angular to well-rounded, indicating the mixing of grains derived from the nearby and distal sources. The well-rounded grains in the Acapulco beach reveals that the sediments were partly supplied by the dunes and re-distributed along the coast by a littoral current. The microtextures on quartz grains in the Acapulco beach are classified as mechanical and chemical origin. The microtextures of mechanical origin includes well-rounded grains with bulbous edges, elongated depression, parallel striations, crater, meandering ridges, arcuate steps, conchoidal fractures, and v-shaped marks. Microtextures of chemical origin are represented by adhered particles, solution pits, silica globule, crystal overgrowth, precipitation, and trapped diatoms.

V-shaped marks, bulbous edges, and meandering ridges are indicating littoral and high-energy marine depositional environment. Parallel striations represent a high energy collision and abrasion during aeolian transport. The combination of v-s and solution pits in a single grain indicates that the grain was suffered by both littoral and a subaqueous marine environment (dual environment). The differences in surface features in quartz grains indicate that the sediments were transported to the Acapulco beach by aeolian and fluvial activities. Silica globules, solution and precipitation in quartz grains reveal a silica saturated marine environment. The diatoms like

Cocconeis guttata and *coccolith* are also identified on quartz grain surfaces.

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AUTHOR CONTRIBUTION

John S. Armstrong-Altrin: Investigation, Writing - Review and Editing, Formal analysis, Resources, Funding acquisition. V. Balaram: Review and Editing. Mayla A. Ramos-Vázquez: Field work, SEM analysis. Jayagopal Madhavaraju: Methodology, Formal Analysis, Editing. Sanjeet K. Verma: Methodology, Formal Analysis, Review and Editing. Rathinam Arthur James: Data curation, Methodology, Formal analysis. All authors contributed equally in writing, reviewing, and editing the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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