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ORIGINAL PAPER

Microtextures of detrital sand grains from the Tecolutla, Nautla, and Veracruz beaches, western Gulf of Mexico, Mexico: implications for depositional environment and paleoclimate

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Abstract Detrital sand grains from three beaches (Tecolutla, Nautla, and Veracruz) along the western Gulf of Mexico were studied by a scanning electron microscope, to investigate the depositional environment and paleoclimate. Totally, 24 microtextures are identified; among them, 13 are grouped as mechanical origin, 5 as mechanical and/or chemical origin, and 6 as chemical origin. These microtextures are nonuniformly distributed among the three beach areas. Concoidal fractures, straight and arcuate steps at Tecolutla and Veracruz beaches indicate that the sand grains were derived from the crystalline rocks. The abundance of angular outline grains at the Nautla beach supports for short transportation probably close to the source area. The domination of rounded sand grains in the Veracruz beach reveals that the sediments were derived by the aeolian mechanism. Chattermark trials at the Veracruz beach sands are indicating a wet tropical climate. Chemical features like silica globules, silica pellicle, and trapped diatoms in the Tecolutla and Veracruz beach sands suggest a silica saturated environment. Similarly, chemical etching and solution pits are common in the Veracruz beach sands, which are probably linked to the contaminated sea water. Desiccation crack at Veracruz beach sands is an indicator of temperature changes in the beach environment. Broken benthonic foraminifera *Elphidium discoidale* sp. present in the Veracruz beach indicates a high-energy littoral environment.

Keywords Surface features · Roundness · Quartz grains · SEM · Provenance · Chattermark trails

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Introduction

The combination of microtextures on detrital sand grain surfaces can be able to explain the palaeo-environmental history of the area from which the grains were originally derived. Identifying microtextures using a scanning electron microscope (SEM) is one of the important tools to interpret the ancient sedimentary environments and potential transport mechanisms (Krinsley and Marshall 1987; Helland and Diffendal 1993; Mahaney et al. 2001, 2004; Alekseeva and Hounslow 2004; Armstrong-Altrin et al. 2005; Kenig 2006; Madhavaraju et al. 2006; Kasper-Zubillaga and Faustinos-Morales 2007). The diagnostic patterns of microtextures on sand grain surfaces depend largely on the type of environmental provenance, and one can be able to differentiate them from various environments like fluvial, marine, aeolian, and glacial. If the sand grain was subjected to different environments, then the surface features may consists a mixture of different microtextures produced during transportation (Chakroun et al. 2009; Newsome and Ladd 1999).

Microtextures are commonly classified as mechanical, mechanical, and/or chemical, and chemical, based on its origin. Conchoidal fractures, v-shaped fractures, and straight or arcuate steps are linked to mechanical origin, while aeolian pitting, relief, and adhering particles are referred to mechanical/chemical origin (e.g., Madhavaraju et al. 2006; Kenig 2006). Silica globules, effects of silica dissolution, and precipitation are classified as chemical origin (e.g., Kasper-Zubillaga and Faustinos-Morales 2007).

Kasper-Zubillaga and Faustinos-Morales (2007) investigated the characteristics of sand grain surface features between desert and coastal dune environments (Altar desert, NW Mexico) and pointed out that quartz grains from the coastal dunes characterize more chemical features than the mechanical features. They further demonstrated that the chemical surface textures are linked to the hydrothermal activity near the Colorado River. Madhavaraju et al. (2009) summarized the microtextures found on quartz grains of two beaches along the Gulf of California coast and concluded that the beach sands are transported by fluvial and aeolian processes.

In this study, we analyze the microtextures of sand grains from the Tecolutla, Nautla, and Veracruz beaches along the western Gulf of Mexico. Based on the microtexture variety, the aim of this study is to (1) characterize the distribution of microtextures on sand grain surfaces among the three beach areas, (2) interpret the depositional environment, and (3) palaeoclimate. In addition, we report two distinct microtextures, chattermark trails, and desiccation cracks, for the first time, from the Veracruz beach.

Study area

The Tecolutla, Nautla (20°13′15.56″ N and 96°46′04.12″ W), and Veracruz (19°09′52.46″ N and 96°06′17.44″ W) beaches are located in the western part of the Gulf of Mexico, Veracruz State, Mexico (Fig. 1). The rivers feeding sediment to the Tecolutla and Nautla beaches are the Tecolutla and Nautla Rivers, respectively. The Veracruz beach area is receiving sediments by Actopan, San Juan, and Jamapa Rivers (Fig. 1).

The coastal plain is narrow in the middle of the Tecolutla beach and is wider towards the north and south. The climate is tropical to temperate with rainfall and temperature dependent on elevation (Tamayo 1991). The annual rainfall averages 1,500 mm over the entire area, with a distinct rainy season occurring in August and September (Self 1975). The coast is classified as transgressive (Boyd et al. 1992). The draining basin of the Tecolutla River is dominated by fluvial deposits (Quaternary), limestones (Cretaceous and Jurassic), sandstones (Tertiary), and extrusive basic igneous rocks (Quaternary).

The Nautla River starts in the Jalapa uplift of eastern Mexico and is one of the major rivers, which drains a large volcanic terrain (Self 1975). The Jalapa uplift is the easternmost extension of the Mexican Volcanic Belt, which is an east–west trending, Neogene to Quaternary geological province extending through Central Mexico for about 1,000 km (Fig. 1). Cenozoic volcanic rocks are Miocene–Pliocene andesites of calcalkaline composition that extend to the western part of the beach at Nautla (Cantagrel and Robin 1979; Negendank et al. 1985; Verma 2001, 2004). Similarly, Pliocene basalts of alkaline composition crops out in the central part of the coastal region (Negendank et al. 1985). The sediments delivered by the Nautla River are largely composed of volcanic rock fragments and dense heavy minerals like magnetite, pyroxenes, and amphibole and a lesser proportion of limestone fragments.

Veracruz beach lies in the western part of the Gulf of Mexico. Two major rivers drain near the study area are the Actopan and Jamapa rivers. The lithology of the rivers catchment area consists mainly of volcanic and volcanic sedimentary rocks (Ortega-Gutierrez et al. 1992). The Veracruz area is considered as one of the intensive industrialized areas in Mexico, which currently contains ~70 large petrochemical plants and various secondary industries like cement manufacturing (Rosalez-Hoz et al. 2003). The outcrops along the western Gulf of Mexico are composed of (1) Quaternary alluvium and soils, (2) Cenozoic volcanic rocks of mafic and intermediate composition, (3) Cenozoic and Mesozoic clastic and calcareous sedimentary rocks, and (4) metamorphic rocks comprising schists and gneisses of Paleozoic and Precambrian age (Padilla-Sanchez and Aceves-Quesada 1990).

Materials and methods

Sixty samples collected from Tecolutla (number of samples $n=20$), Nautla ($n=20$), and Veracruz ($n=20$) beaches along the western Gulf of Mexico were selected for the present study (Fig. 1). Approximately 20 g of each sample was washed in cold 12 % HCl to remove the carbonate coatings and ferruginous contamination. The washed samples were soaked with 30 % H_2O_2 to remove the organic debris. Adhering iron coatings were removed by boiling the grains in stannous chloride solution for 20 min. Finally, the quartz grains were washed for several times in distilled water and dried. Sand grains were picked randomly from each sample using a binocular microscope. Sand grains between 200 and 400 μm sizes were used for the present study, as they are generally considered to record the depositional features of various environments (Krinsley and McCoy 1977). Twenty grains from each sample were selected for the present study, which is considered as sufficient to represent the variability present in a single sample (Higgs 1979; Krinsley and Doornkamp 1973).

Using an optical microscope, the quartz grains were placed on SEM stubs, gold coated in a JFC-1100 Fine Coat apparatus, and examined with JEOL-JSM-6360LV scanning electron microscope at the Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México (UNAM). In general, magnifications between ×100 and ×750 were used, and for larger surface, features such as conchoidal fractures, chattermark trails, and silica precipitation were examined with magnifications from ×1,000 to ×15,000. By following Higgs (1979) and Krinsley and Doornkamp (1973), the environmental implications of various types of microtextures have been identified.

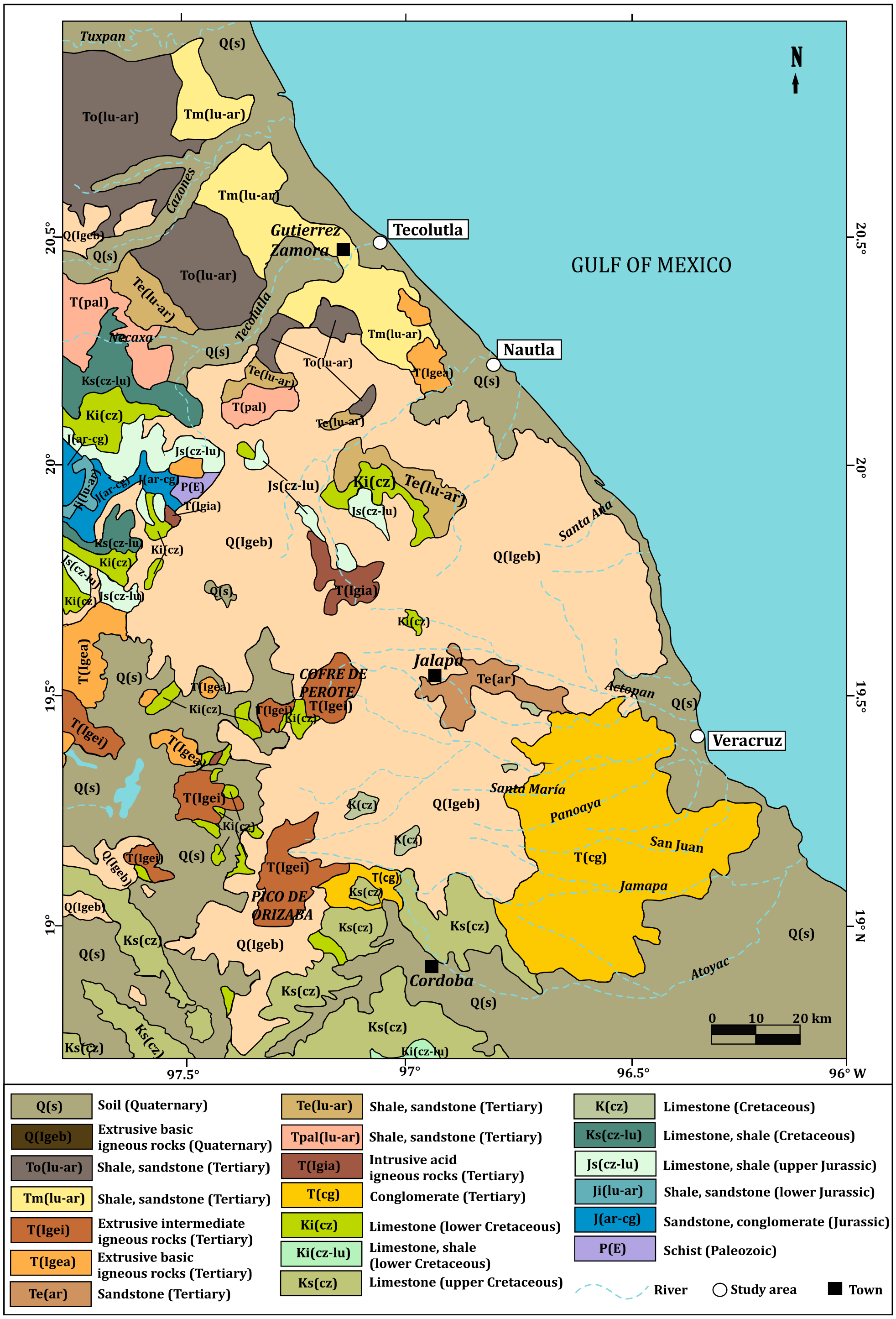

Fig. 1 Simplified geological map showing the location of the study areas

Results

The microtextures studied are listed in Table 1. Totally, 24 microtextures are identified on the sand grains surface of the Tecolutla, Nautla, and Veracruz beach sediments, and based on their origin, they are classified as three main assemblages: mechanical, mechanical/chemical, and chemical. Among 24 microtextures, 13 are classified as mechanical, 5 as mechanical/chemical, and 6 as chemical origin. Chemical origin includes microtextures developed by dissolution and precipitation.

Table 1 Microtextures identified on sand grains from the Tecolutla, Nautla, and Veracruz beaches along the western Gulf of Mexico

Microtextures	Tecolutla	Nautla	Veracruz	Origin
Small pits	Abs	C	A	Mechanical
Medium pits	Abs	C	A	Mechanical
Conchoidal fractures	P	Abs	C	Mechanical
Straight steps	P	R	C	Mechanical
Arcuate steps	P	R	S	Mechanical
Crescent steps	C	A	P	Mechanical
Straight scratches	C	C	C	Mechanical
Angular outline	P	A	Abs	Mechanical
Subangular outline	P	C	S	Mechanical
Rounded outline	Abs	Abs	C	Mechanical
Subrounded outline	P	R	C	Mechanical
V-shaped patterns	Abs	C	P	Mechanical
Smooth surfaces	Abs	Abs	S	Mechanical
Chattermark trails	Abs	Abs	P	Mechanical/chemical
Fracture plates/planes	S	S	C	Mechanical/chemical
Adhering particles	C	P	C	Mechanical/chemical
High relief	P	S	P	Mechanical/chemical
Medium relief	P	P	R	Mechanical/chemical
Solution pits	Abs	R	C	Chemical/dissolution
Etching	Abs	Abs	C	Chemical/dissolution
Silica globules	P	Abs	P	Chemical/precipitation
Silica pellicle	P	Abs	C	Chemical/precipitation
Trapped diatoms	P	Abs	C	Chemical/precipitation
Desiccation cracks	Abs	Abs	C	Chemical/dissolution/precipitation

A abundant (>75 %), *C* common (50–75 %), *P* present (25–50 %), *S* scarce (2–25 %), *R* rare (<5 %), *Abs* absent

Microtextures by mechanical origin

The distribution of microtextures among the three beaches is varying widely. For example, small and medium pits are absent in the Tecolutla beach and its frequency varies from common to abundant in the Nautla and Veracruz beaches (Fig. 2a and b, respectively). Conchoidal fractures are the most frequently found mechanical feature, which are distinctive of a high-energy environment (Krinsley and Donahue 1968). The conchoidal fractures are absent in the Nautla beach, although are present in the Tecolutla (Fig. 2c) and Veracruz (Fig. 2d) beach sands. Similarly, straight, arcuate, and crescent- shaped steps (Fig. 2e–g, respectively) associated with conchoidal fractures are identified in the Tecolutla and Veracruz beach sands, which are rare at the Nautla beach. The frequency of parallel striations (Fig. 2h) varies from present to common among the three beach areas (Table 1). The Tecolutla and Nautla beach sands are concentrated with subangular and angular grains (Fig. 3a, b), whereas Veracruz beach sands are dominated by rounded and subrounded grains (Fig. 3c, d). A subrounded edge sand grain with a combination of microtextures such as straight striations, silica precipitation, and mechanical v-marks is present at the Veracruz beach (Fig. 3e). The grain-to-grain impact features such as v-shaped patterns (Figs. 3f–h) and smooth surfaces (Fig. 4a, b) are common in the Veracruz beach sands.

Microtextures by mechanical/chemical origin

The microtextures such as chattermark trails, fracture plates, adhering particles, and relief are grouped as mechanical/chemical origin (Table 1). Similar to the mechanical surface features, the frequency of distribution of mechanical/chemical features among the three beach areas are varying. For example, chattermark trails (Fig. 4c, d, and e) are present in the Veracruz beach but are absent in the Tecolutla and Nautla beaches. Fracture plates (Fig. 4f) are sparsely distributed in the Nautla and Veracruz beach sands. The sand grains are mostly of medium to high relief (Fig. 4g) and rarely with low relief (Fig. 4h). Adhering particles are common in the sand grain surfaces of the three beach areas (Fig. 5a–c).

Microtextures by chemical origin

Chemical features identified are solution pits, etching, silica globules, silica pellicle, trapped diatoms, and desiccation cracks (Table 1). Depending on the mode of origin, the chemical features are classified as chemical dissolution and precipitation.

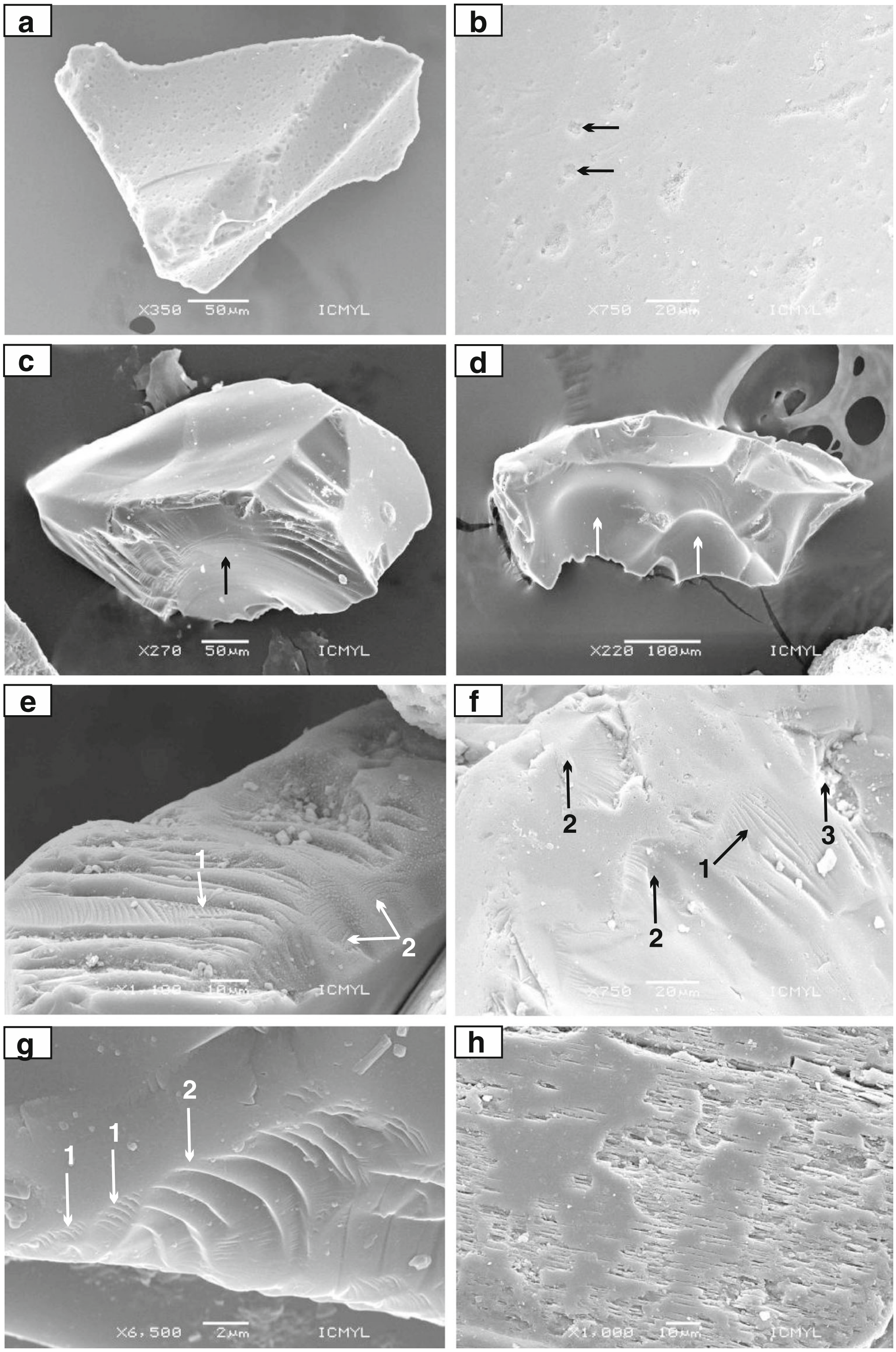

Fig. 2 SEM images of a variety of microtextures observed on sand grains from the Tecolutla (**c**, **e**, and **h**), Nautla (**a**), and Veracruz (**b**, **d**, **f**, and **g**) beaches along the western Gulf of Mexico. **a** Subangular grain with irregular small pits. **b** Medium size pits. **c** Conchoidal fracture. **d** Conchoidal fracture. **e** Straight (1) and arcuate steps (2). **f** Arcuate steps (1). The impact zones (*2*) on the grain surface reveal grain-to-grain collision during aeolian transportation. The fracture zones are filled with carbonate particles (*3*), **g** small (*1*) and large (*2*) size crescent-shaped steps, and **h** parallel striations

Chemical dissolution

The solution pits formed by the chemical dissolution on sand grains are mostly circular and subcircular (Fig. 5d, e), which are frequently distributed in the Veracruz beach. A polished or smooth grain surface (Fig. 5f) showing circular etching (Fig. 5g) with silica precipitation is also identified at Veracruz beach. In some places, the etching appears like a dissolution process by solution activity (Fig. 5h). In addition, rare microtexture like desiccation cracks (Fig. 6a, b) from the Veracruz beach sands are likely due to the temperature changes in the beach environment.

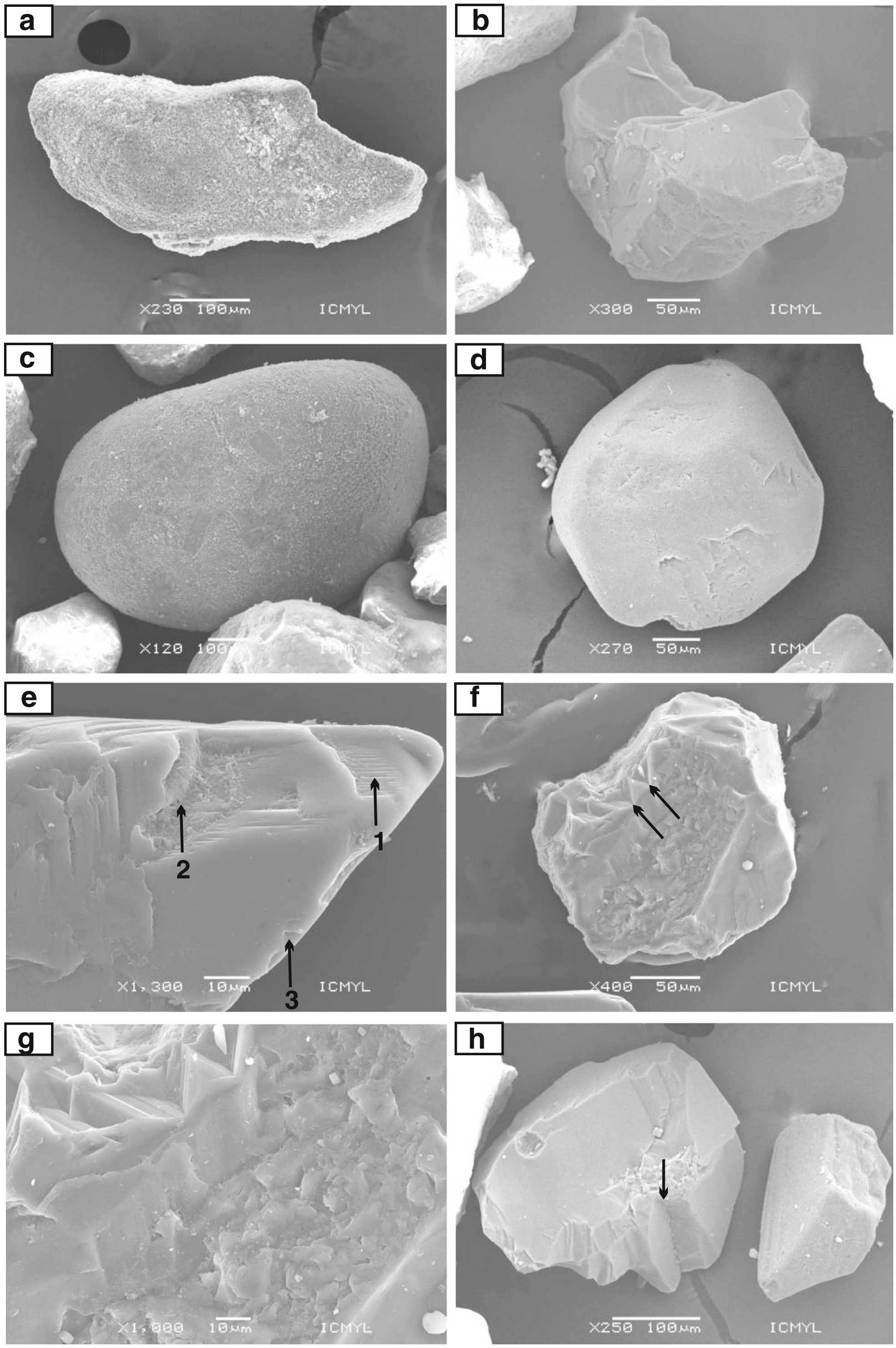

Fig. 3 SEM images of a variety of microtextures observed on sand grains from the Tecolutla (**a**), Nautla (**b**, **f**, and **g**), and Veracruz (**c**, **d**, **e**, and **h**) beaches along the western Gulf of Mexico. **a** Subangular grain. **b** Angular grain. **c** Rounded grain. **d** Subrounded grain. **e** Curved edge grain with straight striations (*1*), silica precipitation (*2*), and mechanical v-marks (*3*). **f** v-shaped patterns. **g** Higher magnification of the previous micrograph. **h** v-shaped patterns

Chemical precipitation

Silica globules, silica pellicle, and trapped diatoms are grouped as chemical precipitation origin. The silica globules (Fig. 6c) at Veracruz and Tecolutla beach sands are probably formed during its contact with solutions supersaturated with silica (Madhavaraju et al. 2009). This leads to the formation of amorphous silica in the form of silica pellicles (Fig. 6d), identified at Veracruz and Tecolutla beach sands. The fresh appearance is emphasized by a chemical cleaning of the grain in the beach environment (Cremer and Legigan 1989). Trapped diatom (Fig. 6e) within the fracture surface of the

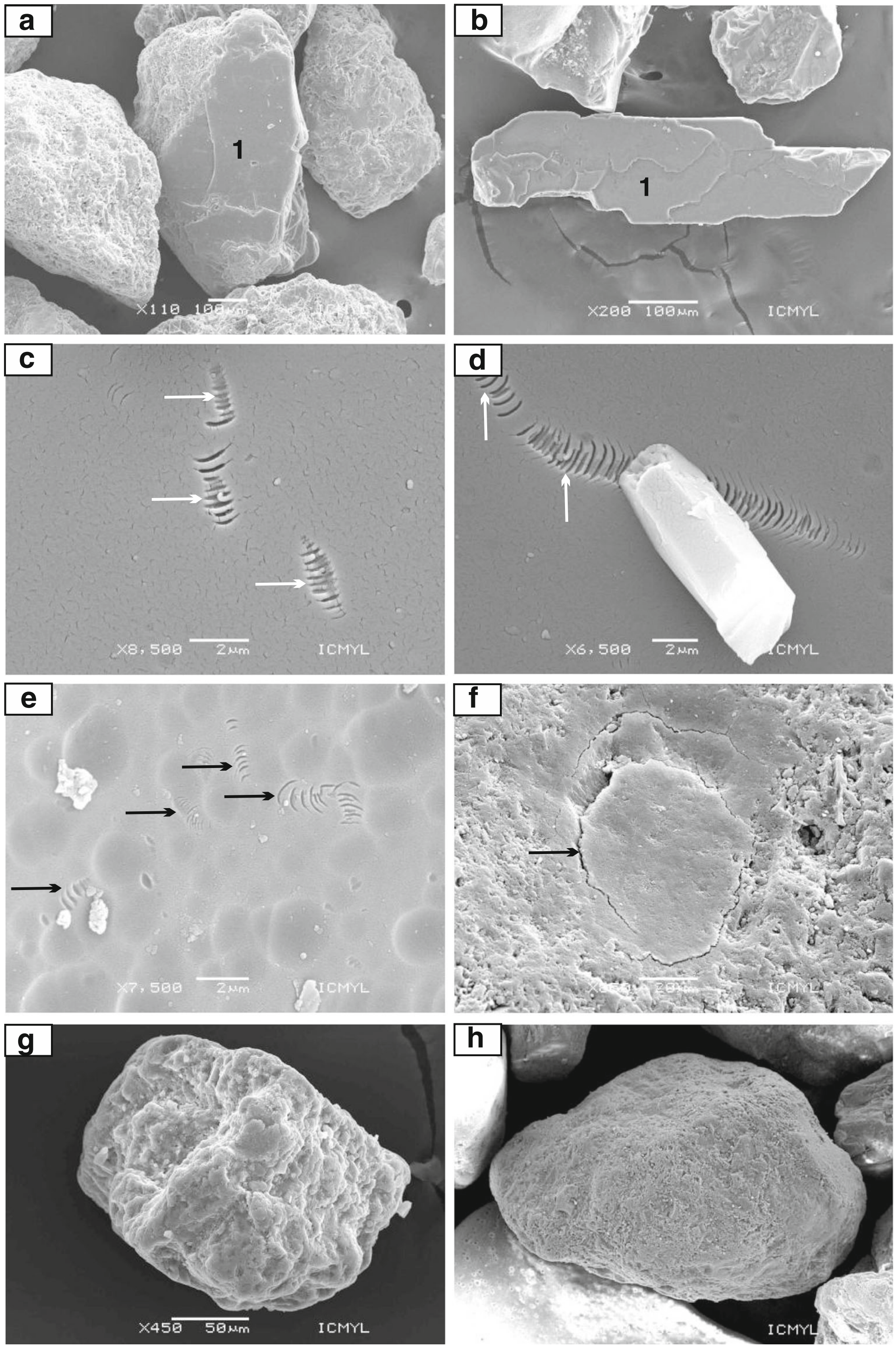

Fig. 4 SEM micrograph observed on sand grains from the Veracruz (**a**–**g**) and Nautla (**h**) beaches along the western Gulf of Mexico. **a**, **b** Grains with smooth surface (*1*). **c**–**e** Irregular chattermark trails. **f** Sand grain with fracture plate. **g** Subangular sand grain with high relief. **h** Low relief subangular grain

sand grains is rarely identified in the Nautla beach sands, although is common in the Veracruz beach sands. Crystalline overgrowth on the quartz grain surface is common in the Veracruz beach sand (Fig. 6f). Similarly, sand grains of Veracruz beach are enriched by foraminifera (Fig. 6g) and coral fragment (Fig. 6h), affected by dissolution and precipitation features.

Discussion

Depositional environment and paleoclimate

The sand grains from three beach areas show a wide variety of microtextures originated by mechanical, mechanical/chemical, and chemical processes (Figs. 2, 3, 4, 5, and 6).

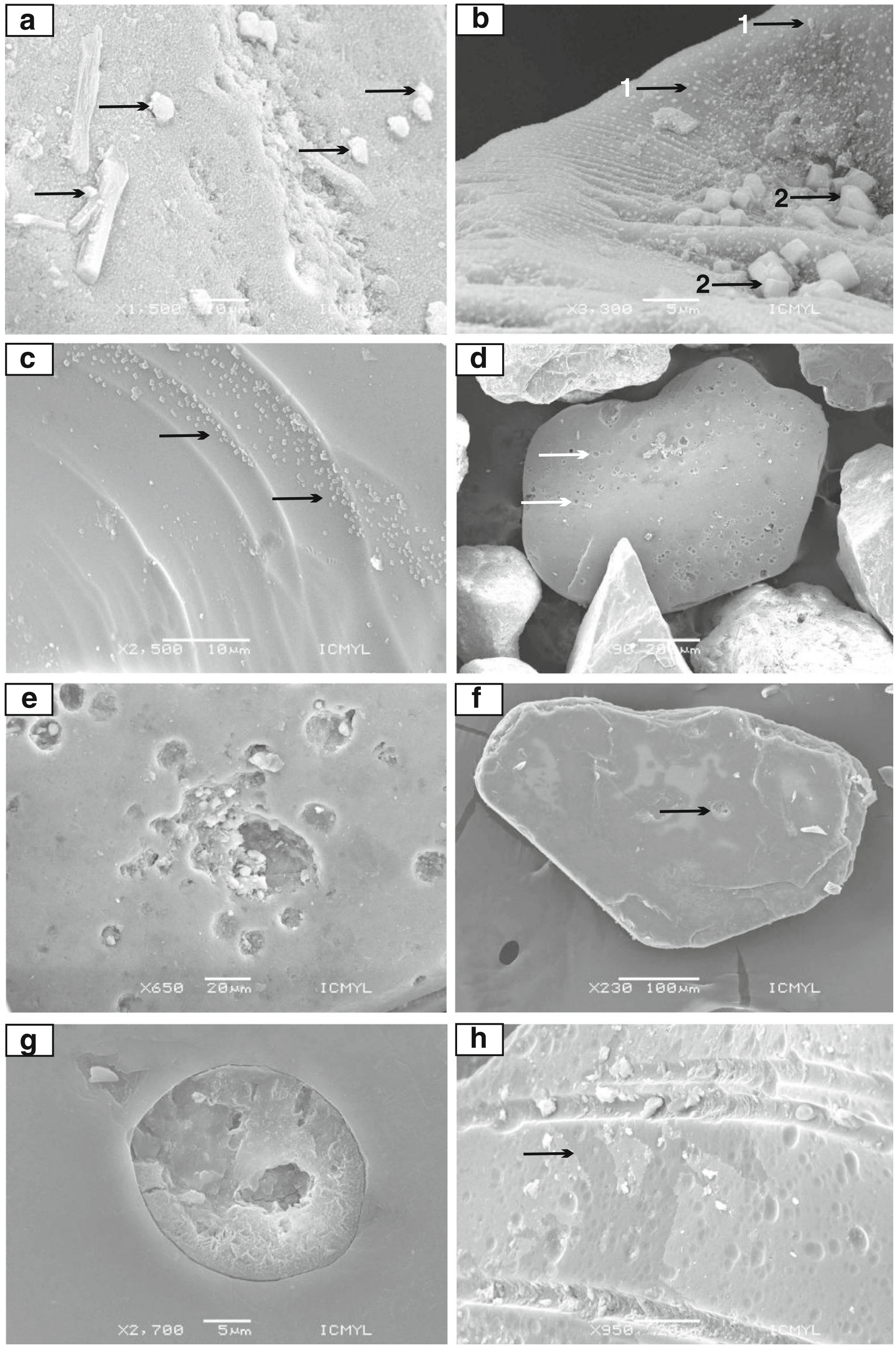

Fig. 5 SEM micrograph observed on sand grains from the Tecolutla (**a**) and Veracruz (**b–h**) beaches along the western Gulf of Mexico. **a** Adhering particles. **b** Adhering particles (*1*) with cubic halite crystals (*2*). **c** Small size cube-shaped halite crystals. **d** Circular and **e** subcircular solution pits formed due to chemical dissolution. **f** Circular etching on a polished grain surface. **g** Higher magnification of the previous micrograph. **h** Chemical etching dissolution

The frequency of distribution of microtextures on sand grains among the three beach areas is not uniform. However, Tecolutla and Veracruz beach sands are showing similarities in some of the microtextures (Table 1).

Medium and small pits (Fig. 2a, b) identified in the Nautla and Veracruz beach sands are probably suggesting the grain-to-grain collision during transportation by wind (saltation). Similarly, mechanical breakdown can also occur due to wave action during fluvial transportation (Armstrong-Altrin et al. 2005). Conchoidal fractures with arcuate steps and edge rounding are microtextures normally associated with glaciogenic sediments (e.g., Margolis and Kennett 1971;

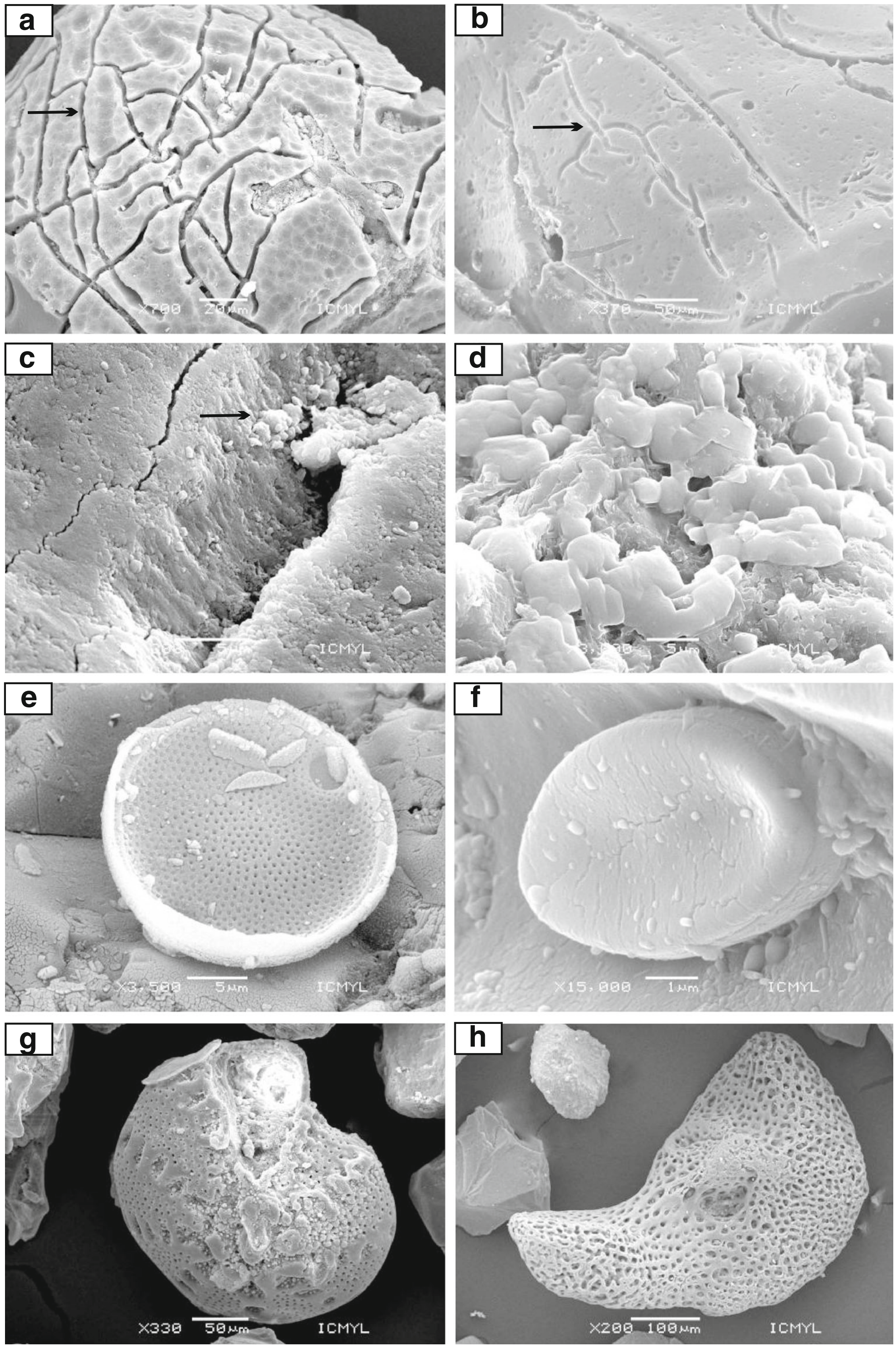

Fig. 6 SEM images of the Veracruz (**a–h**) beach sands, western Gulf of Mexico. Desiccation cracks of polygonal (**a**) and root like (**b**) shapes, likely showing temperature variations in the beach environment, **c** silica globule, **d** silica pellicle, **e** trapped diatom, **f** close-up view of crystalline overgrowth, **g** well-sorted sand-sized benthic foraminifera (*Elphidium discoidale*), and **h** coral fragment

Mahaney and Kalm 2000; Cowan et al. 2008; Deane 2010). However, many studies illustrated that conchoidal fractures and arcuate steps are the most frequently found mechanical features among the sand grains derived from the crystalline rocks, in a high energy environment, such as wave action in the littoral environment (Cardona et al. 1997; Madhavaraju et al. 2004; Armstrong-Altrin et al. 2005; Kenig 2006). The oldest rocks exposed along the western Gulf of Mexico are Precambrian ortho and paragneisses (the Huiznopala gneiss; refer Armstrong-Altrin et al. 2013; Verma 2000), with protolith magmatic ages between 1,200 and 1,150 Ma (Lawlor et al. 1999). Hence, the conchoidal fractures and arcuate steps in the Veracruz and Tecolutla beach sands (Fig. 2c–f) indicate that the sediments were derived largely from the crystalline rocks and deposited in a high energy coastal environment. The crescent-shaped steps indicate an early stage of grain evolution in a continental domain (Fig. 2g) and are related to high energy aeolian transport (Cremer and Legigan 1989). The straight scratches (Fig. 2h) observed in the three beaches are considered to be a product of high-energy transport in riverine and/or littoral environments (Krinsley and Doornkamp 1973; Alekseeva and Hounslow 2004). At Veracruz beach area, we identified a sand grain (Fig. 3e), which consists of different microtextures such as v-shaped mechanical marks, straight striations, and silica globules on its surface with polished edge. These diverse surface textures and grain morphology are indicating a multicyclic character with different histories of transportation, and provenance. For example, v-shaped marks formed in the high-energy environments such as the surf zone of the beach; rounded edge and straight striations are originated during transportation by wind (Kasper-Zubillaga et al. 2005; Udayaganesan et al. 2011). The association of diverse microtextures in a single grain suggests that the sediments of Veracruz beach may consist of sand grains derived from different sources.

Roundness depends on specific gravity, solubility, and hardness, and varying degrees of roundness of sand grains are linked with high energy environment (Costa et al. 2013). A round shape is an indicator of sands derived by aeolian processes (Kasper-Zubillaga 2009), since rounding of sand grains by aqueous traction transportation requires travel of many thousands of miles (Costa et al. 2013). In this study, a rounded grain (Fig. 3c) is identified at Veracruz beach, indicating an aeolian transport, probably derived from the dunes and consequentially mixed with the beach environment. In contrast, the Nautla beach sands are dominated by angular (Fig. 3b) and subangular (Fig. 3f) sand grains. These subangular grains with v-shaped fractures at the Nautla beach indicate its nearby source, short transportation, and rapid deposition.

The irregularly distributed v-shaped pattern pits and fractures (Fig. 3f–h) are microtextures that preferentially develop in medium- to high-energy subaqueous environments due to abrasion (Margolis and Krinsley 1974), which also can result from cumulative abrasion over multiple transport cycles and recycling (Margolis and Kennett 1971; Corcoran et al. 2010). The abundance and size of the v-shaped pits and fractures may increase when the grains are subjected to agitation in a subaqueous environment for a large span of time (Mahaney 1998). The sand grains with smooth surface are identified at the Tecolutla and Veracruz beaches (Fig. 4a, b), which seems like crushed grains indicating a postdepositional disturbance of sediments (Mahaney et al. 2004).

The chattermark trails found in different sand grains of Veracruz beach (Fig. 4c–e) are not reported previously along the coastal regions of Mexico. Chattermark trails consist of a series of linearly arranged, crescent-shaped rune-like grooves (crevasses on a grain surface). There are controversies about the origin of this chattermark trails (Gravenor et al. 1978; Peterknecht and Tietz 2011). Folk (1975) propose a glacial origin for the chattermark trails identified on a garnet grain surface and also he described the textural parameters like standard deviation, mean, sorting, skewness, and kurtosis (Folk and Ward 1957). Similarly, the usefulness of heavy minerals to identify the depositional environments is well explained in a recent study by Mehdilo and Irannajad (2013). Other studies show that the chattermark trails are probably a type of mechanical feature and not necessarily peculiar to garnet grains (Bull 1977) or to glacial environments (Bull et al. 1980). Bull et al. (1980) and Orr and Folk (1983) suggest a mechanical and/or chemical origin for these chattermark trails. Furthermore, Le-Ribault (1975) showed that the chattermark trails should have been oriented in a same direction if its origin is glacial. In our study, the chattermark trails identified in different grains are not uniform in orientation, length, and/or size. Recently, a review by Peterknecht and Tietz (2011) reveals that the chattermark trails are indicative of transport and climate history of sand grains. Thus, by following Chakroun et al. (2009) and Peterknecht and Tietz (2011), we interpret that these chattermark trials are the result of friction between sand grains (mechanical collision), subjected to sever shocks associated with an intertidal beach environment, probably in a wet tropical climate (Marcelino et al. 1999).

A grain-to-grain impact feature (Fig. 4f) is noticed in the sand grains of the Tecolutla and Veracruz beaches, which happens during the transportation of sediments by wind or by wave action during fluvial transportation. This sand grain is also subjected to silica precipitation, which indicates two provenances. It appears that the concentration of dune or wind transported sand grains are quantitatively higher in the Tecolutla and Veracruz beaches than in the Nautla beach.

Adhering particles (Fig. 5a) on sand grain may be composed of NaCl. Together with the adhering particles, well-developed halite cubes are also observed (Fig. 5b) in a fracture zone and in a plane surface (Fig. 5c) of a sand grain, investigated from the Tecolutla and Veracruz beaches, which are attributed to the presence of sufficient concentration of Na^{+} and Cl^{-} ions in the water, the high rate of evaporation, and the availability of space for crystallization (Howari and El-Saiy 2008).

Chemical dissolution features such as circular pits on a polished surface and etching on sand grain surfaces (Figs. 5d–h) are noticed at Veracruz beach, which suggests the sea water contamination due to the dominance of the local petrochemical industries. A complex microtexture with desiccation cracks and fractures (polygonal and root like; Fig. 6a and b, respectively) is identified at Veracruz beach sands, probably an indication of chemical weathering. The fracture spaces on the sand grain surfaces are subjected to dissolution and mineral precipitation, suggesting that the fissure cracks were formed before dissolution occurred.

The sand grains of Tecolutla and Veracruz beaches are also associated with chemically formed microtextures such as silica globules, trapped diatoms, and crystalline overgrowth (Fig. 6c–f). Diatoms on quartz grains are indicative of silica reprecipitation or silica biogenic globules. In fact, these chemical precipitation features are related to a humid weather and to an intertidal zone saturated with silica (Madhavaraju et al. 2009). The silica enrichment is also consistent with our earlier studies on geochemistry of beach sands along the Gulf of Mexico: the SiO_2 content in Tecolutla (~47–69 wt%; Armstrong-Altrin 2009; Armstrong-Altrin et al. 2012) and Veracruz beach sands (~ 67–76 wt%; Natalhy-Pineda 2013) are higher than in the Nautla beach sands (~ 18–46 wt.%; Armstrong-Altrin et al. 2012).

Benthonic foraminifera, *Elphidium discoidale* (D'Orbigny 1839), identified at the Veracruz beach sediments indicates a high-energy littoral environment (Fig. 6g), and its distribution is common along the Gulf of Mexico deep-sea sediments (Machain-Castillo 2010). The bioclastic coral fragment at the Veracruz beach sediments is probably derived from the nearby coral islands (Fig. 6h).

Conclusion

The abundance of microtextures from the three beaches is helpful in studying the different stages in the provenance history, even though the beach sediments are associated with sand grains of multiple origins. The sand grains of the Veracruz and Tecolutla beaches are dominated by microtextures of both mechanical and chemical origins, while sand grains of the Nautla beach are composed mostly of mechanical origin. The association of microtextures of mechanical/chemical origin corresponds to a littoral environment. The mechanical features indicate a high-energy subaqueous depositional environment.

A well-rounded sand grain at the Veracruz beach is an evidence of aeolian origin and larger transportation history. The abundance of subrounded and angular grains with conchoidal fractures at Nautla beach is indicating its nearby provenance. A rounded edge grain from the Veracruz beach consists of diverse microtextures such as v-shaped mechanical marks, straight striations, and silica globules on its surface, indicating that it was subjected to different provenance histories and multicyclic character.

The Chattermark trails identified at Veracruz beach sands is associated with an intertidal beach environment; indicating a wet tropical climate, which is consistent with other surface feature like desiccation crack. Chemical dissolution etching at Veracruz sand grain is an indicator of contaminated alkaline sea water, probably influenced by the nearby petrochemical industries. This study further illustrates that the microtextures such as arcuate steps, crescent-shaped steps, and chattermark trails are not always attributed to glacial sediments.

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