Microtextures on quartz grains in the beach sediments of Puerto Peñasco and Bahia Kino, Gulf of California, Sonora, Mexico

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ABSTRACT

Beach sand samples collected from two localities of the Gulf of California (Puerto Peñasco and Bahia Kino, Sonora) were analyzed in order to identify their provenance and depositional history on the basis of the different microtextures on the quartz grains. The quartz grains were examined under a scanning electron microscope which brought out thirty two distinct microtextures that can be grouped into three modes of origin, i.e., mechanical (eighteen features), mechanical and/or chemical (five features) and chemical (seven features) origin. Among nine microtextures of chemical origin, two features are of dissolutional origin, whereas five features are characteristic of precipitational origin. Most of the microtextures are common in both areas (Puerto Peñasco and Bahia Kino) but frequency of occurrence slightly varies. Quartz grains from Puerto Peñasco and Bahia Kino show conchoidal fractures, straight steps and arcuate steps, which are characteristic features of quartz grains derived from crystalline source rocks. The presence of angular to subangular outline together with straight and arcuate steps indicates that these sediments have undergone short transportation and rapid deposition. V-shaped patterns, straight scratches and curved scratches, which are characteristic features of marine environments, are common on the quartz grains of the analysed samples. Many quartz grains show subrounded outline with bulbous edges that are considered to be the product of fluvial transport. In addition, many quartz grains show subrounded to rounded outline, upturned plates and meandering ridges, which indicate that aeolian mechanisms controlled the transport of these grains. Some quartz grains show chemical precipitational features such as silica globules, silica flower, silica pellicle and trapped diatoms, which suggest that these quartz grains were derived from the silica saturated environments of intertidal zones. The present study reveals the following inferences: 1) the beach sediments in Puerto Peñasco area were transported to the area by fluvial and aeolian processes and subsequently deposited in the marine environment, and 2) the beach sediments in the Bahia Kino area were dominantly transported by fluvial processes, whereas subordinate quantity were contributed by aeolian processes and subsequently deposited in the marine environment.

Key words: microtextures, quartz grains, Gulf of California, Sonora, Mexico.

RESUMEN

De las áreas de Puerto Peñasco y Bahía Kino, Sonora se colectaron muestras de arena de playa con el fin de estudiar las diferentes microtexturas de los granos de cuarzo y así inferir la proveniencia y la

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historia de depósito de las arenas costeras del Golfo de California. El examen de estos granos de cuarzo realizado en un microscopio de barrido electrónico produjo treinta y dos microtexturas distintivas que de acuerdo a su origen, pueden clasificaron en tres grupos: origen mecánico (dieciocho rasgos), origen mecánico y/o químico (cinco rasgos) y origen químico (siete rasgos). Entre las nueve microtexturas de origen químico, dos rasgos se originaron por disolución, mientras que cinco rasgos son característicos de precipitación. La mayoría de las microtexturas observadas son comunes tanto en Puerto Peñasco como en Bahía Kino aunque su frecuencia de ocurrencia varía ligeramente. Los granos de cuarzo de Puerto Peñasco y Bahía Kino muestran fractura concoidal, bordes rectos y curvos, los cuales son rasgos típicos en granos de cuarzo derivados de una fuente de rocas cristalinas. La presencia de formas angulares a subangulares junto con bordes rectos y curvos indica que estos sedimentos experimentaron un transporte y depósito rápidos. Son comunes en los granos de cuarzo de las muestras analizadas patrones en forma de "V", así como estrías rectas y curvas, las cuales son características de ambientes marinos. Muchos granos de cuarzo tienen forma subredondeada con prominencias abultadas, las cuales se consideran como producto de un transporte fluvial. Además, muchos granos de cuarzo tienen una forma subredondeada a redondeada, placas volcadas y bordes subdivididos (meándricos) lo que indica que también los mecanismos eólicos controlaron el transporte de estos granos. Algunos granos de cuarzo muestran rasgos de precipitación química tales como glóbulos de sílice, "flores" de sílice y diatomeas atrapadas, lo que sugiere que estos granos de cuarzo se derivaron de ambientes saturados de sílice de zonas de intermarea. Del presente estudio se concluye que: 1) los sedimentos en Puerto Peñasco fueron transportados por procesos fluviales y eólicos y posteriormente depositados en el ambiente marino, y 2) los sedimentos de Bahía Kino fueron transportados principalmente por procesos fluviales con cantidades subordinadas de sedimentos que fueron transportados por procesos eólicos y más tarde depositados en el ambiente marino.

Palabras clave: microtexturas, granos de cuarzo, Golfo de California, Sonora, México.

INTRODUCTION

The study of quartz grain microtextures (>200 µm) with scanning electron microscopy (SEM) techniques has been shown to be a valid method in sedimentary petrology for interpreting sedimentary environments and transport mechanisms (Krinsley and McCoy, 1977; Bull, 1981; Krinsley and Marshall, 1987; Helland and Diffendal, 1993; Madhavaraju *et al.*, 2004;). 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; 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; Brown, 1973; Whalley and Krinsley, 1974; Baker, 1976; Al-Salech and Khalaf, 1982; Rahman and Ahmed, 1996). Hence, the microtextural study on quartz grains is considered as a power full tool in the identification of provenance, processes of transport and diagenetic history of the detrital sediments (Krinsley *et al.*, 1976; Madhavaraju and Ramasamy, 1999; Abu-Zeid *et al.*, 2001; Madhavaraju *et al.*, 2004, 2006; Armstrong *et al.*, 2005; Kasper-Zubillaga and Faustinos-Morales, 2007). The different impact features and the abrasion marks on the quartz grains were formed during transportation in different dynamic environments and they generally record those mechanical processes. The features of chemical origin consist of various types of etching and overgrowth.

Quartz grains from marine environment generally exhibit V-shaped patterns (V's), straight and curved scratches, with several protrusions (Krinsley and Doornkamp, 1973; Higgs, 1979; Madhavaraju and Ramasamy, 1999; Madhavaraju *et al.*, 2004, 2006). The presence of subrounded features, bulbous edges along with certain amount of V-shaped pits indicate fluvial origin (Linde, 1987; Mahaney, 1998). According to Margolish and Kenett (1971), V's generally occur on less than 50% of the grains from the fluvial origin and on more than 50% of those from high energy beaches. Those quartz grains of aeolian origin exhibit well rounded shape, pattern of meandering ridges that resulted from the intersection of slightly curved conchoidal breakage patterns and upturned plates on their surfaces (Krinsley and Takahashi, 1962; Krinsley and Doornkamp, 1973; Mazullo and Ehrlich, 1983; Mazullo *et al.*, 1986). Quartz grains from glacial origin display parallel striations, chattermarks and imbricated grinding features (Margolis, 1968; Higgs, 1979; Mahaney, 1995a, 1995b; Mahaney *et al.*, 1996). On the basis of the different types of microtextures observed on the quartz grains, it is possible to distinguish the particular depositional environments such as marine, fluvial, aeolian and glacial. The purpose of the present study is to investigate the microtextures that are present on quartz grains of beach sands from the Gulf of California (Puerto Peñasco and Bahia Kino), Sonora, and also to unravel the provenance and depositional history on the basis of the variety of these features.

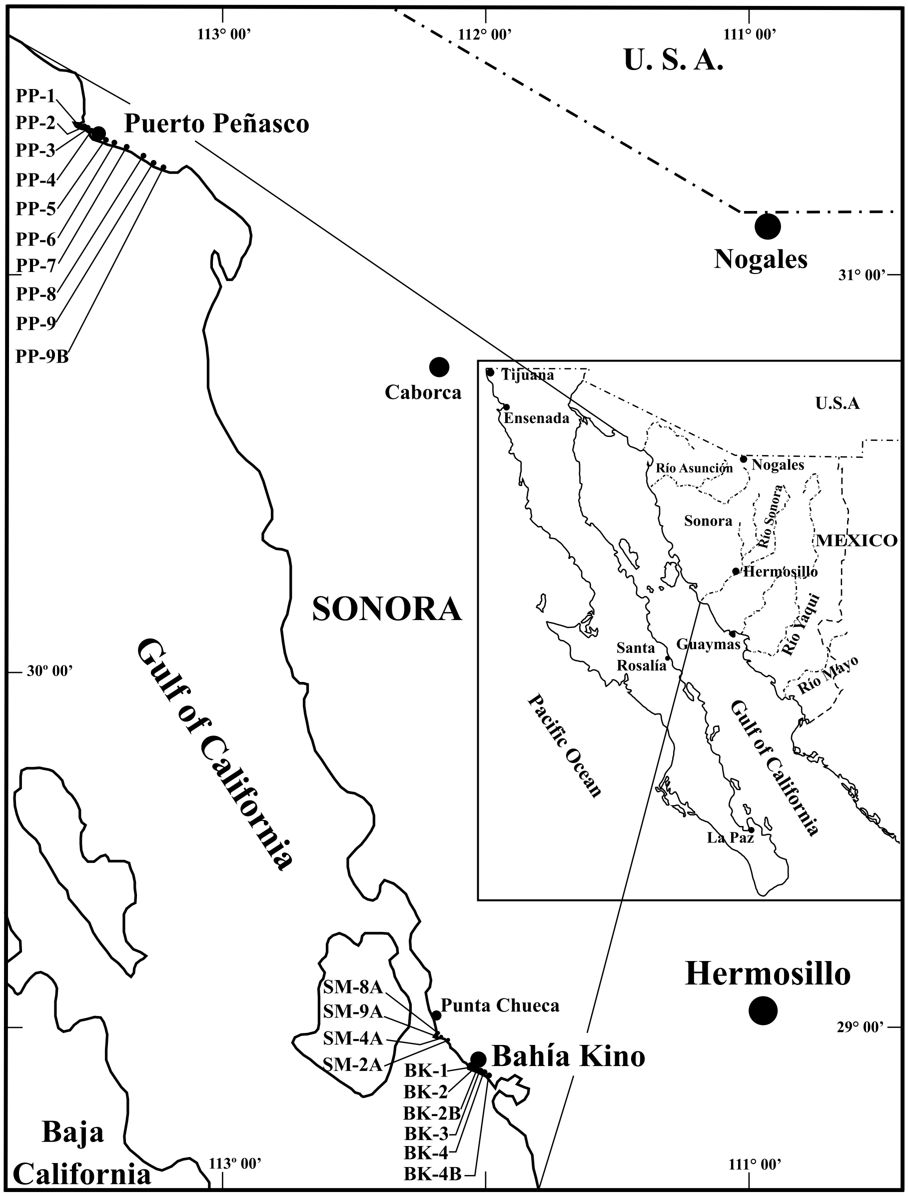

Figure 1. Location of studied beach sand samples in the Puerto Peñasco and Bahía Kino areas, Gulf of California, Sonora, México.

GEOLOGICAL SETTING OF THE STUDY AREA

The Gulf of California is an intercontinental NW-SE rift zone with oblique separation of the Baja California peninsula to the west (Pacific plate) and Sonora to the east (North American plate) (Figure 1). The structural pattern of the gulf is thus explained by an alternation of short spreading axes and longer dextral transform faults. The continental geologic framework adjacent to the coastal region between Puerto Peñasco and Bahia Kino is dominated by igneous, sedimentary and metamorphic rocks with ages ranging from the Proterozoic to Recent. The dominant lithology of the study area includes upper Precambrian and Cambrian carbonate rocks, a chert-graywacke-volcaniclastic sequence (Carboniferous age) and Jurassic volcanic-volcaniclastic rocks (Gastil and Krummenacher, 1977). These rocks are intruded by granitic rocks with ages between 91 and 30 Ma. and by younger basaltic and dacitic dikes. The older rocks are overlain by Cenozoic rhyolite and basalt flows (pre- 22 Ma) that are followed by a sequence of andesite (20 to 18 Ma), marine conglomerate and pyroclastic deposits, and a widespread, predominantly rhyolitic sequence (14 to 10 Ma) (Gastil and Krummenacher, 1977).

Kasper-Zubillaga and Faustinos-Morales (2007) studied the desert and coastal dune sands from San Luis Rio Colorado, El Pinacate, Gulf of Santa Clara and Puerto Peñasco areas and reported that the majority of the sands are fine to medium grained and moderately to well sorted. The study areas receive an average annual rainfall of less than 10 cm and most of the rainfall occurs during the July-

September season (Stensrud *et al.*, 1997). Onshore winds from the NW and NE (velocities of 2–6 m s^{-1}) prevail in the northern part of Gulf of California and occur 20 – 60% of the time during one month. Southerly onshore winds with velocities of 2–4 m s^{-1} prevails in the Puerto Peñasco area, occurring 60% of the time during one month (Pérez-Villegas, 1990). The longshore current that flow adjacent to the study area in the coast region of the Gulf of California mainly generates sediment transport from SE to NW (Fernandez-Eguiarte *et al.*, 1990a, 1990b), whereas semidiurnal tides also redistribute the sediment in the coastal part of this region due to their potential influence on the transport of sands (Thompson, 1968). The Sonoyta and Sonora rivers are continental mainstreams that have contributed the sediments into Gulf of California in Puerto Peñasco and Bahia Kino, respectively

METHODOLOGY

Beach sand samples were collected from the two locations (Puerto Peñasco and Bahia Kino) of the Gulf of California, Sonora. Samples were collected from the foreshore along transects at regular interval of 500 m. Ten sand samples were collected from each location (Figure 1) for the microtextural study. Approximately 20 g of each sample was treated with 30% HCl and stannous chloride solution to dissolve carbonates and to remove iron stains from the quartz grains and then washed several times with distilled water (Krinsley and Doornkamp, 1973; Helland and Holmes, 1997). Then, these samples were soaked with H_2O_2 solution to remove organic matter. The treated samples were sieved to separate the sand size fraction.

Quartz grains between 200 and 400 µm sizes were hand-picked under a binocular microscope, mounted on stubs, sputter-coated with gold, and examined using a JEOL JSM 6360 scanning electron microscope available at Department of Geology, University of Madras, Chennai, India. Approximately twenty five quartz grains were randomly selected from the sand size fraction of each sample, which is considered as sufficient to understand the variations present in a single sample and also to interpret the depositional history (Krinsley and Doornkamp, 1973; Baker, 1976).

Quartz grain microtextures were analyzed under the scanning electron microscope using checklist approach, as used previously by various authors (Bull, 1978; Higgs, 1979; Williams and Morgan, 1993). The various types of quartz grain microtextures have been established by Higgs (1979) on the basis of published data (Krinsley and Donahue, 1968; Krinsley and Margolis, 1971; Margolis and Kennet, 1971, Krinsley and Doornkamp, 1973; Le Ribault, 1975). The check list composition (Table 1) was based upon the compilation of data by Higgs (1979). In addition, we have also referred the published work of Bull *et al.* (1987) and Mahaney *et al.* (1996).

Table 1. Identified microtextures, and their abundance, on quartz grains of the Gulf of California, Sonora, Mexico.

Features	Puerto Peñasco	Bahia Kino
Mechanical origin		
Small pits	A	A
Medium pits	C	C
Large pits	C	C
Small conchoidal fractures	P	A
Medium conchoidal fractures	P	C
Large conchoidal fractures	P	C
Straight steps	S	P
Arcuate steps	S	P
Upturned plates	P	S
Chatter marks	S	S
Parallel striations	R	R
Imbricated grinding features	AB	R
Meandering ridges	R	S
Straight scratches	P	P
Curved scratches	C	C
Subangular outline	P	C
Rounded outline	C	P
V-shaped patterns	C	C
Mechanical/chemical origin		
Fracture plates/planes	S	S
Low relief	S	S
Medium relief	P	P
High relief	P	P
Adhering particles	P	C
Chemical origin - Dissolutional		
Solution pits	S	S
Solution crevasses	R	R
Chemical origin - Precipitational		
Silica globules	S	P
Silica flower	S	S
Silica pellicle	P	S
Crystalline overgrowth	R	R
Trapped diatoms	S	R

A: Abundant (>75%); C: common (50–75%); P: present (25–50%); S: sparse (5–25%); R: rare (<5%); AB: absent.

MICROTEXTURES

In the present study we identified thirty types of microtextures (Figures 2-5) that have been grouped into three modes of origin, *i.e.*, mechanical (eighteen features), mechanical and/or chemical (five features) and chemical (seven features) origins. Among nine identified microtextures of chemical origin, two features are of dissolutional origin and five are characteristic of precipitational origin (Table 1). Most of the microtextures are common in both areas (Puerto Peñasco and Bahia Kino) but frequency of occurrence is slightly varied, however, the mechanically formed microtextures predominate over the chemically formed features (Figure 6). The important characters of each microtexture are discussed below in detail.

Mechanical features

The studied quartz grains from the Puerto Peñasco and Bahia Kino areas show three types of irregular pits, *i.e.*,

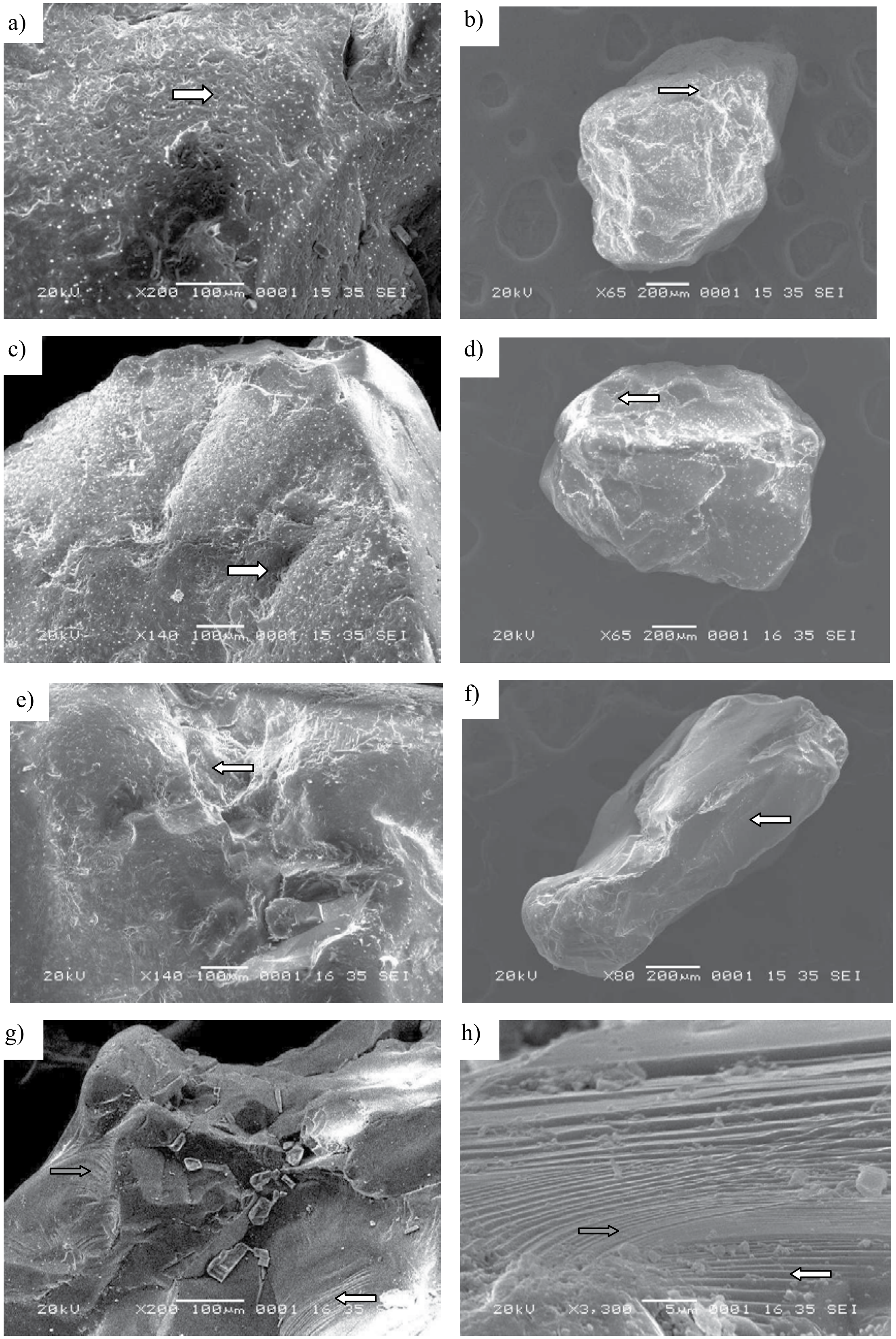

Figure 2. Microtextures observed on quartz grains form the Bahia Kino (a-d and h) and Puerto Peñasco areas (e-g), northern Gulf of California. a: Quartz grain showing small pits. b: Quartz grain showing medium pits. c: Subangular quartz grain showing large pits. d: Subrounded quartz grain that shows small conchoidal fractures. e: Quartz grain showing close-up view of medium conchoidal fractures. f: Large conchoidal fractures on an angular quartz grain. g: Straight (white arrow) and arcuate (gray arrow) steps seen on quartz grain. h: Close-up view of straight and arcuate steps observed on a quartz grain.

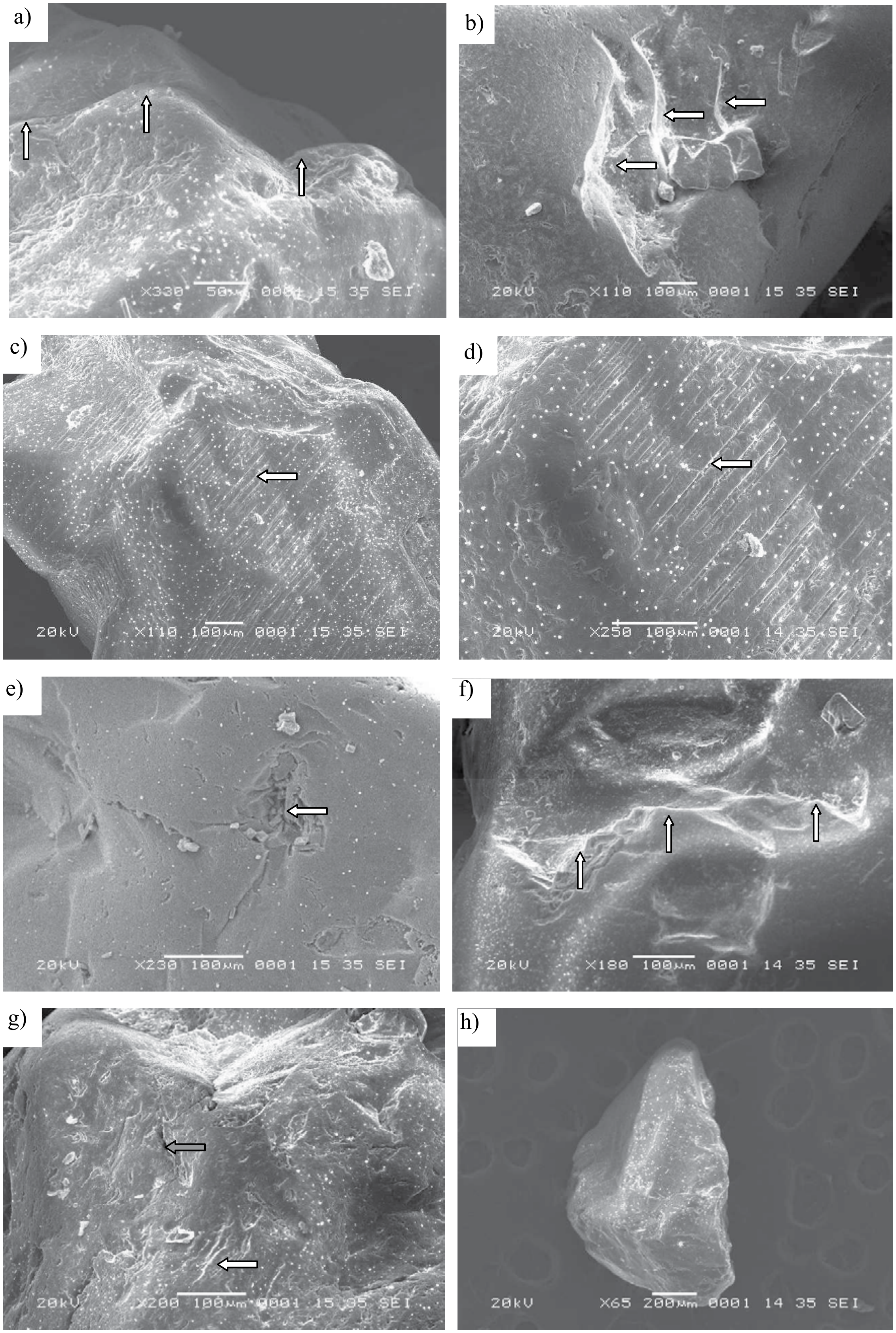

Figure 3. Microtextures observed on quartz grains form the Bahia Kino (a, c-e, g-h) and Puerto Peñasco (b, f) areas. a: Quartz grain showing upturned plates. b: Chatter marks on quartz grain. c: Numerous parallel striations on quartz grain. d: Close-up view of parallel striations. e: Quartz grain showing imbricated grinding feature. f: Meandering ridges observed on quartz grains. g: Straight (white arrow) and curved (gray arrow) scratches. h: Quartz grain showing angular outline.

small, medium and large (Table 1), with class limits of 10 and 100 microns (Higgs, 1979). Small pits are abundant, whereas medium and large pits are common in the studied areas (Figures 2a-2c). Like irregular pits, conchoidal fractures are also categorized into small (<10 µm), medium and large (>100 µm) on the basis of the size of the fracture. Small to large conchoidal fractures (Table 1) are common to abundant in the beach samples from Bahia Kino (Figures 2c-2f). Straight and arcuate steps (Figures 2g-2h) are closely associated with conchoidal fractures and are present in considerable amount in the sand samples of Bahia Kino, whereas these features are sparsely distributed on the quartz grains from the Puerto Peñasco (Table 1). The frequency of upturned plates is higher in the quartz grains from the Puerto Peñasco area than in the Bahia Kino samples (Figure 3a). They appear as thin, parallel plates, which may be either continuous or discontinuous. The ridges extent upwards to about 10 µm from the surface of the quartz grains, and may be up to 50 µm in length. These plates are generally affected by subsequent chemical processes which tend to produce subdued features. Chatter marks (Figure 3b) are sparsely distributed, and parallel striations (Figures 3c and 3d) are rarely present on the quartz grains from the both areas (Table 1). Imbricated grinding features (Table 1) are completely absent in the beach samples from Puerto Peñasco, whereas these features are rarely present on the quartz grains from Bahia Kino (Figure 3e). Meandering ridges (Figure 3f) are sparsely distributed on the studied quartz grains (Table 1). Straight scratches are moderately present, whereas curved scratches are common (Table 1; Figure 3g). These scratches vary in length from 1 to 100 µm and are randomly oriented. Samples from Puerto Peñasco show a considerable amount of quartz grains with rounded outline (Figure 4a), whereas angular shapes predominate in the quartz grains from Bahia Kino (Table 1; Figure 3h). V-shaped impact pits are common on quartz grains from Puerto Peñasco and Bahia Kino (Table 1). V-shaped pits (Figure 4b) are irregular, differ in shape and size and occur as crescentic and elongated slit-like openings 0.5–50 µm in length. The density of the V's appears to be in direct relationship to the number of straight and curved scratches. V's, straight and curved scratches were formed by grain-to-grain collisions in an aqueous medium (Krinsley and Margolis, 1969; Higgs, 1979).

Mechanical/chemical features

Fracture plates/planes (Figure 4c) are sparsely distributed on the quartz grains from the Puerto Peñasco and Bahia Kino (Table 1). Quartz grains reveal varied relief (low, medium and high; Figures 4d-4f). The relief of the quartz grain resulted from the mechanical and chemical action of the medium, which occurred since the liberation of the grains from the source region (Higgs, 1979). Adhering particles (Figure 4g) are distributed on the quartz grains from Puerto Peñasco and Bahia Kino (Table 1).

Chemical features

Quartz grains from the Puerto Peñasco and Bahia Kino show both types of chemical (dissolutional and precipitational) features, *viz.* solution pits, solution crevasses, silica globules, silica flower, silica pellicles, crystalline overgrowth and trapped diatoms (Table 1).

Solution pits (Figure 4h) are sparsely distributed on the quartz grains from Puerto Peñasco and Bahia Kino. Solutions pits are highly variable in size and shape, although circular and subcircular shapes are common (Krinsley and Doornkamp, 1973). Solution crevasses (Figure 5a) that are rarely present on few quartz grains from Puerto Peñasco and Bahia Kino (Table 1), mainly occur in association with solution pits (Krinsley and Doornkamp, 1973). Silica globules (Figure 5b) and silica flower (Figure 5c) are sparsely distributed on the studied quartz grains, but silica globules are common in the samples from Bahia Kino (Table 1). Silica globules may grow concurrently to form silica flowers (Le Ribault, 1975), which are convex-upward and display radial structures with hexagonal symmetry. Coalescence of silica globules leads to the formation of soluble silica pellicles (Figure 5d), which grow partly or wholly, depending upon the available silica solution, and may mask the earlier microtextures. Few quartz grains from Puerto Peñasco and Bahia Kino show minor crystalline overgrowth (Figure 5e and 5f). Generally, quartz overgrowth observed in the present study is much smaller in size as compared with the overgrowth formed in subsurface diagenetic environments. Hence, this type of smaller overgrowth likely formed during pedogenic processes. Diatoms (Figure 5g and 5h) are seen on the fractured surfaces of some quartz grains from the Puerto Peñasco and Bahia Kino (Table 1).

PROVENANCE AND DEPOSITIONAL ENVIRONMENT

Quartz grains from Puerto Peñasco and Bahia Kino exhibit different types of microtextures. The conchoidal fractures are characteristic of glacial origin and also of grains derived from crystalline source rocks (Higgs, 1979). In the studied areas, the microtextures of glacial environment are sparsely distributed on the quartz grains. Hence, the observed abundant conchoidal fractures on the quartz grains from both areas indicate that the quartz grains were mainly derived from crystalline source rocks. In addition, straight and arcuate steps are closely associated with conchoidal fractures (Higgs, 1979), which also support that the studied quartz grains were liberated from crystalline source rocks. The conchoidal fractures and the straight and arcuate steps are common in quartz grains of Bahia Kino (Figure 7), which indicates that the coastal area of Bahia Kino received more sediment from the crystalline source rocks than the coastal part of Puerto Peñasco. The quartz grains of the present study exhibit angular to rounded

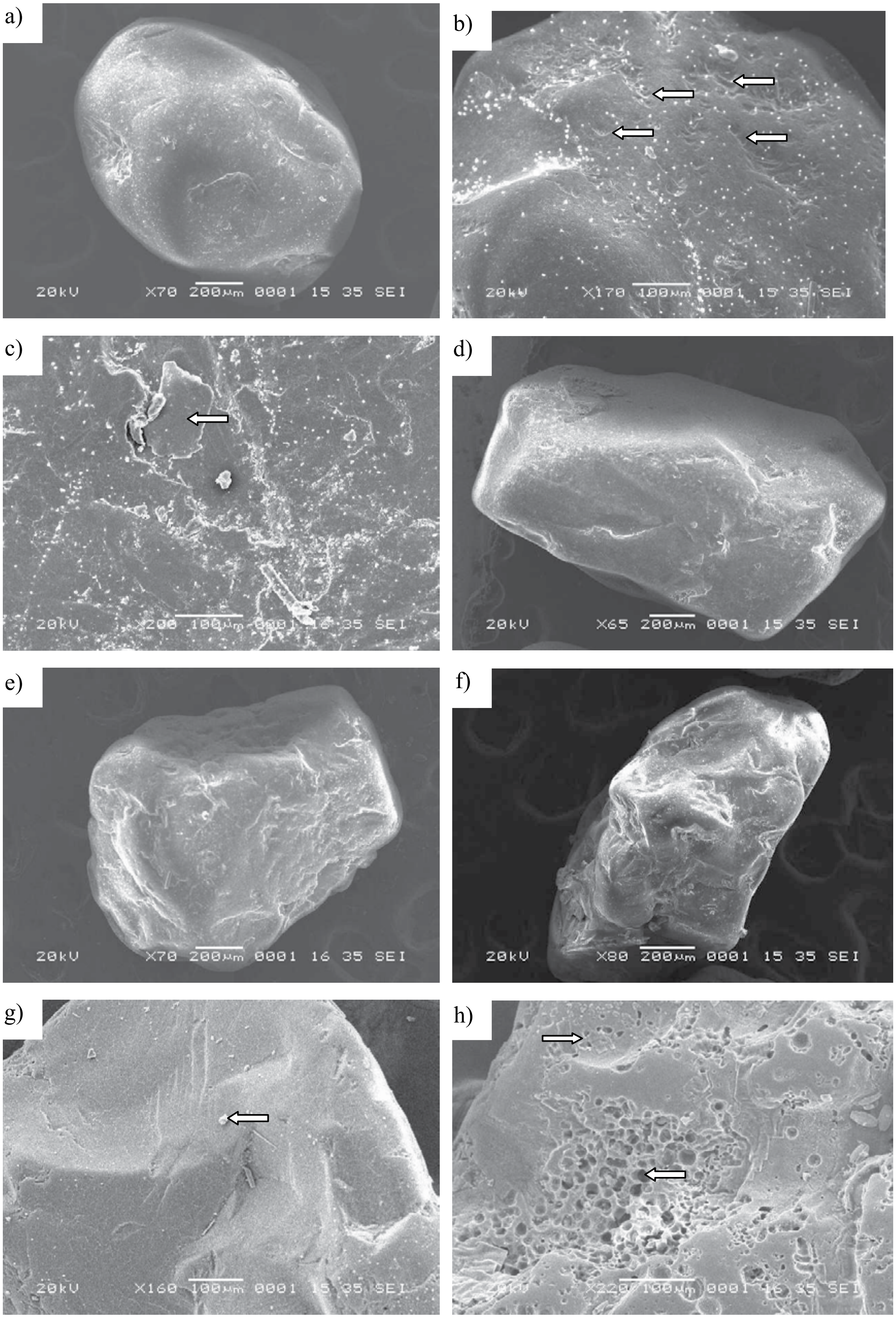

Figure 4. Microtextures observed on quartz grains form the Bahia Kino (b-c, g) and Puerto Peñasco (a, d-f, h) areas. a: Quartz grain showing rounded outline. b: Numerous small and medium V's are observed on quartz grains. c: Quartz grain that shows fracture plates. d: Subangular quartz grain showing low relief. e: Quartz grain that exhibits medium relief. f: Subangular quartz grain showing high relief. g: Adhering particles on quartz grain. h) Quartz grain with numerous solution pits.

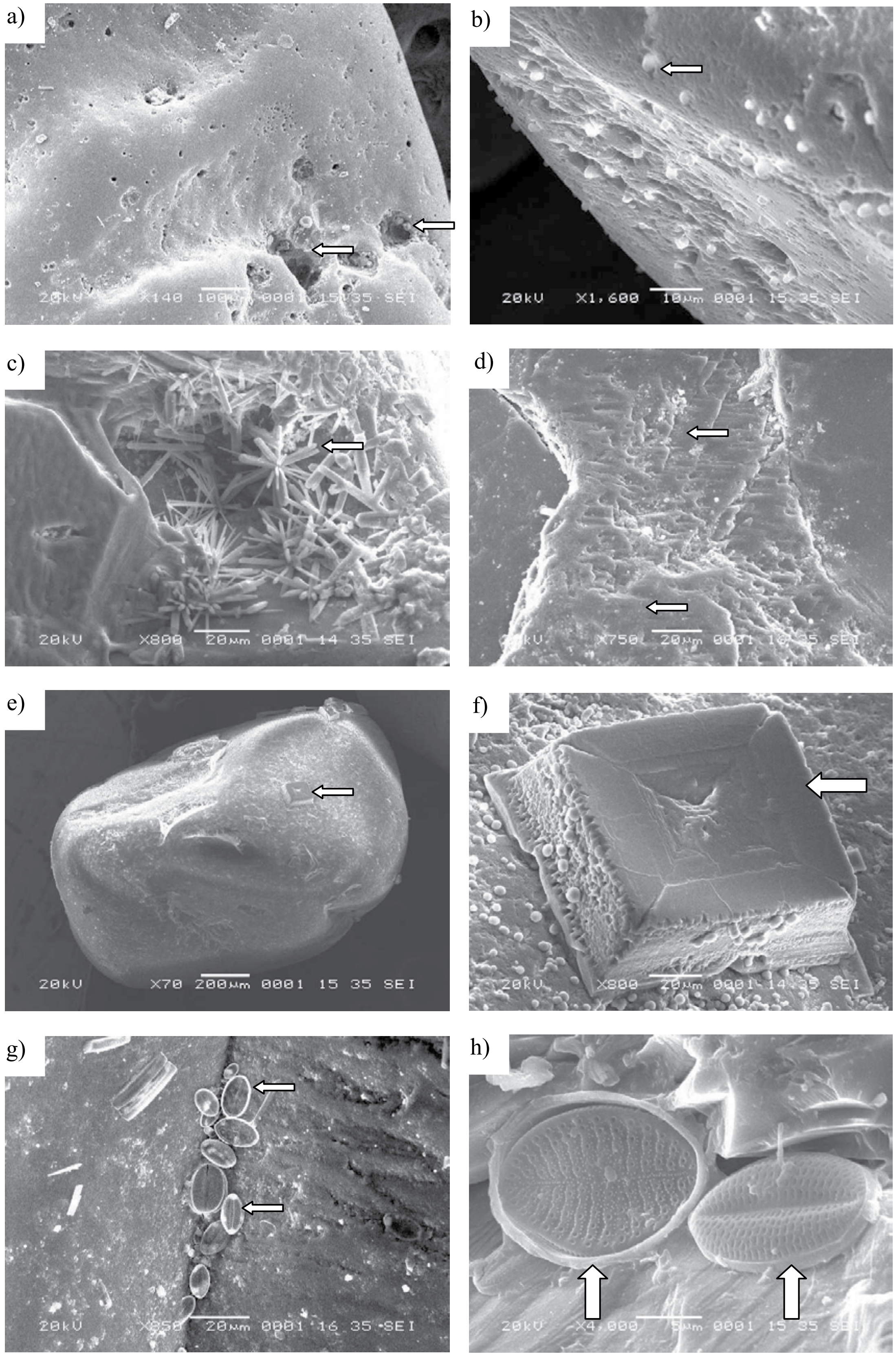

Figure 5. Microtextures on quartz grains form Bahia Kino (a-b, d) and Puerto Peñasco (c, e-h) areas. a: Solution pits and solution crevasses on quartz grains. b: Quartz grain with numerous silica globules. c: Silica flowers seen on the surface of the quartz grain. d: Quartz grains showing close-up view of silica pellicle. e: Smaller crystalline overgrowth. f: Close up view of crystalline overgrowth. g: Numerous diatoms are observed along a fracture on the quartz grain. h: Close-up view of diatoms.

outline. The beach sediment from Puerto Peñasco show more rounded outline than angular outline (Figure 7a and 7b), whereas the sediment from Bahia Kino exhibit more angular outline than rounded grains (Figure 7c and 7d). The dominance of angular grains and the presence of straight steps and arcuate steps suggest that the quartz grains in the Bahia Kino have undergone short transportation and rapid deposition. Straight and arcuate steps are delicate features. If the quartz grains undergo long transportation, then these features may be destroyed during transportation. The presence of abundant angular grains support a local source rock origin as suggested by Folk (1978). On the contrary, the abundance of rounded grains in the beach sediments from Puerto Peñasco suggests that the coastal part of this area received a considerable amount of recycled sediments.

Solution pits and silica deposits observed on the quartz grains from Puerto Peñasco and Bahia Kino are generally formed by chemical processes in tropical or silica-saturated areas like the intertidal zones of the beach (Le-Ribault, 1975; Higgs, 1979; Moral-Cardona *et al.*, 1997). The quartz grains from the studied areas exhibit certain chemically formed microtextures such as silica globules, silica flower, silica pellicle and diatoms. The overprinting or superposition of silica precipitation with respect to other microtextures suggests that these features represent the final event to affect the quartz grains. The presence of silica precipitation, including diatoms, is related to high humidity and high rainfall rates, and intertidal zones saturated with silica (Pye and Mazzullo, 1994; Kasper-Zubillaga *et al.*, 2005). Silica flower, silica globules and silica pellicles are generally formed on the quartz grains during post deposition/diagenesis on the broken surfaces (Madhavaraju *et al.*, 2004). In the present study, the quartz grains exhibit well preserved silica flower and diatoms which are seen on the broken part of the grains. Hence, it is considered that these types of microtextures are post-depositional in nature. If these features were formed prior to their deposition, then they would have been partly or wholly destroyed during the transportation. The chemically formed microtextures observed on the analysed quartz grains suggest that these features were derived from the intertidal zones with silica-saturated environments.

V-shaped patterns (V's), straight scratches and curved scratches are present on many quartz grains from Puerto Peñasco and Bahia Kino. Such features are characteristics of moderate to high energy subaqueous conditions as suggested by Margolis and Krinsley (1974), and mainly occur on quartz grains from shallow marine, fluvial (high energy) and deltaic (seaward) environments (Higgs, 1979). V-shaped patterns result from both mechanical and chemical processes. V's that result from mechanical processes exhibit irregular shape and randomly oriented patterns, whereas V-shaped patterns having regular outer edges with oriented patterns result from chemical etching.

V-shaped features of mechanical origin are caused by grain-to-grain collision in subaqueous environment when one grain strikes another (Manker and Ponder, 1978). One set of V's may have resulted from projection of one grain striking another grain with linear motion, whereas second collision may cause another set of V's with different orientation (Krinsley and Donahue, 1968). The quartz grains from Puerto Peñasco and Bahia Kino exhibit different orientations of V's, which is a characteristic feature of a mechanical origin. V-shaped patterns of mechanical origin mainly originate in subaqueous medium with high-energy conditions. In addition to that, V's are associated with straight and curved scratches, which also support the mechanical origin for their formation.

Having defined V's being of mechanical origin, the abundance and size of V's tend to increase when grains are subjected to longer period and higher intensities of subaqueous agitation (Linde and Mycielska-Dowgiallo, 1980). Sand grains from modern and ancient fluvial, littoral and shelf deposits exhibit V-shaped pits, and the density and abundance of V's are related to the duration and intensity of

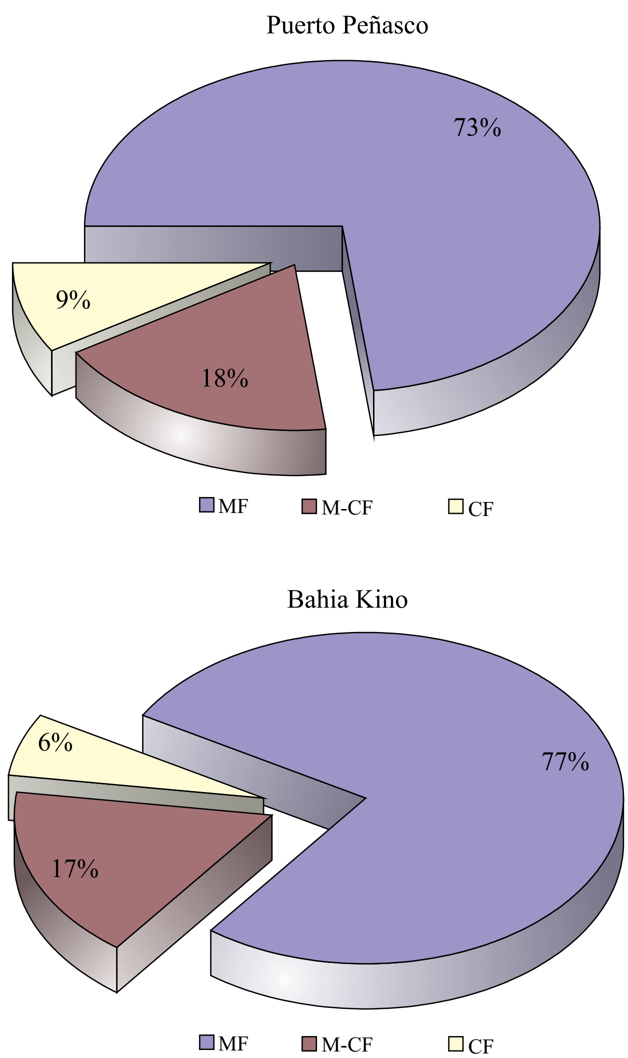

Figure 6. Percentage of various types of microtextures seen on the quartz grains from Bahia Kino and Puerto Peñasco. MF: Mechanical features; M-CF: mechanical/chemical features; CF: chemical features.

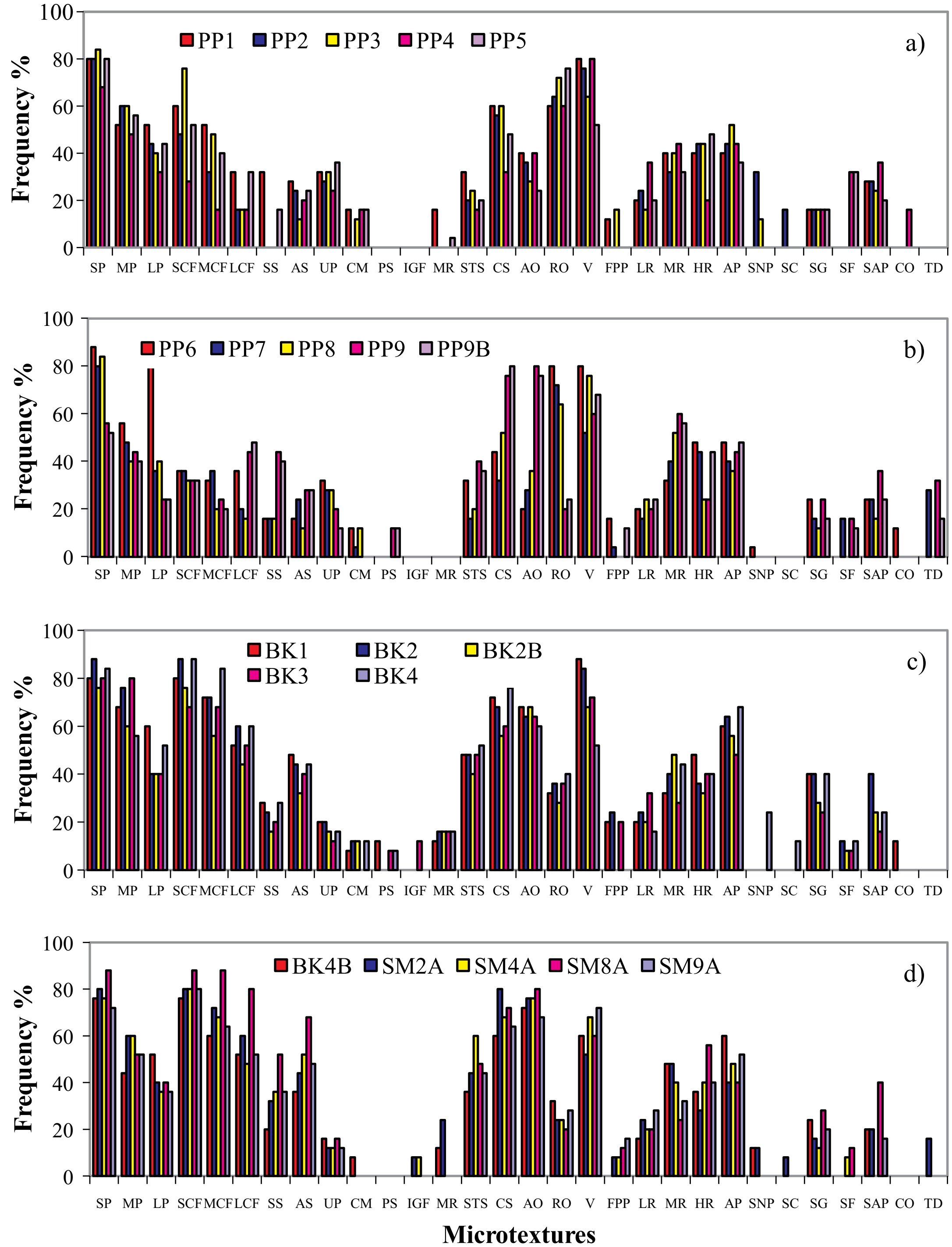

Figure 7. The frequency of various types of microtextures observed on the quartz grains from Puerto Peñasco and Bahia Kino. SP: Small pits, MP: Medium pits, LP: Large pits, SCF: Small conchoidal fractures, MCF: Medium conchoidal fractures, LCF: Large conchoidal fractures, SS: Straight steps, AS: Arcuate steps, UP: Upturned plates, CM: Chatter marks, PS: Parallel striations, IGF: Imbricated grainding features, MR: Meandering ridges, STS: Straight scratches, CS: Curved scratches, AO: Angular outline, RO: Rounded outline, V: V-shaped patterns (V's), FPP: Fracture plates/planes, LR: Low relief, MR: Medium relief, HR: High relief, AP: Adhering particles, SNP: Solution pits, SC: Solution crevasses, SG: Silica globules, SF: Silica flower, SP: Silica pellicles, CO: Crystalline overgrowth, TD: Trapped diatoms. PP: Samples from Puerto Peñasco; BK and SM: samples from Bahia Kino.

subaqueous agitation in such environments (Margolis and Kennett, 1971). Margolis and Kennett (1971) mentioned that V's occur on less than 50% of the grains from fluvial environment whereas they are abundant in grains from high-energy beach environment. In the present study, the quartz grains from both Puerto Peñasco and Bahia Kino show irregular V's on more than 50% of grains (Figure 7). In addition, many quartz grains show subrounded to rounded outline with bulbous edges, which is considered as a product of fluvial transport. Hence, we suggest that V's, straight and curved scratches resulted from the combination of fluvial processes and high energy beach environments.

Many quartz grains from Puerto Peñasco show upturned plates, but they are sparsely distributed on the quartz grains from Bahia Kino (Figure 7); these features were developed in an aeolian environment (*e.g.*, Krinsley and Doornkamp, 1973; Mazullo and Ehrlich, 1983). Upturned plates are considered as high-energy impact features that occur on the quartz grains that are transported by high velocity winds (Mazullo *et al.*, 1986). The coastal area of Puerto Peñasco received more sand grains from the aeolian processes when compared with the coastal area of Bahia Kino. In addition, quartz grains from the studied areas also show meandering ridges. Meandering ridges are formed during grain to grain collision in an aeolian environment (Krinsley and Takahashi, 1962; Moral-Cordona *et al.*, 1997). Many grains from Puerto Peñasco show a subrounded to rounded outline that suggests a moderate distance of aeolian transport, whereas the lower percentage of rounded grains in Bahia Kino indicates minor aeolian transport.

Microtextures such as microstriations, chatter marks, lattice shattering, curved and linear troughs and imbricated grinding features on quartz grain surfaces provide evidence of glacial transport (Folk, 1975; Le Ribault, 1975; Mahaney and Vortisch, 1989; Mahaney, 1995a, 1995b; Mahaney *et al.*, 1996). The glacial features such as chatter marks, parallel striations and imbricated grinding features are observed on few grains from Puerto Peñasco and Bahia Kino. These features are sparsely distributed on quartz grains from both areas, which suggest that a small population of grains were contributed by glacial processes.

In summary, the microtextural study of quartz grains from the Gulf of California leads to the following inferences: 1) the beach sediments in Puerto Peñasco were dominantly transported to the region by fluvial and aeolian processes, and subsequently deposited in the marine environment; and 2) the Bahia Kino beach sediments were mainly transported by fluvial processes, whereas only a subordinate amount of sediments were derived from aeolian processes, and subsequently deposited in the marine environment.

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