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# MICROTEXTURES OF DETRITAL SAND GRAINS FROM THE COX'S BAZAR BEACH, BANGLADESH: IMPLICATIONS FOR PROVENANCE AND DEPOSITIONAL ENVIRONMENT

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**Abstract:** Surface features on detrital sand grains were studied by a scanning electron microscope (SEM) to infer the provenance, depositional environment and paleoclimate. Twelve sand samples were collected from Laboni, Sugandha and Himchori points along the Cox's Bazar beach, Bangladesh. Twenty six microtextures were identified and classified as mechanical (16 features), mechanical/chemical (5 features) and chemical (5 features) origins. The microtextural features of sand grains were characterized by straight scratches, v-shaped patterns (Vs), smooth surfaces with sub-angular to sub-rounded outlines. Conchoidal fractures, Vs and sub-angular to sub-rounded grains indicate mechanical origin. The sub-rounded to rounded grains suggesting long-distance transportation under fluvial environment (e.g. Himalaya). The abundance of sand grains with angular to sub-angular outlines revealed a short transportation and derived from the nearby Chittagong-Tripura folded belt and/or Indo-Burman Ranges. Etching in the sand grains represents chemical origin under the influence of sea-water.

**Keywords:** Surface features; Quartz grains; SEM; Cox's Bazar beach; Collision

## 1. INTRODUCTION

Microtextural study of detrital sand grains using SEM has been widely used to decipher the environmental and transportation history of sediments (Krinsley & Funnel, 1965; Krinsley & Doornkamp, 1973; Margolis & Krinsley, 1974; Krinsley & McCoy, 1977; Mahaney, 1995, 2002; Mahaney & Kalm, 2000; Alekseeva & Hounslow, 2004; Armstrong-Altrin et al., 2005; Kenig, 2006; Madhavaraju et al., 2006; Kasper-Zubillaga & Faustinos-Morales, 2007; Kirshner & Anderson, 2011; Armstrong-Altrin & Natalhy-Pineda, 2013; Costa et al., 2013). The transportation of sediments by glacial, fluvial and aeolian environments may cause the mechanical features on sand grains surface (Krinsley & Funnell, 1965; Doornkamp & Krinsley, 1971; Setlow & Karpovich, 1972; Bull, 1981; Carter, 1984; Mahaney et al., 2001, 1996; Moral-Cardona et al., 1996, 1997; Mahaney, 1998; Newsome & Ladd, 1999; Sweet & Soreghan, 2010; Costa et al., 2013).

Krinsley & Doornkamp (1973) and Mahaney (2002) categorized the origin of microtextures as mechanical (percussion, polygenetic and sustained high-stress) and chemical (diagenesis, chemical dissolution, weathering and mineral growth). Grain relief is a microtexture defined as the difference between high and low points on grain surface (Mahaney, 2002; Sweet & Soreghan, 2010). Moreover, sand grains from aeolian and/or shoreface environments are characterized by rounded edges with low relief (Kairo et al., 1993; Sweet & Soreghan, 2010), whereas sub-rounded grains with polished surface are considered to be marine environment (Krinsley & Trusty, 1985; Moral-Cardona et al., 1997; Madhavaraju et al., 2006). Sand grains from glacial origin exhibit chattermark trails and were attributed to a wet tropical climate (Armstrong-Altrin & Natalhy-Pineda, 2013), and sand grains from debris flow environment typically show medium to high relief (Sweet & Soreghan, 2010).

Cox's Bazar beach of Bangladesh is the world's longest natural sandy beach, and is located 150 km south of the industrial port of Chittagong (Fig. 1). It is bounded to the west by the Bay of Bengal and to the east by the Chittagong-Tripura folded belt. The latitude and longitude of the study area are 21°5´N to 21°25´N and 92°0′E to 92°10´E, respectively (Fig. 1). Matamuhuri and Boghkhali are the two rivers draining from northern part of the Chittagong-Tripura folded belt and feeding sediments to the beach area. Sugandha, Laboni and Himchori are the three sand beach points closer to the Cox's Bazar town.

Sand grain surface features of the Permian Gondwana sediments have been reported by Rahman & Ahmed (1996), and textural characteristics of heavy minerals in beach and dune sands of Cox's Bazar, Bangladesh were studied by Mitra & Ahmed (1990). The aim of this study is to investigate the microtextures of sand grains from the Cox's Bazar beach in order to infer the provenance, depositional environment and transport history of sediments.

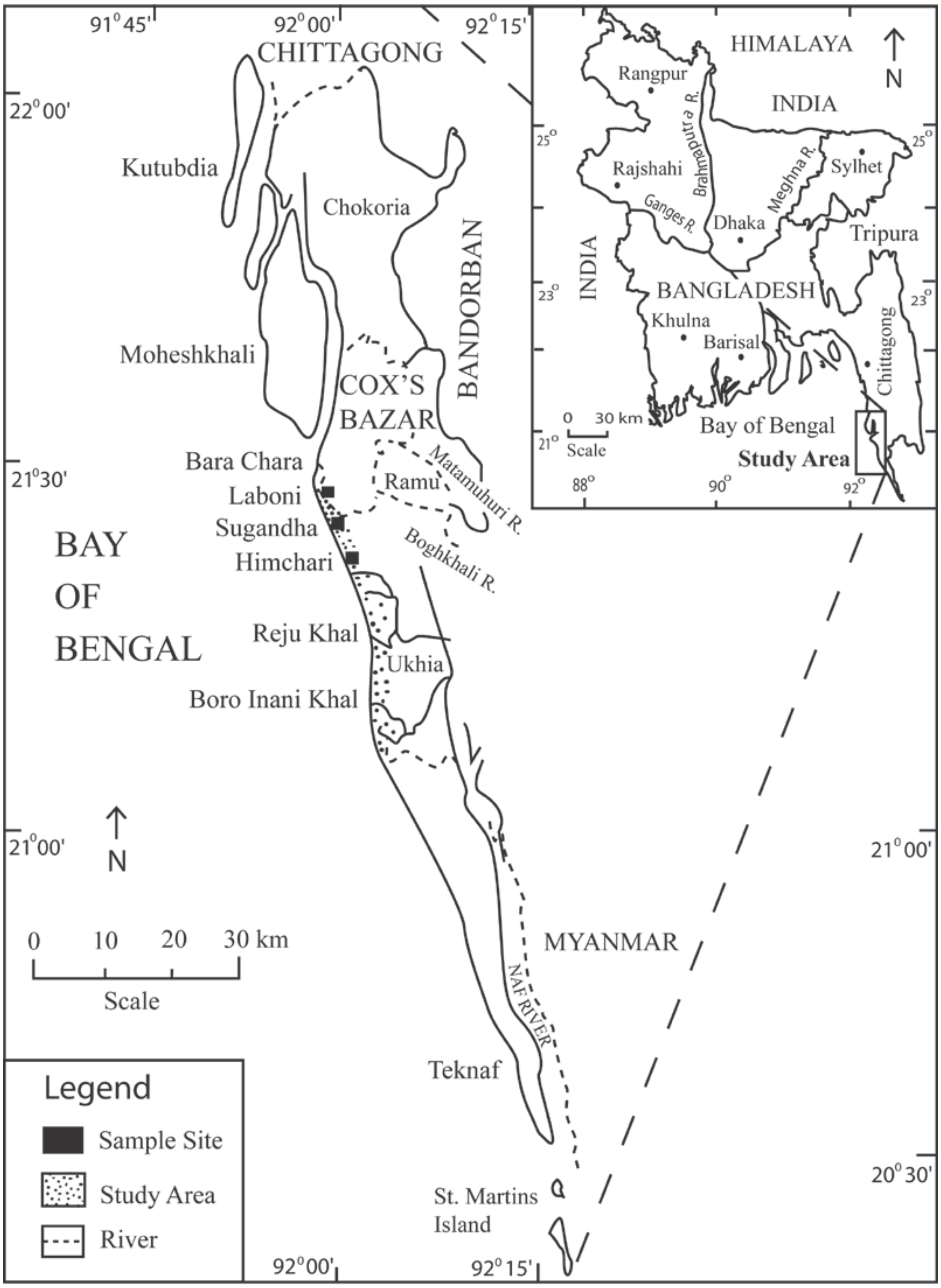


Figure 1. Location map of the study area showing sample sites of the Cox's Bazar beach, Bangladesh.

## 2. GEOLOGICAL SETTING

Bengal Basin lies in the northeastern part of the Indian sub-continent, occupying Bangladesh, west Bengal, Assam, Tripura and part of the Bay of Bengal (Fig. 1). The collision between the Indian and the Eurasian plates, resulting the formation of Himalayas and Indo-Burman Ranges, and thereby loading the lithosphere to form flanking sedimentary basins (Uddin & Lundberg, 1998). The Himalayas were uplifted to a higher degree through the Miocene (Fairbridge, 1983), and a large delta complex was developed on the northeastern side of the Bengal Basin (Alam, 1989). The clastic sediments were funneled by turbidity currents to the deeper part of the Bengal Basin mostly from the northeast (Alam, 1989). The Basin with its subaerial delta and prodelta was formed by the seaward progradation of the Ganges-Brahmaputra river systems (Einsele et al., 1996). The Ganges River drains most of the southern slope of the Himalayas, while the Brahmaputra River drains most of the northern slope of the rising Himalayas (Curray & Moore, 1974).

Beach forming processes are related with the evolving stages of the coast through time, and consequent fluctuation of energy level of the coast, directly influenced by sea-level changes. The shoreline of the Bay of Bengal was placed more than 100 km southward from the present coast during 18,000 years BP. At the end of the last glaciations, eustatic sea level started rapidly rising and the shoreline of the Bay of Bengal started shifting northward (Monsur & Kamal, 1994). Eventually the beach forming phase is attaining now with the evidences of dune, strand plain and sand flat formation through the entire coast and leaving behind the eroded remnants of the Tertiary hills in the beach area (Kibria et al., 2000). Previous study on sedimentology, demonstrated that the beach sands were fine-grained, well to moderately well sorted, fine skewed to near symmetrical and mesokurtic to leptokurtic (Bari et al., 2003).

## 3. MATERIALS AND METHODS

Twelve detrital sand samples were collected from the Cox's Bazar beach, southeast Bengal Basin, Bangladesh. Location of the sample sites is shown in the figure 1. About 20 g of each sample was washed with cold 12% HCl to eliminate the carbonate coatings and ferruginous contamination. Washed samples were then soaked with 30% $H_2O_2$ to remove the organic debris. Stannous chloride solution was used to remove adhering iron coatings from the sand samples. The sand grains were then washed with distilled water and subsequently dried in room temperature. Twenty sand grains (between 200 and 400 μm sizes) from each sample were selected for SEM study and were hand-picked by a binocular microscope (Krinsley & Doornkamp, 1973; Krinsley & McCoy, 1977; Higgs, 1979). The quartz grains were then placed on SEM stubs, gold coated in a JFC-1100 fine coat apparatus, and examined with JEOL-JSM-6360LV SEM at the Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México (UNAM). The larger and smaller surface features were identified using magnifications between ×100 and ×750 and between ×1,000 and ×15,000, respectively following the methodology of Higgs (1979) and Krinsley & Doornkamp (1973).

## 4. RESULTS

Surface microtextures of detrital sand grains in Cox's Bazar beach are listed in Table 1. Totally, twenty six microtextures are identified on the sand grains surfaces and based on its origin they are grouped into three assemblages: mechanical, mechanical/chemical and chemical (Table 1). The mechanical origin includes pits, conchoidal fractures, straight and arcuate steps, straight and curved scratches, angular, sub-angular, sub-rounded and rounded outlines, v-shaped patterns (Vs), smooth surfaces and mechanically upturned plates. The mechanical and/or chemical origin features are relief, fracture plates/planes and adhering particles. The chemical origin features include solution pits, etching, silica globules and silica flowers. Microtextures of chemical origin are features developed either by dissolution or diagenetic processes (Table 1). Microtextures of mechanical origin are abundant in the sand grains form the Laboni, Sugandha and Himchori points. The sand grains exhibit several types of pits such as small, medium and large. These irregular pits indicate that the sand grains were derived from two different sedimentary environments (Higgs, 1979; Madhavaraju et al., 2006).

Small pits are widespread in the Laboni and Sugandha points, whereas medium and large pits are abundant in the Himchori point (Fig. 2). Similarly, conchoidal fractures (small, medium and large) are common in the detrital sand grains from the Himchori, Laboni and Sugandha points. However, medium and large conchoidal fractures are omnipresent in the Himchori point. These microtextures are typically of a high energy littoral environment (Krinsley & Donahue, 1968; Armstrong-Altrin & Natalhy-Pineda, 2013).

Table 1. Microtextures identified on the sand grains from the Cox's Bazar beach, Bangladesh.

| Microtextures | Laboni | Sugandha | Himchori | Origin |
|---|---|---|---|---|
| Small pits | A | A | C | Mechanical |
| Medium pits | C | C | A | Mechanical |
| Large pits | S | P | A | Mechanical |
| Small conchoidal fractures | A | A | C | Mechanical |
| Medium conchoidal fractures | C | C | A | Mechanical |
| Large conchoidal fractures | A | C | A | Mechanical |
| Straight steps | C | P | P | Mechanical |
| Arcuate steps | C | C | P | Mechanical |
| Straight scratches | C | C | A | Mechanical |
| Curved scratches | A | A | C | Mechanical |
| Angular outline | S | P | A | Mechanical |
| Sub-angular outline | P | C | A | Mechanical |
| Sub-rounded outline | A | A | C | Mechanical |
| Rounded outline | A | A | S | Mechanical |
| V-shaped patterns | A | C | P | Mechanical |
| Smooth surfaces | A | P | S | Mechanical |
| Low relief | P | P | S | Mechanical/chemical |
| Medium relief | P | P | C | Mechanical/chemical |
| High relief | S | S | C | Mechanical/chemical |
| Fractured plates/planes | S | P | P | Mechanical/chemical |
| Adhering particles | P | C | P | Mechanical/chemical |
| Solution pits | P | P | S | Chemical dissolution |
| Etching | S | P | S | Chemical dissolution |
| Silica globules | - | - | S | Chemical/precipitation |
| Silica flowers | S | - | - | Chemical/precipitation |
| Quartz overgrowth | - | S | - | Chemical/precipitation |

A = Abundant (>75%); C = Common (50-70%); P = Present (25-50%); S = Sparse (5-25%)

Straight and arcuate steps are largely associated with conchoidal fractures (Fig. 2). These microtextures are identified in all the three points. Similarly, straight and curved scratches are equally distributed in the sand grain of the three points along the Cox's Bazar beach. Angular and sub-angular grains are abundant in the Himchori point, whereas sub-rounded and rounded grains are abundant in the Laboni and Sugandha points (Fig. 3). Rounded grains are largely associated with aeolian (Krinsley & Smalley, 1973) or beach environments (Gravenor, 1985) or aqueous traction transportation in fluvial environments (Costa et al., 2013). V-shaped patterns and smooth surfaces are of mechanical origin distributed in all the detrital sand samples (Fig. 3). The Vs are originated as a result of grain-to-grain collision (Manickam & Barbaroux, 1987; Udayaganesan et al., 2011). These microtextures are common diagnostic features of subaqueous environment (Joshi, 2009). Mechanically fractured plates are also identified in the beach sands.

Microtextures of mechanical and/or chemical origin such as low, medium and high relief are identified in the sand grains. High relief is common in the Himchori point, while some grains show low to medium relief. However, sand grains from the Laboni and Sugandha points are characterized by low to medium relief. Both fracture plates and adhering particles are present in the studied sand grains (Fig. 4).

The solution pits and etching surface features are sparse or present in the sand grains from three points (Table 1). These microtextures were formed by chemical dissolution process. Microtextures of chemical precipitation origin are rarely present in the sand grains (Fig. 4).

## 5. DISCUSSIONS

Sand grains from the Cox's Bazar beach show various types of microtextures of different origin (Table 1). Small, medium and large pits are the common microtextures identified in the sand grains from the Cox's Bazar beach. Abundance of large pits is identified in the Himchori point (Fig. 2). Pits are likely to be originated by the collision among grains in aeolian and/or beach environments (Armstrong-Altrin et al., 2005).

Conchoidal fractures are also common microtextures identified in the sand grains (Fig. 2) and are closely associated with straight and arcuate steps, indicating their derivation from crystalline rocks (Krinsley & Margolis, 1969, Krinsley & Smith, 1981; Madhavaraju et al., 2004; Kenig, 2006).

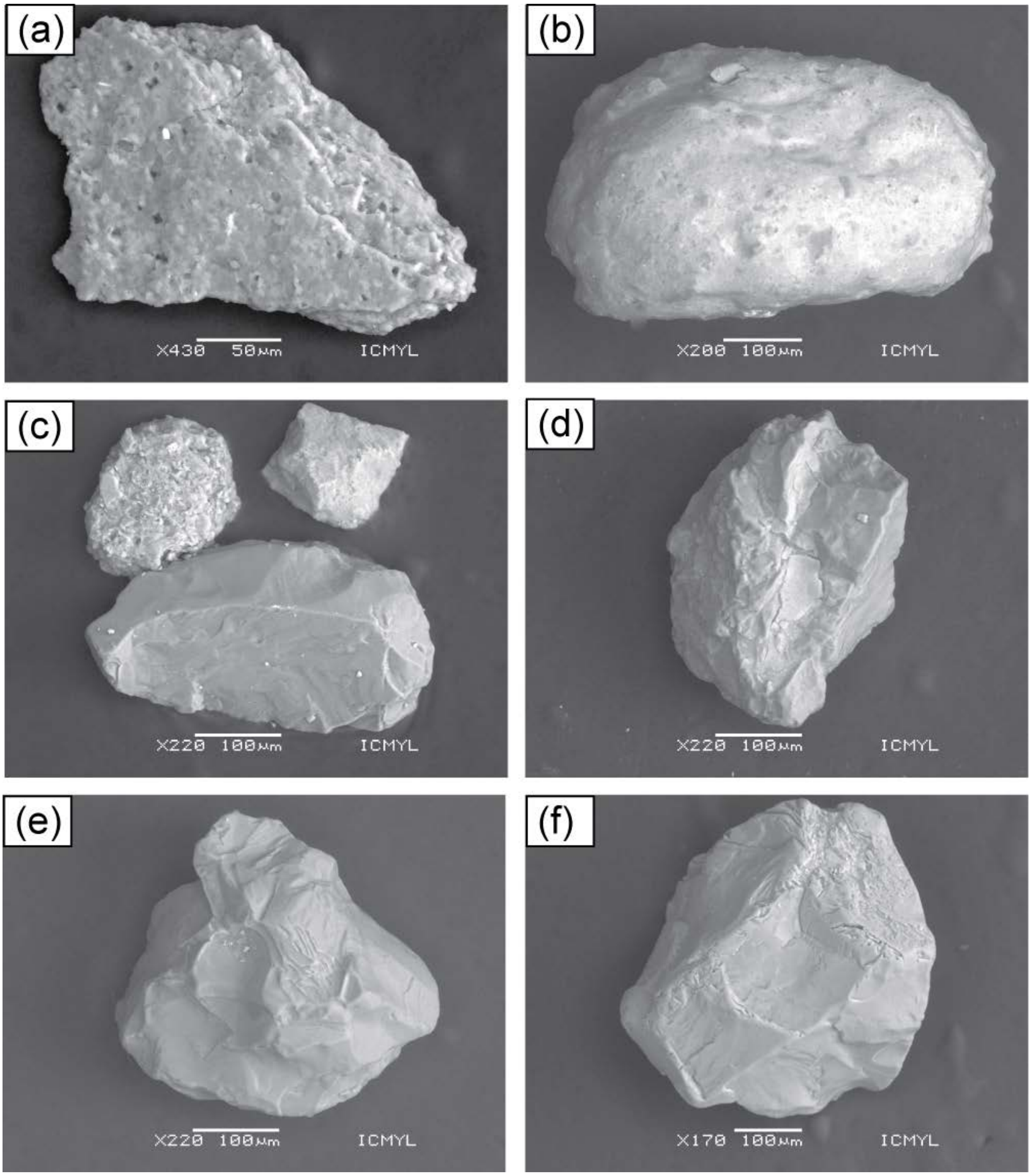


Figure 2. SEM images of detrital sand grains, Cox's Bazar beach, Bangladesh. (a) Angular grain showing small and medium pits. (b) Sub-angular grain showing large pits. (c) Sub-angular grain showing small and medium conchoidal fractures. (d) Sand grains showing small, medium and large conchoidal fractures. (e) Straight and arcuate steps. (f) Sub-rounded grain exhibits straight and curved scratches.

Similarly, this type of microtexture is also developed in a high energy subaqueous/littoral environment (Cardona et al., 1997; Madhavaraju et al., 2004; Armstrong-Altrin et al., 2005; Kenig, 2006; Armstrong-Altrin & Natalhy-Pineda, 2013). In the study area, the crystalline rocks were exposed in the western and eastern Himalayan syntaxes (DeCelles et al., 1998; Heroy et al., 2003; Hossain et al., 2010). Bengal Basin sediments were largely derived from erosion of the Himalayan orogeny and Indo-Burman Ranges and subsequently transported by the Ganges, Brahmaputra and Meghna rivers (Ensele et al., 1996; Allen et al., 2008; Hossain et al., 2010). Rahman et al., (2008) reported that heavy minerals of the Inani beach sediments probably derived from crystalline and sedimentary deposits of the rising Himalayas, Rajmahal hills, Shillong Massif and Indo-Burman Ranges. Therefore, different types of conchoidal fractures with straight and arcuate steps, and rounded edge of the beach sand grains are suggesting crystalline and/or glaciogenic origin. Abundances of rounded grains and low relief features in the sand grains were probably reflect shoreface and/or near shore aeolian processes (Campbell & Thompson, 1991; Kairo et al., 1993; Mahaney & Kalm, 1995, 2000; Mahaney, 2002; Sweet & Soreghan, 2010). Additionally, partially rounded and polished surfaces with varying protrusions are indicating an aeolian or beach environments (Krinsley & Smalley, 1973; Gravenor, 1985).

The sand grains are characterized by abundant angular and sub-angular outlined grains in the Himchori point, whereas sub-rounded to rounded grains are abundant in the Laboni and Sugandha points (Fig. 3).

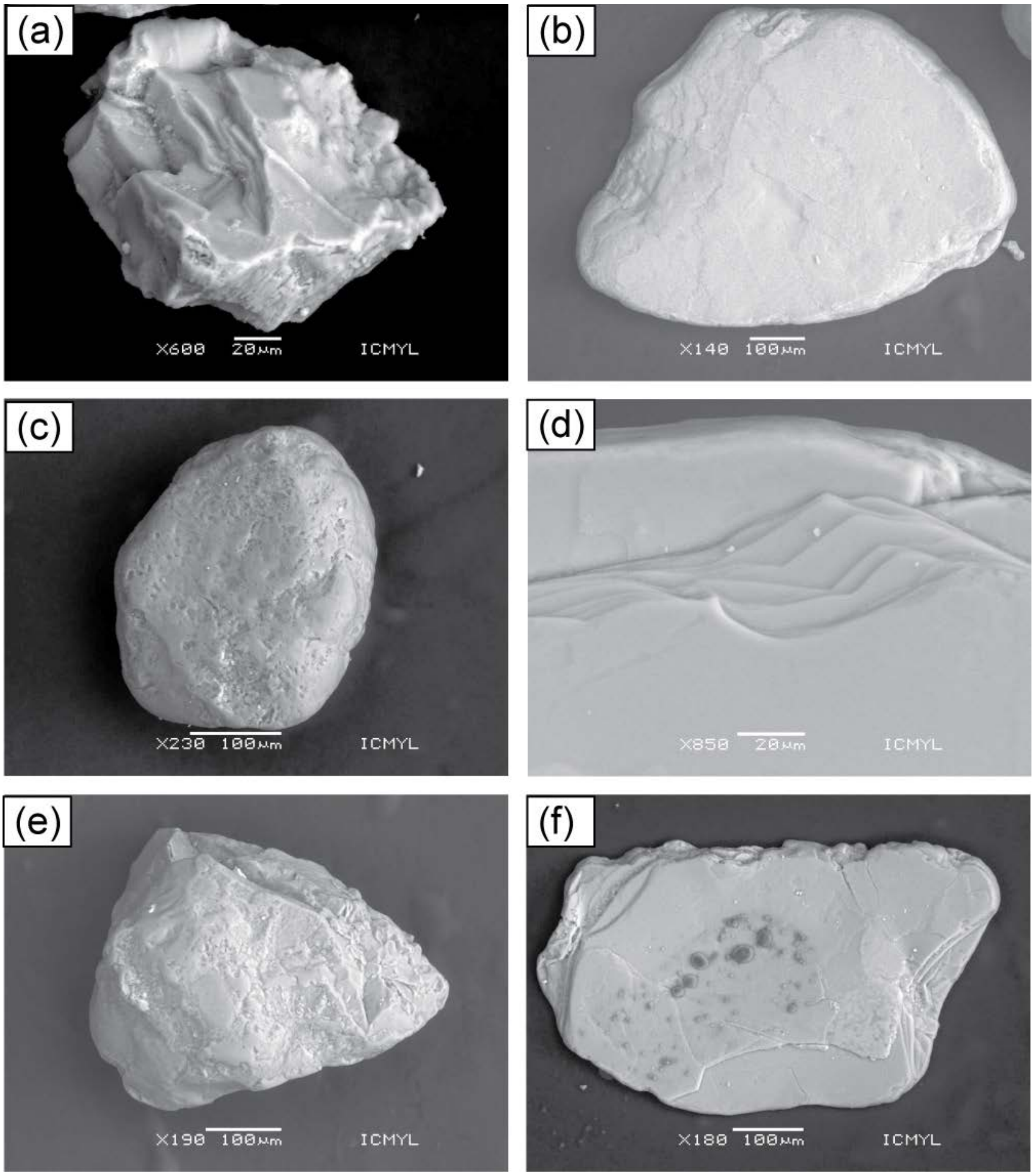


Figure 3. SEM images of detrital sand grains, Cox's Bazar beach, Bangladesh. (a) Sand grain showing angular to sub-angular outline, high relief and large Vs. (b) Sand grain showing small pits, straight scratches and rounded outline. (c) Well rounded grain exhibits small Vs, small pits and arcuate steps. (d) Sand grains showing smooth surface, large Vs and fracture planes. (e) Sub-angular grain showing large fracture planes and low to medium relief. (f) Sand grain with sub-rounded outline and quartz precipitation.

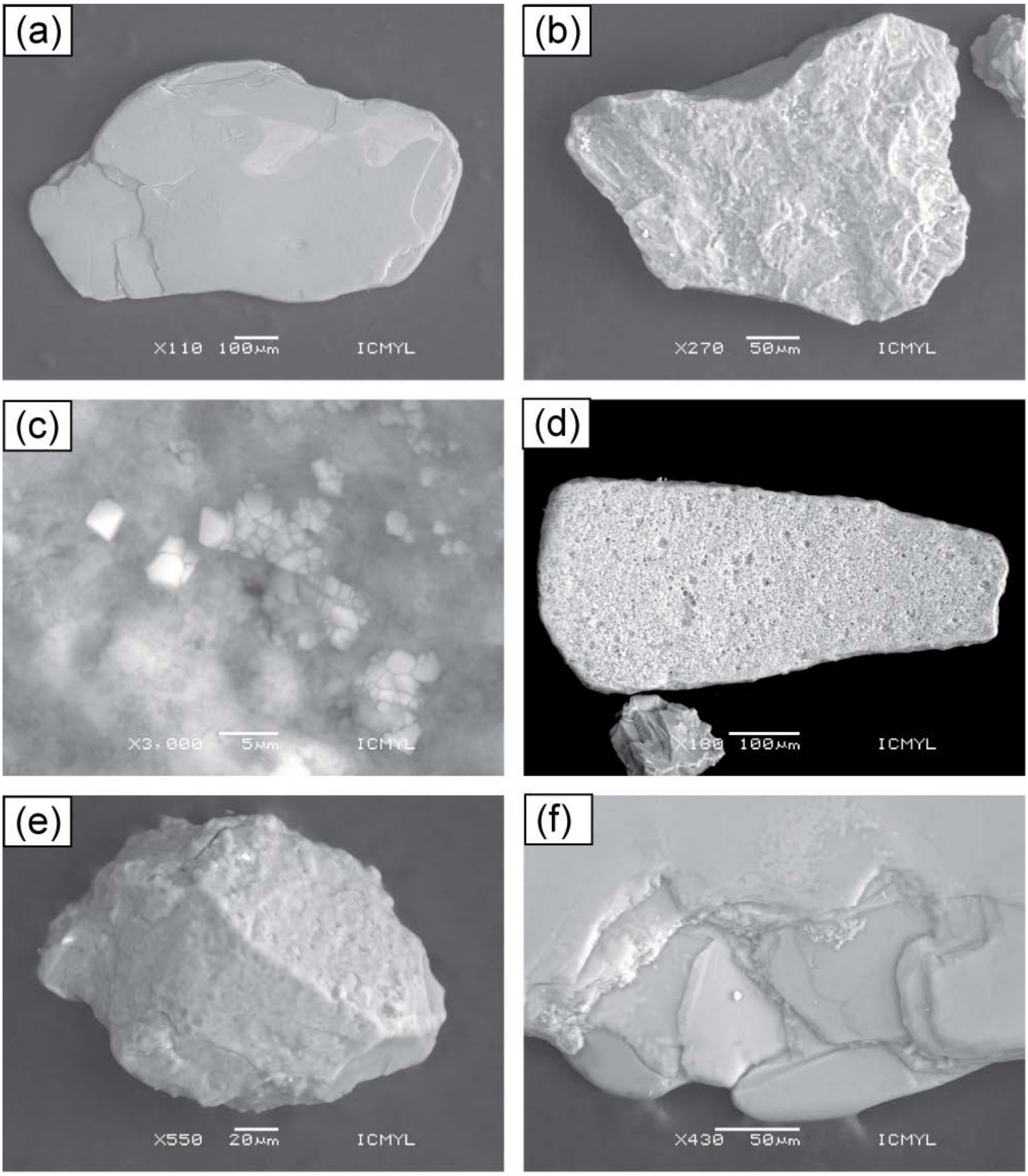


Figure 4. SEM images of detrital sand grains, Cox's Bazar beach, Bangladesh. (a) Sand grain displaying circular etching on a polished surface. (b) Angular grain showing medium relief and sporadic adhering particles. (c) Sand grain showing close up view of adhering particles. (d) Sub-angular sand grains showing circular solution pits of varying strength. (e) Sand grain showing large fracture plate and randomly oriented small conchoidal fracture as well as Vs. (f) Sand grain exhibits silica globule.

Abundance of angular to sub-angular grains with straight and arcuate steps is associated with short transportation and rapid deposition (Madhavaraju et al., 2006). Costa et al., (2013) reported that roundness in sand grains may depends on specific gravity, solubility, hardness and transportation distance in an aqueous environment. The sub-rounded to rounded sand grains of this study are ascribed to derive by long distance transportation (e.g. Himalaya) and angular to sub-angular by short distance transportation i.e., Chittagong-Tripura folded belt and/or Indo-Burman Ranges.

V-shaped pattern in sand grains is commonly triangular in shape with maximum diameter of 5 microns and their density ranges between 1 and 6 individuals per square micron (Krinsley & Donahue, 1968; Krinsley & Margolis, 1971; Krinsley & Doornkamp, 1973). The Vs are subjected to agitation in subaqueous/littoral environment for prolonged transportation as well as recycling (Mahaney, 1998; Krinsley & Takahashi, 1962; Krinsley et al., 1964; Margolis & Krinsley, 1974; Margolis & Kennett, 1971). Marine, high energy fluvial and deltaic sediments are dominated by Vs, straight and curved scratches (Mahaney & Kalm, 2000; Mahaney, 2002; Madhavaraju et al., 2006). Mechanically originated Vs in sand grains show uneven inner surface, irregular outer edges and randomly oriented features (Fig. 3), whereas sand grains having flat inner surface with regular outer edges are considered to chemical etching (Madhavaraju et al., 2006). Sand grains with straight and curved grooves, deep pits and crescentic gouges are likely to be a result of sustained high shear stress environment (Mahaney & Kalm, 2000; Mahaney, 2002; Sweet & Soreghan, 2010). Randomly oriented Vs of variable size and depth on grain surfaces are thought to record percussion transport (Campbell & Thompson, 1991; Jackson, 1996; Mahaney & Kalm, 2000; Mahaney, 2002). Sweet & Soreghan (2010) demonstrated that high stress microtextures on sand grain surfaces are attributed to glacial transport, and sand grains with percussion fractures indicate fluvial and/or marine transport. Thus, the presence of variable orientations of Vs in the sand grains is associated with high-energy subaqueous environment (Jackson, 1996; Mahaney, 2002; Madhavaraju et al., 2006). The Vs of mechanical origin are abundant in the sand grains and Vs of chemical origin are rarely present. Smooth surfaces are present in the studied sand grains inferring a post-depositional disturbance of sediments (Mahaney et al., 2004; Armstrong-Altrin & Natalhy-Pineda, 2013). The medium and high relief features identified are typically originated from debris-flow environment (Sweet & Soreghan, 2010).

Fracture plates/planes (Fig. 4) are probably formed due to the action of wind or wave during fluvial transportation (Armstrong-Altrin & Natalhy-Pineda, 2013). Adhering particles are also common in the sand grains, and developed in both fracture planes and smooth surfaces.

Circular pits and etching are important chemical dissolution features identified in the studied sand grains (Fig. 4), indicating marine depositional environment (Higgs, 1979; Madhavaraju et al., 2006). Quartz overgrowth is a chemical precipitation feature or euhedral growth of silica on grain surface formed during diagenesis is sparsely identified in the studied sand grains (Folk, 1978; Mahaney, 2002; Madhavaraju et al., 2006; Sweet & Soreghan, 2010). Silica globules and silica flowers are chemical precipitation features found in the studied beach sands. These microtextures were originated between grain contacts supersaturated with silica under the influence of humid climatic condition (Madhavaraju et al., 2006, 2009; Armstrong-Altrin & Natalhy-Pineda, 2013).

## 6. CONCLUSIONS

Microtextures of detrital sand grains from the Cox's Bazar beach were used to demonstrate provenance, depositional environment and paleoclimate. Twenty six microtextures are identified and are classified as mechanical, mechanical/chemical and chemical origin. The sand grains are characterized by predominance of straight scratches, Vs, smooth surfaces and sub-angular to sub-rounded outlines followed by low, medium and high relief, fracture planes, adhering particles and minor etching. Conchoidal fractures, Vs and sub-angular to sub-rounded grains indicate mechanical origin. The sub-rounded to rounded grains reveals long-distance transportation under fluvial regime (e.g. Himalaya). The abundance of angular to sub-angular sand grains indicates short-distance transportation derived from the nearby Chittagong-Tripura folded belt or Indo-Burman Ranges. Etching on the sand grains represents chemical origin under the influence of sea-water. The chemical precipitation features like silica globules and silica flowers are indicating a humid climatic condition of the source area.

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