Chapter V

Quartz-Grain Morphoscopy

5.1. Introduction

Quartz-grain morphoscopy is the statistical determination of the different types of quartz grains in sandy deposits (Cailleux, 1942). The method has been widely used in resolving problems of Quaternary geology, paleoclimatology and geomorphology with timely modifications incorporating the methodology adopted by Kuenen and Perdok (1962), Krinsley and Doornkamp (1973), Borger (2000), Mahaney et al. (2001) and Mahaney (2005).

Quartz-grain morphoscopic studies focus to bring out the history of the evolution of quartz grain since its detachment from the country rock. It is deduced from analyzing the available surface scars and markings, indicative of peculiar exogenic agents, like glacial, pluvial, fluvial, aeolian, coastal, mass wasting and insitu breaking. The study especially determines transport mechanisms undergone by sand grains and it discerns its deposition environments. The surface texture is examined most precisely under scanning electron microscope and it draws out the conclusion from the analysis of a large number of grains.

In quartz grain morphoscopy, to distinguish ancient deposition environments, the surface grain texture of quartz from contemporary environments were studied by Miller and Olson (1955), who divided all properties of contemporary environments into three groups.

The first include properties that exist only in contemporary sediments and not in the lithology; the second includes the properties that can be analyzed both in modern and ancient sediments, but which change over time with diagenetic process; and the third group encompasses properties that are the same in both modern sediments and lithology.
The surface micro textures fall in the second and third group. The correspondence between the modern and ancient micro-textures may be very close depending upon the original textural imprints, grain age and all the digenetic process that operated during post deposition time. If the origin of particular micro-texture is well understood environments can be delineated with a fare degree of certainty. The knowledge of physical and chemical parameters that influenced or created characteristic surface micro-textures can lead us to the exact environmental discrimination. The atlas of Krinsley and Doornkamp (1973) and Mahaney (2005) remains a useful source of illustration of textures.

5.2. Environment of deposition and quartz surface texture

Mahaney (2005) enlists forty-one different micro textures exhibited by quartz surface encrypting the records of events overprinted with time. Often it is possible to reconstruct the entire environment history of a grain as well as related time involved by studying closely the pre-weathering and weathering features. The parameters that had created different surface micro textures in different environments are discussed below.

Sand grains usually travel as saltating or creeping bed load (Bagnold, 1941) and may be subjected to a succession of high energy collisions. During collisions, the kinetic energy of each particle is converted, at least partially into elastic energy in the grain. The energy wave or vibration may bounce back and forth within a given grain a number of times, although it is not known how this affects the grain surface. The result of these collisions, termed “abrasion fatigue” by Pascoe (1961), is a disrupted lattice type of structure on grain surface. This makes the surface of the grains physically and chemically reactive and may cause small silt and clay particles to attach to the grains until they are removed by additional abrasion.

The shape of grains in the deposit regardless of their size depends on a number of factors, including:

- The initial shape of the grain
- Physical and chemical features
- The duration of the process
Character and environment of transport

The type and intensity of weathering following the sedimentation.

The two pre-deposition factors usually affecting the grains are rounding and surface frosting. Their degree depends upon the source of the grain, transportation factors and the intensity of the agent. Thus the character of rounding and surface frosting of the grain is an indicator of the transport environment and of the subsequent digenesis of deposits. The sand grain surface features of the three principal environments viz. aeolian, fluvial and glacial are summarized below.

5.2.1. Aeolian grains

The sediments are transported by wind, i.e. the aeolian transport, when the strength of wind crosses the threshold strength of the immobile loose material that retains it over an immobile surface (Bagnold, 1941; Pye & Tsoar, 1990; Barndorff-Nelson and Willets, 1991; Boggs, 1995). Direct dislodgement from outcrops by wind is also important in grain transport (Greeley & Iverson, 1984; Anderson et al. 1991; Boggs, 1995). As grains are moved by wind, they collide with other grains in transport as well as on the surface below. If collision is sufficiently energetic, portions of grains may chip off, or they may shatter. Various types of cracks and plates may form on the parent grains. Much fine material of silt (63 µm) and clay (<2µm) may be mechanically produced in wind sediments that are transported long distances.

The micro texture observed on aeolian sand grains using SEM in the secondary mode includes:

- Upturned plates, parallel ridges approximately 0.5-10µm or thicker
- Elongate depressions
- Polygonal cracks
- Smoothed over depressions, low relief and ridges
- Bulbous projection
The upturned plates produced are probably the result of sand grains being frequently modified in the desertified environment by solution and precipitation of silica (Margolis & Krinsley, 1971; Krinsley et al. 1976). Plates appear to be sized from 0.1\(\mu\)m to 1\(\mu\)m. Equidimensional or elongate depressions may be the result of glancing impact between saltating or creeping grains. They are observed on grains of sand size larger than about 400\(\mu\)m and are approximately 20\(\mu\)m (or less) to 250\(\mu\)m in diameter, producing medium relief. As grains saltate they also rotate; the effect of this behaviour on abrasion is unknown but it may assist in rounding grains and in the genesis of the bulbous edge.

Arcuate, circular and polygonal cracks (about 0.5\(\mu\)m to several tens of micrometers in length) are observed on most large quartz grains which are typical indicators of Aeolian. Smoothening of all the above mentioned features resulting in low relief is almost ubiquitous in modern desert grains. In the final stage of Aeolian transport a rolling topography is created which generally encompass the entire grain, often resulting in the production of bulbous edges.

5.2.2. Fluvial Grains

The most diagnostic micro feature of the fluvial process is the V-shaped percussion fracture. Well preserved in quartz, percussion scars are also found on other grains, including heavy minerals. The higher the flow regime, the greater the frequency with which this micro-texture appears on a random sample of grains. It is also, present on glacial grains, especially grains emplace by warm based glaciers, where water is available within and at the base of the ice, and moves material at high velocity (Mahaney & Kalm. 1996). The presence of these micro features is taken as evidence of near-catastrophic flow; however, much more work needs to be done with respect to correlating micro-textures with increasing stream velocity (Mahaney, 2005).

Abrasion seen primarily as a rounding factor with quartz is also important in wearing fracture down to plane surface and in some cases obliterating them. The available evidence indicates that upper flow regimes produce greater degrees of abrasion and rounding than middle or lower flow regimes and tend to obscure any previous micro texture signature.
especially over long transport distances. From the data available it appears that low regimes
do not appreciably change the shape of grains inherited from till outcrops.

5.2.3. Glacial Grains

Among all type of sediment grains the glacial grains carry the greatest range of micro-textures than grains affected by other geologic agents. Unlike the Aeolian and fluvial grains, glacial grains are generally held in bondage by the ice or by other grains in rigid suspension resulting in the ultimate grinding of the grain as the glacier moves down. Aeolian and fluvial grains are capable of random motion. Therefore while they are undergoing high-energy collisions, they are not subjected to the concentration of this high energy specifically at one point as glacial grains do. In short the scars and imprints on grain surfaces that have undergone fluvial or Aeolian activities would be less intensive than that exhibited by grains from glaciated environment. Mahaney (2005) ascribes the features like angular grain shape, deep entrenchment of conchoidal and linear fractures and deep groves and frequent directionality of troughs and striations as unique to grains emplaced by glacial transport.

5.3. Methodology

SEM (Scanning Electron Microscopy) imaging capabilities

The SEM (Scanning Electron Microscopy) permits the observation of materials in macro and submicron ranges. The instrument is capable of generating three-dimensional images for analysis of topographic features. When used in conjunction with EDS the analyst can perform an elemental analysis on microscopic sections of the material or contaminants that may be present. An SEM generates high energy electrons and focuses them on a specimen. The electron beam is scanned over the surface of the specimen in a motion similar to a television camera to produce a rasterized digital image.

Electrons are speeded up in a vacuum until their wavelength is extremely short, only one hundred-thousandth that of white light. Beams of these fast-moving electrons are
focused on a sample and are absorbed or scattered by the specimen and electronically processed into an image.

**EDS (Energy Dispersive Spectrometer) analytical capabilities**

Viewing three dimensional images of microscopic areas only solves half the problem in an analysis. It is often necessary to identify the different elements associated with the specimen. This is accomplished by using the “built-in” spectrometer called an Energy Dispersive X-ray Spectrometer. EDS is an analytical technique which utilizes x-rays that are emitted from the specimen when bombarded by the electron beam to identify the elemental composition of the specimen. To explain further, when the sample is bombarded by the electron beam of the SEM, electrons are ejected from the atoms on the specimen's surface. A resulting electron vacancy is filled by an electron from a higher shell, and an x-ray is emitted to balance the energy difference between the two electrons. The EDS x-ray detector measures the number of emitted x-rays versus their energy. The energy of the x-ray is characteristic of the element from which the x-ray was emitted. A spectrum of the energy versus relative counts of the detected x-rays is obtained and evaluated for qualitative and quantitative determinations of the elements present.

Modern SEM/EDS instruments are operated using very sophisticated software. These software programs allow unattended feature analysis and “mapping” of the composition of the elements on the surface of the specimen. Methodology involved in the present study has been elaborated elsewhere (Section 4.2.1.3).

**5.3.1. Sample Collection**

A sample collected in the field is only a representation of a population that may or may not be homogeneous. The sampling plan dictates the number of samples required to estimate sampling error and to characterize a population.

After deciding where to collect and with what intensity, the researcher normally considers some of his or her samples as “representative” for the purpose of microscope...
analysis. Thus, we have the concept of the most “typical” site and sample, which in the collector's mind provides reliable information on the population. Representative samples are collected on the basis of color, mineral content, particle size, or some other easily determined property in the field, and may or may not represent the population.

5.3.1.1. Sub sampling

In sub sampling the sample is divided into a smaller portion to carry out a particular test, such as particle size, moisture content determinations or pH. The test is then carried out, presumably with a “representative” portion of the bulk sample (i.e., with splits or sub samples of the sand fractions) or with various fractions of sand recovered from wet sieving following particle size analysis. In any case, it is necessary to wash samples prior to selection for SEM-EDS analysis.

The various fractions to be analyzed may be recovered following particle size analysis where sand is wet sieved and dried. Individual sand fractions may be analyzed, from very coarse (1-2mm), coarse (1mm-500μm), medium (250-500μm) to the fine (250-125μm) and very fine (125-63μm) grade sizes.

A representative sub sample can be prepared with a sample splitter, or by spreading the sample out on weighing paper, and then using a micro spatula to select small amounts at more or less random intervals to produce the desired weight.

5.3.1.2 Processing the sample

Samples selected for SEM/EDS analysis are first cleaned using toluene and methanol to remove hydrocarbon residue, and then dried in a vacuum oven. The samples are broken to expose fresh interior surfaces. Samples are then cemented to an aluminium stub with epoxy. Carbon paint is used to cover the base of the sample and the epoxy to improve conduction and reduce charging effects in the SEM. Samples is sputter coated with platinum for 5 minutes.
5.3.2. Statistical Tests

The most basic means of summarizing micro textural data is to plot histogram or bar graph showing the frequency of occurrences of individual micro texture.

One means of analyzing bar graph summaries (frequency distribution) of micro texture observations on sediment grains is to quantify similarities or differences among samples in order to compare them. Specifically one may compare samples from three distinct environments of deposition.

The bar graph has different shapes, suggesting immediately that there is distinct signature for each environment. Quantitative analysis of observation on individual grains from all three environments would be required to show these relationships, which is something that would require principal components analysis or classical cluster analysis.

5.4. Observations

The micromorphic textures of quartz grain surfaces show immediate variation among three sub surface Litho Units described in the study area under the scanning electron microscope and they bear the following imprints. Selected SEM photographs of microtextures on quartz of the three litho unit are given in Figures 5.1-5.3. The complete set of data is given in Appendix 3.

In Litho Unit 1

- The morphology and surface features of the quartz grains of this unit essentially show fluvial characteristics (Figure 5.1).

- The grains are smooth and round. The grains tend to attain ellipsoidal shape. Micropercussion cracks formed out of material collision and impact pits are identified.

- No specific stages of maturity can be identified.

- Some of these grains bear the imprints of an early aeolian phase modified under
fluvial environment, identified by the incidences of micro percussion cracks, impact pits and other fluvial features over bulbous projections, which is typical of aeolian surface mould. The imprints of higher regime aeolian grain surface at the back drop of fluvial print over further limits the commentary on the grade of maturity under fluvial activities.

- More heavy minerals are seen in this sediment fraction, with classic fluvial marks.
- Finer grains in this regime, exhibits more fluvial characters.

In Litho Unit 2

- The quartz grains of this unit show mixed characteristics. (Figure 5.2).
- Micro features like etching and chemically altered (weathered) surfaces are observed in grains from this Litho Unit
- Some of the grains from this unit show history of aeolian transport before being altered under the present one.
- Overprinted grains are more abundant indicating a lake environment.

In Litho Unit 3

- The activity of wind predominating over the accommodative space throughout the time of its deposition is identified. The aeolian micromorphic features imprinted on the quartz grains over print erstwhile surface textures (Figure 5.3).
- The grain surfaces range from youth to matured stages
- The grains procured from 2 to 3 m below the ground surface give geographical concentration of textural features. The coarser and fresher grains are seen closer to the backshores (to the west of study area) and matured and reworked grains towards the hinder land (Eastern part of study area).
- Predominantly, the grain surfaces are characterized by bulbous projection, percussion cracks, and roundness of edge, elongate depression and wind abrasion imprints. Other feature like upturned plates, precipitates, polygonal cracks are encountered infrequently.
- Among the micromorphic features seen the incidence of bulbous projections is the most, followed by edge roundness and abrasion imprint
Figure 1. The microtextures in Litho Unit 1 (photo micrograph A to O) shows predominantly percussion cracks (graph B) indicative of fluvial environment. The grains show low relief, fracture faces, sub parallel linear fractures, linear steps, mechanically upturned plates, abrasion features, V-shaped percussion cracks, edge rounding, over-printed grains and ridges and troughs. Angular grain, precipitates on top ledge, bulbous edge on lower left, clear sharp fracture face to right, preceded coating in the upper left part of grain and deep trough in gain A and C. Fracture face front, old etched sub-parallel fractures to left. V-shaped deep scars indicating upper flow regime current in D and E, angular fracture faces, deep V-shaped scars in F.
Figure 1 (contd) Angular grain with preserved weathering surface and etched surface in G, ablation ridges, cone shaped surface ruptures in H, Sharp edges, some v-cracks, minor edge rounding in J, laminations, minor etching and some pre-weathering in K, subrounded edges, and V shaped percussion cracks in L.
Figure 1 (contd) Subrounded grain, dissolution etches, v shaped percussion cracks with precipitates in M, bulbus subrounded smooth surfaces in N and angular grain with dissolution etching with slight weathering in O.
Figure 2. The microtextures in Litho Unit 2 (photo micrograph A to O) shows predominantly bulbous and percussion cracks (graph B) indicative of a mixed environment of deposition, namely aeolian and fluvial. The grains show low relief, fracture faces, sub parallel linear fractures, linear steps, mechanically upturned plates, abrasion features, V shaped percussion cracks, edge rounding, overprinted grains, dissolution features, etching, edge rounding, abrasion features and ridges and troughs.
Figure 2 (contd). The grains show low relief, dissolution features, etching, edge rounding ridges and troughs, V-shaped percussion marks and linear fractures (G-L) and precipitate features (K and L).
Figure 2 (contd). Angular to sub angular edges (M), linear fracture and parallel striations (N) and waethered surface with precipitates (O).
Figure 3. The microtextures in Litho Unit 3 (photo micrograph A to O) show predominantly bulbous texture (graph B) indicative of aeolian environment. The grains show low relief, dissolution features, etching, edge rounding ridges and troughs, V-shaped percussion marks and abrasion features (A, C to F), sub parallel linear features (B), weathered surfaces (A and F) and over printed surfaces (A).
Figure 3 (contd). The grains show low relief, dissolution features, etching, edge rounding ridges and troughs, V-shaped percussion marks and abrasion features (G to L). Fresh surfaces and upturn plates are well seen in J and K. Parallel striations are dominantly observed in K and smooth depressions of aeolian action is explicit in L.
Figure 3 (contd). The grains show low relief, dissolution features, etching, edge rounding ridges and troughs, V-shaped percussion marks and abrasion features (M to O). Note that parallel ridges are prominent in M. The probability of occurrence are plotted against major surface micro textures exhibited by the quartz grain (P), shows that the imprints predominantly are of wind action.
In mature sediments the incidences of features of abrasion are quite low and the grain is almost round or near roundness.

Absence of fluvial imprints and the presence of a fewer younger stage coastal imprints on the grain surface indicate a low flow regime existed prior to the aeolian activity.

Precipitates are seen on grain surfaces which bear younger to middle stage surface features.

5.5. Discussion

The quartz grain morphoscophy presents supportive evidences to draw distinction in stratigraphical records among three major Litho Units identified in the study area. Fluvial origin can be inferred for grains from Litho Unit 1 while Litho Unit 2 exhibits a mixed character. Grains from Litho Unit 3 satisfactorily establishes it to fluvial ones from those impact features produced only during fluvial transportation roundness and elongation of grain along with microfeatures of fluvial character. Some grains have pre history of aeolian transport modified by fluvial agents indicated by micro percussion cracks over bulbous projections. Even though maturity of sediments cannot be identified relief of microfeatures observed decreases with roundness of grains indicating severe fluvial action. Quartz grains for Litho Unit 2 are characterized by etching and weathered surface as well as from the clay particles and adhering neckron mud particles. It conforms to a lacustrine environment.

Litho Unit 3 characterized by grains showing severe wind action. Most of the features via bulbous projection, percussion cracks roundness of edge, elongate depression, and wind abrasion imprints etc. are indicating the particular Litho Unit to be of aeolian. Migration of sand from around the shore towards hinterland along the wind direction is evident from maturity of grains features observed, which varies from younger features along the shore to matured ones as it nears later, as well as from the fining of grains.

The change in the medium clearly deciphered from quartz grain morphoscopy reflects the climatic history of the region in general. Further discussion on this aspect is presented in Chapter VIII.