SCANNING ELECTRON MICROSCOPE STUDIES OF CAVE SEDIMENTS

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ABSTRACT

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The microstructure of the surfaces of quartz sand grains can reveal their history prior to their deposition in a cave. The scanning electron microscope is the ideal tool for such studies. This paper presents examples of the sort of information obtainable from such a study, drawing examples from caves in Australia, Papua New Guinea and Norway.

INTRODUCTION

The analysis of cave sediment sequences is a well–established methodology for the reconstruction of environmental histories. Reduced temperature and humidity fluctuations within caves and rock shelters reduce the post–depositional alteration of sediments (Frank, 1971). Sediment sequences may be preserved intact for millennia and their analysis has provided information on transport mechanisms and depositional environments for archaeologists, geomorphologists and geologists.

Traditional avenues of approach include particle size analysis, clay mineralogy and chemical properties (for an Australian example, see Frank, 1975). A relatively recent method is the analysis of surface features of the quartz sand fraction by means of the scanning electron microscope (S.E.M.) This paper briefly reviews the methodology and methods of this approach and provides some examples from the author's research in Australia, Papua New Guinea and Norway.

BACKGROUND THEORY

The application of the SEM to sedimentology has been developed by Krinsley and his co-workers (Krinsley 1978) since 1968. The objective was to investigate the surface textures of quartz sand grains, as it was considered that quartz, a relatively abundant and resistant mineral with no apparent cleavage, would reflect on its surfaces different palaeoenvironmental features. These features would result from the particular energy conditions characteristic of various transport, depositional and weathering environments. Over the last ten years extensive research, involving field and experimental studies, has permitted characterisation of certain geomorphic environments. Figure 1 is based on the author's work, and the detailed studies of Krinsley and Doornkamp (1973), Margolis and Krinsley (1974) and Krinsley (1978). It must be stressed that only the identification of certain combinations of surface features in statistically significant percentages permits identification of a sedimentary environment.

Glacial environments, in which sediment transport occurs within and contiguous to the ice mass, involve the sediment being subjected to grinding and sliding action. The consequences of this action is the production of angular grains with characteristic conchoidal fractures, breakage blocks, scratches, step-like features and abrasional features termed "chattermarks" (Bull, Culver and Gardner, 1980). Fluvioglacial action tends to round and subdue this suite of surface features, producing a distinctive grain form.

Modification of subaqueous transport in streams and currents seems to be dependent on the energy level involved. Early sedimentary petrologists such as Krumbein (1974) noted the rounding and reduced relief of fluvial grains. In turbulent flow regimes the buffeting of suspended grains produces small irregularly oriented impact pits, chipped into the surface. Both Margolis and Kennet (1971) and Gillieson (1983) suggest that there is a relationship between the density of these pits and different energy levels for subaqueous transport. At high levels of energy, wholesale flaking of the grain surface and abrasional tooling occur. Although abrasion by wind also leads to rounding, upturned plates can be seen exposed on the grain surfaces, and represent the ends of weakly expressed cleavage plates detected by Krinsley and Smalley (1973) and Margolis and Krinsley (1974).

Appreciable solution and reprecipitation of silica can occur in environments where silica mobilisation is widespread, for example, in the leached and laterised soils of tropical Australia and New Guinea. Grain surface solution in these high-energy chemical environments results in a suite of forms such as etch pits and crevasses. Reprecipitation of

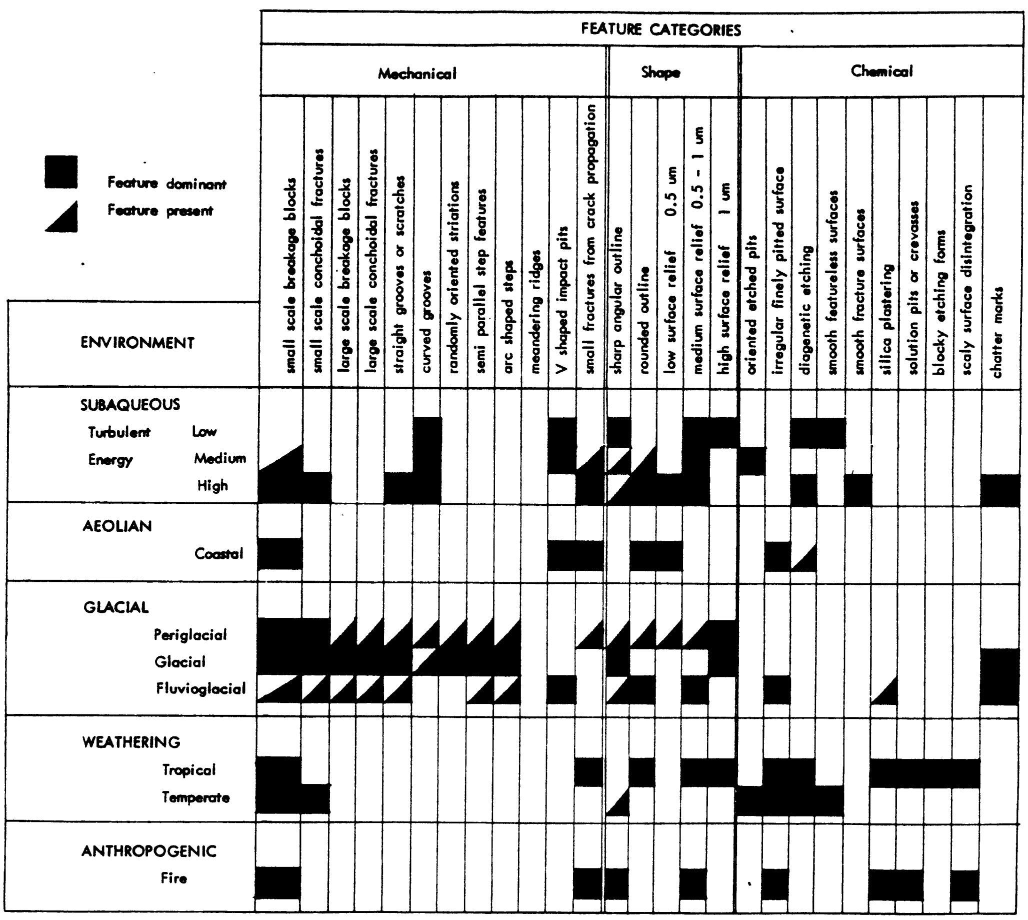

Figure 1: Quartz grain surface features and their environmental occurrence.

silica in alkaline environments results in either amorphous silica plastering or euhedral crystal growth, depending on the rate of deposition.

Experimental and field studies by the author suggests that strong heating of surface grains in an alkaline chemical environment produces scaly weathering and surface disintegration of grains. Such conditions are found in fire and its resultant ash. Examination of grains from archaeological hearths reveals a dominance of this form which is absent from all non-burnt sediments so far examined.

SEM has several advantages over light microscopy, particularly finer resolution and extreme depth of field which permit simultaneous viewing of a suite of features on the grain surface.

METHODS

Sediment samples were dispersed without agitation and the sieved sand fraction retained. Unicrystalline quartz grains were separated, checked for mineralogy using petrographic techniques, and cleaned using boiling concentrated hydrochloric acid. This treatment does not affect the surface texture (Krinsley and Doornkamp, 1973; Tovey and Wong 1978) but removes ferruginous or calcareous coating. The cleaned sample was rinsed, dried and mounted on an aluminium stub for viewing. During SEM examination 20 or more grains were chosen at random and the presence or absence of each of the features in figure 1 noted for each grain. This permits a statistically reliable characterisation of the sample.

SOME RESULTS FROM CAVE STUDIES

The sedimentary sequences in several large P.N.G. caves have been studied by the author as part of doctoral research (Gillieson, 1983). Two cave systems which bear strong similarity in morphology and geomorphic development are the Atea Kananda and Selminum Tem. Although the latter system is now largely abandoned by the streams that fed it, the sediments are comparable. Both caves have evolved from early nothephreatic conduits, through a phase of dynamic phreatic enlargement, to their present state of vadose incision. Each cave has several levels which are related to structural and lithological controls, and the successive capture of surface streams, rather than to uplift. The systems have a wide range of sedimentary environments from high energy, turbulent flow to the small feeders which carry storm rainfall underground. Due to the relatively good preservation of cave sediments, it is possible to examine material with little or no diagenetic modification since emplacement.

The source of most of the quartz fraction is either from the erosion of soils derived from the Darai limestone and shale interbeds or directly from rock erosion. Grains derived from the Darai limestone are usually angular and fractured, with small scale breakage blocks and minimal diagenetic etching.

Quartz grains from surface soils are subangular with high relief and their surfaces are entirely modified by blocky etching and the development of solution pits and crevasses. This suite of textures is similar to that recorded for other tropical weathering environments (Gillieson, 1980). Silica plastering is minimal, suggesting its removal is complete


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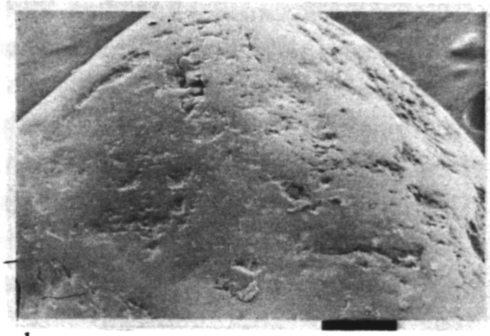
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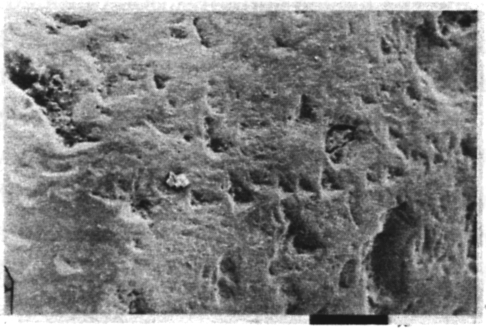
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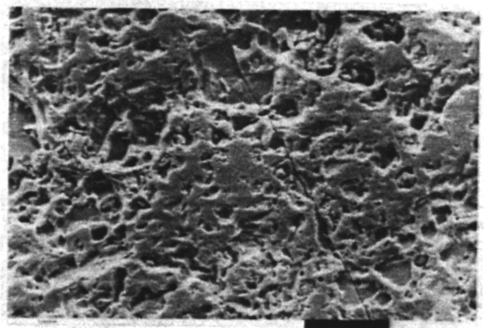
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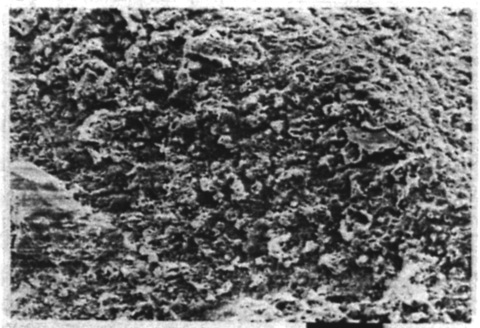
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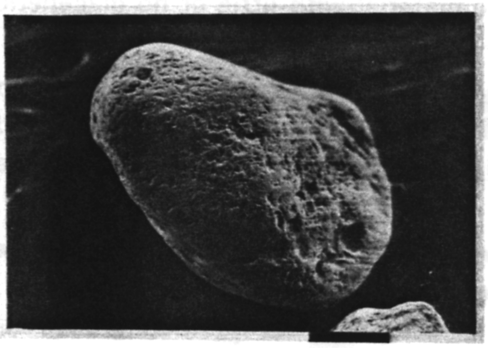
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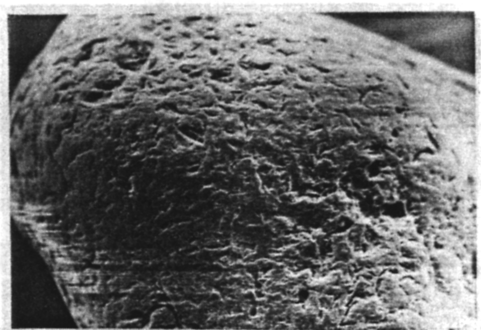
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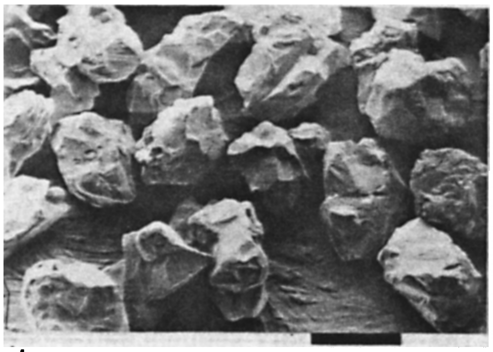

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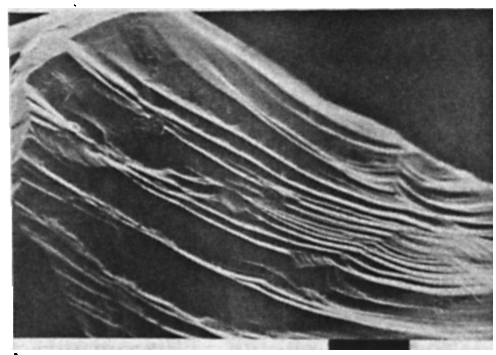

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Plate 1:

- a *Rounded quartz grain from the Fury Tube, Atea Kananda. Note numerous small fractures, curved grooves and incipient chattermarks. Scale 100 μm.*
- b *Grain surface of sand from Ugwapugwa. Area showing minor fractures, extensive v–pitting and diagenetic etching of grain ends. Scale 100 μm.*
- c *V-pits on a grain from the Fury Tube, Atea. Pits are irregularly spaced and deeply incised. Scale 400 μm.*
- d *Deeply-etched grain surface from Rafting Ground, Atea. Surface is completely covered with blocky etching and solution crevasses. Scale 10 μm.*
- e *Grain from the mudflow deposit in Selminum Tem. Note abrasional striations, conchoidal fractures and rounding. Scale 200 μm.*
- f *Scaly weathering of grain from hearth in Albura cave excavations, P.N.G. Scale 20 μm.*
- g *Whole grain from Ashford Cave, N.S.W. The well–rounded quartz sand has extensive diagenetic etching of surface flaws. Scale 100 μm*
- h *Enlargement of g, showing shallow etching forms, crevasses and minor fractures. Scale 40 μm.*
- i *Quartz grain from relict sediments in Greftskjelen pothole, Norway. Highly angular with extensive conchoidal fractures. Scale 200 μm.*
- j *Conchoidal fracture from i showing arc-shaped steps, striations, and small-scale pressure blocks. Scale 40 μm.*

in these leached soils. Plate 1d shows the texture of these soil–derived quartz grains. Washing of this material into caves by small, ephemeral surface streams causes little modification apart from rounding of grains and some fracture development. Grains that have been subjected to fluvial transport at higher energy levels are extensively modified. The grains are well rounded (Plates 1a and 1b) with extensive areas of abraded, featureless surfaces and a suite of fractures, scratches and grooves as well as v-pits (Plate 1c). In hollows, the etched surface is preserved. At high levels of fluvial energy, wholesale flaking of the grain surface results in numerous fresh fracture surfaces on which abrasional tooling marks - chattermarks - are recorded.

Mass movement processes are of great importance in land surface reduction in the montane tropics. Mudflow deposits are widespread and may profoundly alter the characteristics of stream channels by infilling. In Selminum Tem a large mudflow deposit has entered the cave conduit and traces of it are found up to 3 km from the upstream entrance. The quartz fraction of this deposit has surface textures which reflect the fluidised transport of this unsorted, matrix-supported clay gravel. The grains have abundant fractures, abrasional tooling and small conchoidal fractures. It is also possible to differentiate fluvial from soil derived material and to rank fluvial deposits in terms of depositional energy. This permits reconstruction of the sedimentary sequence in a cave which may be related to landscape evolution or climatic change.

Ashford Cave is located in north–eastern New South Wales at the headwaters of the McIntyre River. It is a horizontal epiphreatic system with at least three levels of development, evidenced by flat roof sections and accordance of phreatic pendants and spongework. A brief description has been provided by Grimes (1977) and the cave has been mapped by the author. Old stream cliffs near the upstream entrance suggest that the cave may have functioned as a meander cut-off cave, and the uppermost level of cave development is accordant with a terrace remnant on nearby Limestone Ck. 3.6m of sediment stratigraphy were obtained by augering in an infilled phreatic section. The upper part of the sequence is guano-derived banded clay sediment. Below 2.9m the sediments change to orange and reddish–brown earths with grey clay nodules. It is suggested that this unit represents soil–derived sediments washed into the active cave system. Samples were prepared as above for SEM analysis. The quartz grains are subrounded, supporting water transport, and their surfaces are wholly covered by a complex of solution pits (Plates 1g and h) and crevasses, suggesting a strong chemical weathering environment. In many respects they are similar to the P.N.G. material but lack the intensity of pitting and features of high energy fluvial sediments. The basal sediment therefore represents fluviatile material, possibly related to the creek terraces, which has been washed into the cave during the period in which it functioned as a meander cut–off. The diagenetic modification to the grains may have occurred during one or more phases of reworking and indicates a strong weathering environment not inconsistent with the present humid mild winter climate.

Just north of the Arctic Circle in Norway are found extensive areas of intensely folded Cambro–Silurian limestone. The outcrops tend to occupy narrow zones in the glaciated valleys and dip at between 45 and 80 deg. The most recent glaciation (Würm–Wisconsin) resulted in the excavation of the present topography with a relative relief of at least 500m. Preglacial cave systems would therefore have to be formed at depths of 500m and would have been nothephreatic. There is, however, an absence of the forms associated with this hydrologic regime in Norwegian caves, which are dominantly dynamic phreatic or vadose in nature. A more likely explanation is that the caves were developing subglacially and have enlarged in the 10,000 years following glacial retreat. Both water circulation and carbonate solution near the soles of extant glaciers have been noted by Ford, Fuller and Drake (1970).

At the northern margin of the Svartisen ice cap two cave systems, Greftkjelen and Greftsprekka, have been mapped to depths of 340m and 225m respectively. The caves have developed on several levels and contain pressure tube sections inclined at angles of up to 35 degrees. Relict sediments are found on high level ledges in the caves and are well–sorted sands. The surface textures of the quartz fraction show the suite of forms characterising glacial transport. Examples are shown in Plates 1i and j. This, and the bedrock morphological evidence of extensive frost shatter and glacial mills in the entrance dolines, would support a subglacial origin for the caves. Comparison with till deposits pushed into Setergrotten, a cave near Mo–i–Rana, shows identical surface features.

CONCLUSIONS

Scanning electron microscopy is a useful addition to the methods used by cave geomorphologists in their reconstructions of speleogenesis and palaeoenvironmental change. Used in conjunction with granulometry, it permits differentiation of depositional processes which might yield similarly–textured deposits. Although an extensive European literature has provided examples of textures from known geomorphic environments, what is needed in Australasia is a comparative collection from the wide range of climatic and geomorphic regions which comprise our sphere of activity.

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