PROVENANCE STUDIES OF FINE-GRAINED SEDIMENTS WITH SCANNED CATHODOLUMINESCENCE OF QUARTZ: POTENTIAL APPLICATIONS IN PLANETARY EXPLORATION. J. Schieber[1], D. Krinsley[2]; and Tennison, E.[1] [1]Department of Geology, The University of Texas at Arlington, Arlington, Texas 76019, schieber@uta.edu; [2]Department of Geological Sciences, University of Oregon, Eugene, Oregon, 97403, krinsley@oregon.uoregon.edu.

Introduction: Monotonous under the petrographic microscope, quartz grains show a range of textural features when examined by Scanned Cathodoluminescence (SEM-CL). Preliminary studies [1] have shown that quartz grains from different sources (volcanic, plutonic, metamorphic) differ in appearance when examined by SEM-CL (Fig. 1).

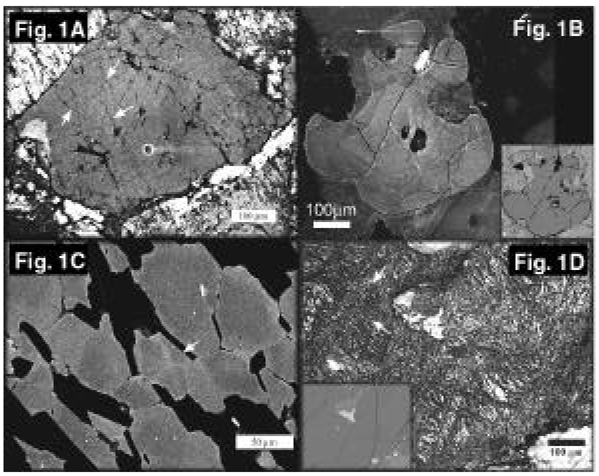
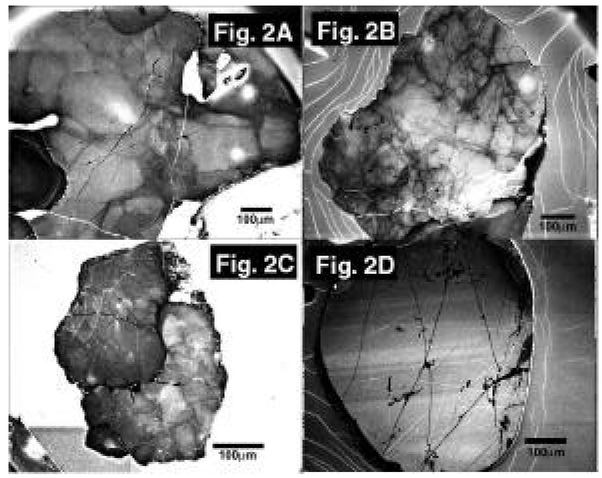


Figure 1A shows quartz from a granodiorite . Non-luminescent dark patches, filled fractures (black), and dark CL streaks (arrows), are typical CL features of plutonic quartz. None of these features are visible in backscatter images (BSE). They are completely healed with quartz and the grain surface is uniform. Figure 1B shows a quartz grain from a volcanic tuff. The CL image shows concentric oscillatory type zoning. Inset at lower right (BSE) shows that zoning is only visible in SEM-CL images. Figure 1C shows metamorphic quartz from a schist, with indistinctly mottled to nearly uniform CL texture (possibly due to metamorphic annealing). Arrow points out grain that might represent annealed (originally detrital) quartz grains. Figure 1D shows a quartz grain from a tectonically emplaced intrusive, and demonstrates that SEM-CL can also provide information about grain history. It shows initial shears (NW-SE arrow) that are cut and offset by a second generation of shears (SW-NE arrow). Inset a lower left shows featureless BSE image of the same grain.

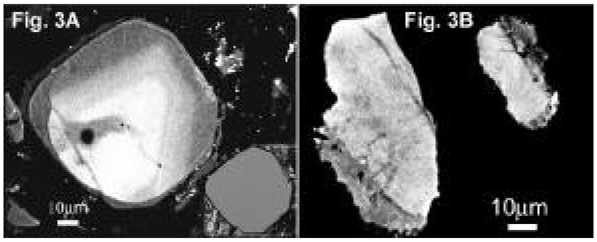
SEM-CL and the sedimentary cycle: In order to examine whether such features of original source rocks survive the sedimentary cycle of weathering, erosion, and deposition, we examined source rocks as well as their derived soils and stream sediments. As demonstrated with examples from the Llano uplift in central Texas (Fig. 2), we conclude that exogenic processes do not alter source-related SEM-CL signatures.



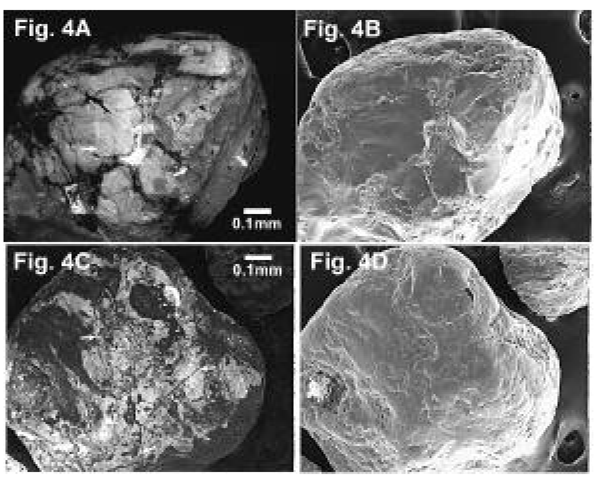
Figures 2A, B, C show cataclasic texture, a common feature in quartz grains from gneisses and schists. It reflects fragmentation and subsequent cementation/healing. Fig. 2A is from a schist, Fig. 2B from a soil above that schist, and Fig. 2C shows cataclasic texture in quartz grains from a stream that drains the schist area. Fig. 2D shows semi parallel bands/lineations of differing CL intensity; another feature that we find associated with metamorphic quartz. It is considered a reflection of slip/gliding during deformation at high pressures and temperatures.

Although source rock CL features survive without alteration into soils and stream sediments, their recognition is grain-size dependent. Sand size or larger quartz grains typically allow identification of the source, whereas at coarse silt size approximately 50% of the quartz grains can still be identified. At finer grain sizes the proportion of identifiable grains drops sharply. Because quartz is chemically and mechanically very resistant, as well as ubiquitous in most sediments, understanding SEM-CL features from different source rock types has the potential to greatly aid provenance determination.

Application to mudstones: Examining thin sections from various mudstone successions by SEM-CL confirms further that source rock characteristics are still recognizable in fine sand to silt size quartz grains. Figure 3 shows some examples of this. Fig. 3A shows zoned volcanic quartz from a tuff bed in the Late Devonian Chattanooga Shale of Tennessee, and Fig. 3B shows non-luminescent dark patches and fracture fills suggestive of plutonic quartz.



Application to whole grains: We also examined whether SEM-CL can be studied on grain mounts, so that we might get information not only about the likely source rock, but via surface textures (in SEM mode) also get information about transport processes and sedimentary environments [2]. To this end we studied a number of sedimentary quartz sand grains from Arran, Scotland, the Texas Gulf Coast, Montauk Point, Long Island New York, and several other locations, with the above combined technique. It appears that five to ten sand grains are sufficient to detail provenance, transport history, and at times even diagenesis. Figure 4 shows a comparison of features observed in SEM-CL mode (Fig. 4A,C) and in secondary mode (Figs. 4B,D).



Surface textures of the grain shown in Fig. 4A,B indicate abundant eolian abrasion (upturned plates, edge rounding) as well as aqueous abrasion in last transport cycle (v-shaped patterns). Dark blotches and dark lineations in CL suggest derivation from a pluton that solidified at moderate depth. Surface textures of grain shown in Fig. 4C,D indicate aqueous abrasion (v-shaped patterns, prominent smoothing and rounding). Large irregular dark patches are probably surface covers of diagenetic quartz. Dark fractures suggest plutonic derivation.

Potential use in planetary exploration: As outlined above, we are in the process of refining SEM-based techniques to extract a maximum of information from sedimentary quartz grains with regard to source and transport processes. The SEM-CL side also provides information about the presence of processes like crustal deformation, hydrothermal activity, and volcanism. This methodology should work on terrestrial and extraterrestrial sediments alike.

The first material likely to be returned from Mars will probably be collected by a robotic lander, and would consist of small batches of surface sediment. Simply because of the chemical and mechanical stability of quartz, we can expect this surface sediment to be enriched in quartz grains. Also, these grab samples are likely to contain abundant fine-grained material in addition to larger rock fragments. Many millenia of eolian mixing should ensure that the fine-grained matrix is quite homogenized. From experience with terrestrial sediments [3] it is a reasonable assumption that its composition should approximate the Martian crustal average. Using a non-destructive methodology on a small sample volume, our approach would not only allow us determination of principal source rock types and prevailing transport mechanisms, but would also provide us with the relative abundance of more differentiated rock types, and, by extension, with the magnitude of crustal recycling.

Keeping in mind the many difficulties we might encounter with sample return by robotic spacecraft, one might even contemplate to install a light-weight SEM on a large Martian rover. Remote analysis of SEM-CL and SEM surface texture seems within reach in light of recent technological advances. We now have available small and compact electron microscope columns that could be further miniaturized, as well as variable pressure SE and BSE detectors. Furthermore, producing a vacuum would be facilitated by the thin Martian atmosphere. Thus, as long as actual sample return is not possible, space probes equipped with a remote controlled SEM could provide a wealth of information about crustal and surficial processes from quartz grains collected in the vicinity of the landing site.

References: [1] Seyedolali, A., Krinsley, D.H., Boggs, S., O'Hara, P.F., Dypvik, H., and Goles, G.G. (1997) *Geology, 25*, 787-790. [2] Krinsley D. & Doornkamp J. (1973) Atlas of Quartz Sand Surface Textures, Cambridge. [3] Taylor, S.R., and McLennan, S.M. (1985) The Continental Crust: its Composition and Evolution. Oxford, Blackwell.