

Kimberlite xenocryst wear in high-energy fluvial systems: experimental studies

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ABSTRACT

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Xenocryst minerals from kimberlite have been mixed with gravels of varied grain size and artificially worn in a rotating drum. Results indicate that the minerals are transported with less wear when the finer-grained proportion of the gravel is increased. This is an important consideration when evaluating the natural dispersion of these minerals from their kimberlite host, and can aid in prioritizing stream-sediment anomalies in kimberlite exploration.

INTRODUCTION

The strongest tool in the exploration for diamond-bearing kimberlites is the dispersion of mantle-derived minerals from the kimberlite host into secondary environments. These xenocryst minerals – pyrope and pyrope-almandine garnet, picroilmenite, magnesian chromite, chrome diopside and omphacite – are derived from mantle xenoliths and megacrysts which are disaggregated during emplacement and weathering of the kimberlite. Much emphasis has been placed on recognizing significant xenocryst mineral anomalies based on chemical criteria (Boyd and Gurney, 1982; Gurney, 1984; Dummert et al., 1987; Thompkins, 1987; McCandless and Gurney, 1989) but little has been done to identify the factors controlling their dispersion. This is due to the difficulty in quantifying the numerous processes which contribute to xenocryst mineral wear and dispersion in secondary environments. Mosig (1980) noted for South Australian kimberlites that chrome diopside was not recovered more than 3 km from its source. In contrast, Mannard (1968) seldom found chrome diopside more than 2 km from its source in tropical areas, but recovered it in samples over 45 km from its source in arctic regions. Dum-

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mett et al. (1987) point out that the xenocryst mineral dispersion patterns of the Sloan kimberlites in Colorado are a function of their primary mineralogy. Some kimberlites are deficient in pyrope and chrome diopside, whereas others contain pyrope and chrome diopside megacrysts several centimeters in size, which when disaggregated can overwhelm adjacent drainages with xenocryst minerals. A difference in the optimum grain size for recovery of xenocryst minerals in stream-sediment samples has also been noted (Dummett et al., 1987), which may relate to primary morphology of the minerals, or to the fluvial conditions under which they have been transported.

High-energy fluvial systems such as braided streams, alluvial fans, glacial outwash, and wadis are often present in areas where kimberlite exploration occurs. These systems are characterized by short-lived, high-energy movement of sediments, resulting in the deposition of poorly sorted gravels. It is a common preconception that in such high-energy systems, where large clasts can comprise up to 50% of the bedload, rapid destruction of the xenocrysts would be expected to occur over short distances from the kimberlite. Yet the poorly sorted gravels and conglomerates representing these systems often contain xenocryst minerals a considerable distance from their source (Muggeridge, 1986).

In this study, xenocrysts of garnet and pyroxene from kimberlite are artificially transported in gravel sediments of varying grain size, and the degree of wear (from impact, abrasion and grinding; Krumbein, 1941) of their primary surfaces is described.

XENOCRYST SURFACE FEATURES

Primary surface features are universally common and develop on the xenocryst minerals prior to and during emplacement of the kimberlite. Curvilinear surfaces are closely spaced, arcuate, parallel surfaces caused by shearing when the minerals are still megacrysts or are enclosed in xenoliths in the mantle. As the megacrysts and xenoliths are entrained into the ascending kimberlite, the xenocrysts react with the kimberlite and form a kelyphite shell of fine-grained secondary minerals such as chlorite, fuchsite, amphibole and clinopyroxene. Secondary minerals also form along curvilinear surfaces and cleavage planes where the kimberlite volatiles have penetrated. The kelyphite is usually removed in the early stages of weathering and abrasion to expose a distinctive sub-kelyphitic surface (Garvie, 1981; Garvie and Robinson, 1984) resembling the skin of an orange (Fig. 1a). A dendritic reaction surface can also develop beneath secondary minerals along curvilinear surfaces and cleavage planes (Fig. 1a,b). Conchoidal breaks are also common, caused by brittle fracture of the xenocrysts during kimberlite emplacement, or to the release of stress built up in the minerals at surface temperatures and pressures (McCandless, 1982; Fig. 1a,c).

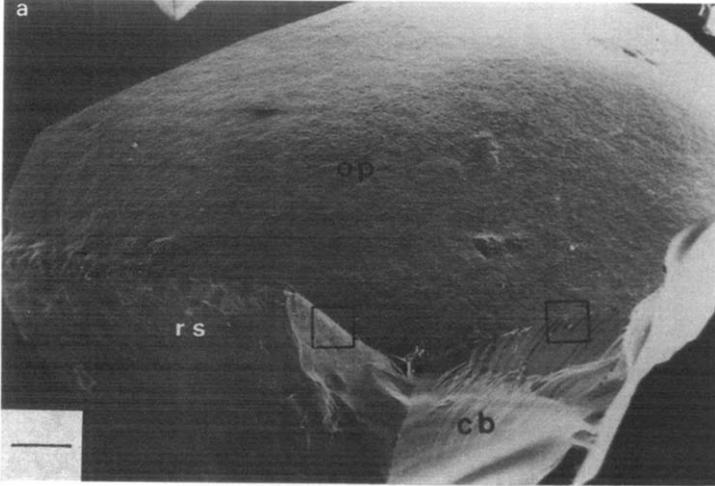


Fig. 1. (a). A garnet from kimberlite with well-developed orange-peel surface (*op*), and with conchoidal breaks (*cb*) on the lower right. The lower left is a curvilinear surface on which a reaction surface (*rs*) has developed. Scale bar = 100 μm .

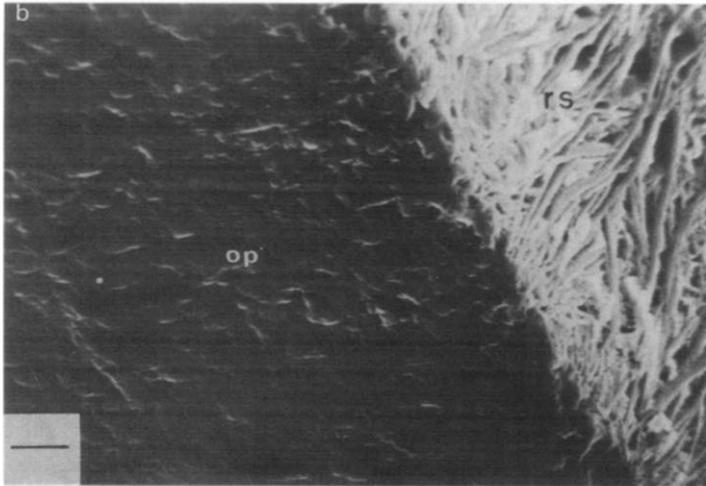


Fig. 1. (b). A closer view showing a sharp contact between the orange-peel and reaction surfaces. Scale bar = 10 μm .

Rapid weathering of the secondary minerals formed along curvilinear surfaces and cleavage planes causes the xenocryst minerals to be quickly disseminated into fluvial environments. Once released into a fluvial system, wear with other minerals produces frosting and pitting, and a rough abrasion sur-

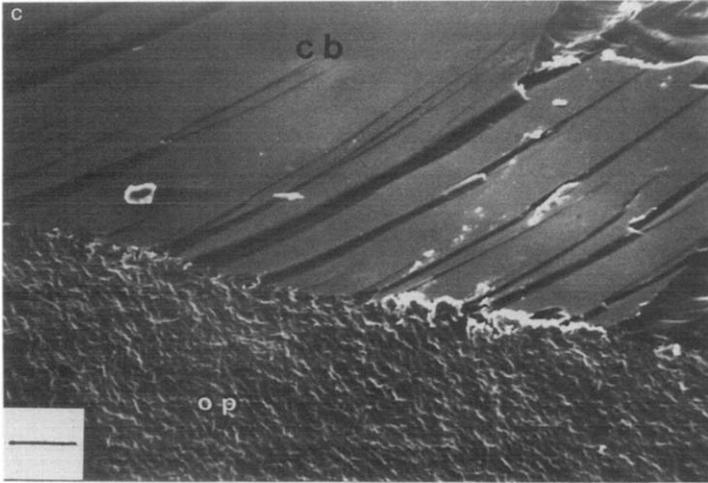


Fig. 1. (c) Closer view of the sharp orange-peel/conchoidal break contact. Scale bar = 30 μm .

face consisting of numerous minute conchoidal chips develops at the sharp edges of the mineral grains and expands from the edges across the grain surfaces with increasing wear. Abrasion surfaces appear similar to orange-peel texture at low magnification, though at high magnification the abrasion surface is rough and choppy, in contrast to the hummocky orange-peel texture (compare Figs. 1b and 2d). Artificially produced abrasion surfaces are similar to those occurring on naturally worn garnets (Fig. 2; McCandless, 1984).

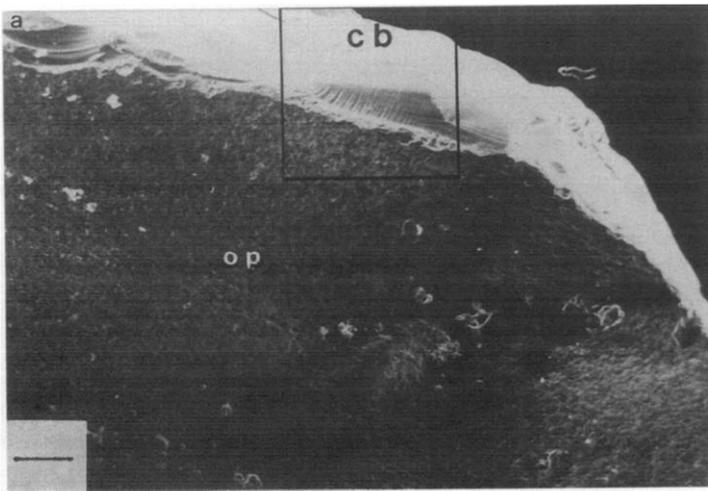


Fig. 2. (a) A garnet with orange-peel and conchoidal (*cb*) surfaces after 30 hours of abrasion in the coarse-gravel charge. Note the pitting of the orange-peel surface. Scale bar = 100 μm .

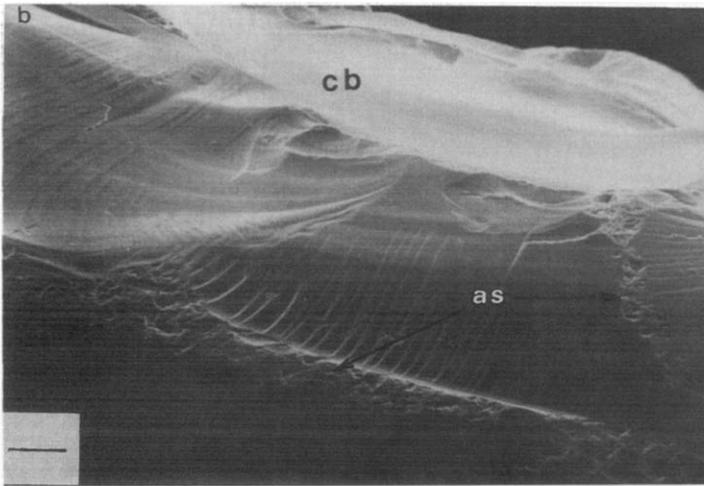


Fig. 2. (b) Closer view shows an abrasion surface (*as*) developing at the orange-peel/conchoidal break intersection and along high points of the conchoidal surface (arrows). Scale bar = 30 μm .

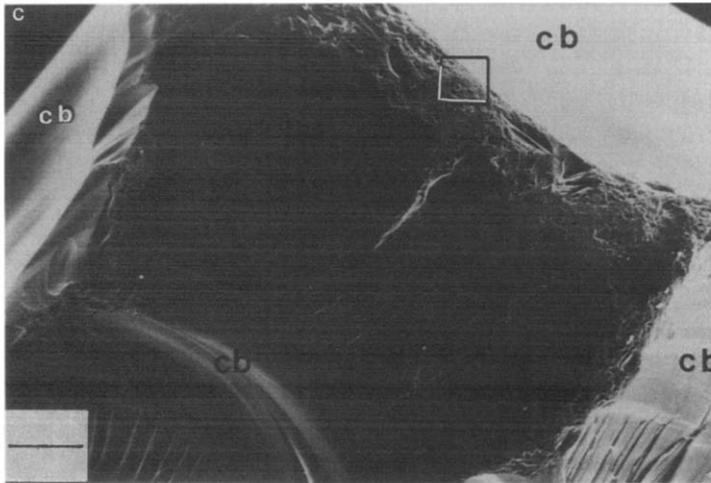


Fig. 2. (c) A garnet after 30 hours of abrasion, with broad abrasion surfaces at the intersections of conchoidal breaks. Scale bar = 100 μm .

METHODS

Three experimental gravel charges composed of sediment ranging in size from <0.0039 to 64.0 mm were used as transport media. The clay-dominated

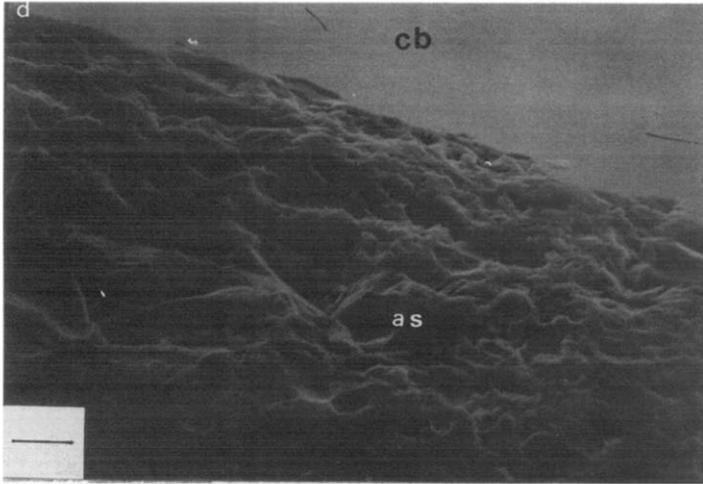


Fig. 2. (d). Close-up of garnet shows the rough, choppy texture of the abrasion surface. Scale bar = 10 μm .

charge contained material ranging in size from cobble to clay (64.0 to <0.0039 mm) with the clay fraction comprising 50% by volume. The sandy charge was composed of material from cobble to very fine sand, with 50% from coarse to very fine sand (1.0–0.10 mm). The coarse-gravel charge consisted of material larger than coarse sand, with 50% from 1.0 to 6.0 mm in size. The remaining 50% of the sediment in each charge consisted of clasts 1.0–64.0 mm in diameter. The clasts in each charge were of identical lithologies, consisting of sub-angular to subrounded limestone, quartzite and granite. Each charge was placed in a drum with water (volume of water:sediment = 2:1) and unabrased xenocryst minerals 1.0–6.0 mm in diameter. The drum used in this experiment is made of rubber, and has twelve flat surfaces forming a dodecagon along its interior circumference. The flat surfaces cause the grains to roll down a more constant slope instead of an arcuate surface, and the rubber lining forces grains in contact with it to roll rather than slide along the drum interior. This alleviates the problem of earlier rotating-drum experiments in which grains would lie dormant until a maximum height was reached, then roll across the top of the trailing grains (see Kuenen, 1956). A fast drum rotation of 25 revolutions per minute allowed some of the finer material to move as suspended load rather than as bedload, which is similar to natural conditions. Krumbein (1941) found that the wear of rock fragments in rotating drums was comparable to abrasion in streams, and felt that overall dynamic processes were similar. The conditions of this experiment are also considered to duplicate processes which would be encountered under natural conditions.

RESULTS

The minerals were removed and examined with a binocular microscope every 10 hours over a total time of 60 hours. None of the minerals were completely destroyed over the 60-hour interval, and abrasion did not develop on all the grains of a given sample nor on all the edges of a single grain at the same rate. Larger grains were abraded more quickly than smaller ones, however. The results are therefore summarized for the larger grains at the end of the 60-hour interval for each charge. The actual distances which the minerals have travelled are unique to the conditions of this experiment; for this reason the use of distance as a measurement of wear is deliberately avoided.

In the coarse-gravel charge, evidence of wear appeared rapidly, with pitting integrated enough to be readily visible on cleavage, curvilinear and conchoidal surfaces. Scattered pits developed on the high points of the orange peel surfaces. Abrasion surfaces were strongly developed along the edges of intersecting surfaces (Fig. 2). Abrasion surfaces on the clinopyroxenes could be seen without the aid of the microscope. Major breakage along cleavages greatly reduced the size of some clinopyroxene grains.

Mineral wear in the sandy charge is less advanced than in the coarse-gravel charge. Slight frosting appeared on the garnets, and narrow abrasion surfaces began to develop along sharp edges. The orange-peel texture on both garnets and clinopyroxenes was unaffected. Clinopyroxenes evidenced minor wear along cleavages, as chips 0.50 mm or less in size.

For the clay-dominated charge, very minimal effects of wear were detected over the total transport interval. Some mineral grains still have sharp edges, with no abrasion surfaces present. No pitting or chipping was present on the orange-peel surfaces. On the garnets, the curvilinear surfaces and conchoidal breaks have a few small (<0.10 mm) pits scattered over the surface. Clinopyroxenes showed minor pitting of the cleavage surfaces, but no breakage along the cleavages had developed.

CONCLUSIONS

The results show that the presence of fine-grained material in a gravel can significantly hinder the wear of the xenocryst minerals, even when much larger clasts comprise 50% of the sediment. Presumably the fine-grained component cushions the xenocryst minerals from contact with other clasts by increasing the overall viscosity of the sediment charge.

These effects must be considered when attempting to correlate the wear of xenocryst minerals from stream-sediment samples with the proximity of their source. The dominant grain size of sampled gravels or conglomerates from high-energy environments can be measured in the field as an aid in evaluating the distance in which the xenocryst minerals have travelled from their kim-

berlite source. When coupled with geochemical results, this information provides additional criteria in which to prioritize stream-sediment anomalies in kimberlite exploration.

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