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Technical note

Kimberlite weathering: Effects of organic reagents

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ABSTRACT

Kimberlite material is one of the primary sources of diamonds. Accelerated weathering that leads to a physical breakdown of the material over a short period of time has possible benefits in diamond processing such as reduction in the energy consumption when used as a pre-comminution stage. This study investigated accelerated weathering by utilising organic reagents; acetic acid, ethanol, formamide, n-hexane, oxalic acid, and urea, in comparison to the use of Cu^{2+} solution that was previously shown to be very effective in weathering kimberlite. Oxalic acid was the organic agent that showed promising weathering capabilities. However, the use of organic solutions was not as efficient as with Cu^{2+} solutions. Results showed that 67% of the particles passed 12 mm screen size in Cu^{2+} weathering compared to 48% in oxalic acid. It was also found that time of exposure had a small effect on weathering. Increasing the organic chemical concentration twofold, from 0.025 M to 0.5 M, improved weathering by ~20% points. Different weathering mechanisms were observed at different solution concentration between oxalic acid (1st to 2nd order) and Cu^{2+} (2nd to 3rd order).

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1. Introduction

Kimberlite is one of the primary sources of diamonds. Kimberlite processing described by Hodgson (1981) involves crushing the run-of-mine ore in two or three stages followed by a scrubbing stage to wash off fine particles (<1 mm) which are removed through screening. The washed ore is screened into various size fractions which are sent for further treatment in the DMS circuit. The primary concentration utilises DMS whilst final concentration usually employs grease tables followed by X-ray sorting. The waste from fines processing is thickened and dumped as tailings and the water is recovered. The coarse stream is sent for re-crushing to ensure that smaller diamonds are liberated before discarding the gangue material.

Kimberlites vary in mineralogical properties but are described as inequigranular textures consisting of crystal and mantle derived xenoliths and xenocrysts (Benvie, 2007). The macrocrysts are imbedded in a fine-grained matrix (groundmass) of second generation primary olivine and/or phlogopite as well as serpentine, perovskite, calcite, chlorite and dolomite (carbonates) and spinels. Weathering process such as carbonation and serpentisation often alter the early formed groundmass minerals. This replaces the primary minerals olivine, phlogopite, monticellite and apatite by clay minerals serpentine, calcite and chlorite.

This study investigates kimberlite weathering with a focus on the accelerated physical breakdown of the material. Accelerated weathering weakens the rock, especially the groundmass or matrix minerals. This leads to a reduction in the comminution effort required to liberate diamonds, which may lead to reduced diamond damage. The energy savings may be by far the greater benefit. This may also lead to completely different processing flowsheet, moving away from multi-stage crushing to a less energy intensive process.

Studies on kimberlite accelerated weathering have been performed utilising cationic salts, i.e. inorganic solutions (Boshoff et al., 2007; Morkel, 2006, Morkel et al., 2007). Results showed that swelling clay minerals, especially the smectite species, were responsible for accelerating the breaking down of kimberlite material. The break down occurred as a result of clay structure expansions and the process of exchanging cations. The Cu^{2+} solutions were reported to be the most effective reagents.

This study targets the presence of clays in kimberlite and is the first evaluation of the effect of organic species on kimberlite weathering. Chin and Mills (1991), Grim (1968) and Weiss (1989) have shown that organic molecules can be adsorbed onto clay surfaces, which influences the clay interlayer spacing. Clay minerals with the ability to swell, such as smectites and vermiculite, have shown the highest degree of organic species adsorption (Gates, 2004; Tahani et al., 1999).

2. Experimental work

2.1. Material

Kimberlite ore samples were obtained from Finsch Mine, one of the De Beers Consolidated Mines in South Africa. The ore sample

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was received crushed to −19 + 13.2 mm size fraction. Samples were prepared as per test requirement, with mineralogical characterisation determined through cation exchange capacity (CEC), XRD and XRF analysis.

2.2. Weathering

Samples of 300 g Finsch ore, −16 + 13.2 mm size fraction, were immersed in 1 L of solution in flat bottomed plastic containers (250 × 140 × 70 mm). Particles were spread in a single layer with no physical contact to each at room temperature (~25 °C) and immersed in 0.5 M solution concentration for a period of 6 days. Reagents tested were; ethanol, n-hexane, formamide, oxalic acid, urea and acetic acid as well as distilled water and 0.5 M Cu^{2+} in chloride form for comparison purposes. After the test, the weathered samples were air dried for 1 day. The particle size distribution was then determined. The effect of exposure time; 2, 6, 15, and 30 days was investigated at 0.5 M oxalic acid concentration. The effect of concentration on weathering was determined with 0.025, 0.1, and 0.5 M oxalic acid for 6 days.

2.3. Kinetic evaluation

Utilising oxalic acid and Cu^{2+} as the weathering medium on a 300 g −16 + 13.2 mm material, 50 ml of the weathering solutions was extracted at intervals 0, 4, 24, 72, 360 and 720 h for ICP analysis. The tested solution concentrations were 0.025, 0.1 and 0.5 M. ICP analysis measured the quantity of Na^+ released into the solution with time. ICP analysis was performed at Set Point Laboratories in Johannesburg, South Africa.

3. Results and discussion

3.1. Ore characterisation

The XRD analysis results indicated that the ore contained ~35%, 5%, 7%, 8%, 11%, 7%, and 8% smectite, serpentine, mica, calcite, dolomite, plagioclase, and pyroxene, respectively, and had a CEC value of 28.21 cmol/kg. According to Morkel (2006), a correlation can be drawn between CEC and the smectite content, which can predict the weathering behaviour. Kimberlite that contains around 30 per cent swelling clay minerals will show rapid weathering in cation solutions compared to very low weathering in distilled water (Morkel, 2006). The Finsch ore was therefore a suitable ore sample for accelerated weathering test. XRF results displayed fairly high amounts of Mg and Ca of 19.6% and 13.2%, respectively.

3.2. Weathering

Weathering tests were evaluated by a particle size distribution after weathering and compared to the initial particle size of 100% passing −16 + 13.2 mm (−16,000 + 13,200 μm). Less or no information could be gathered on the d_{80} or d_{50} values. Therefore, a reference of the amount of particles passing 12 mm (12,000 μm) was adopted from Morkel (2006), so as to compare the results.

All the organic media tested improved weathering compared to the water that produced the least weathered product of ~25% passing 12 mm (Fig. 1a and b). Oxalic acid produced a promising weathering of 48% passing 12 mm that was slightly more than the rest of the organics. The effect of oxalic acid on mineral weathering has been confirmed by Varadachari et al. (1994). The combined action of H^+ attack as well as oxalate complex formation on dissociation is one of the reasons highlighted by Barman et al. (1992), Bigham et al. (2001), and Chin and Mills (1991).

From Fig. 1, despite the fact that oxalic acid was a better organic agent, the Cu^{2+} medium showed superior weathering results of 67% passing 12 mm (~20% higher than oxalic acid). According to Morkel (2006), Cu^{2+} has the ability to adsorb not only at interlayers of the particle crystal structure but also on other sites such as crystal edges. This process reduces the surface energy that reduces the energy required to produce fresh crack surfaces during weathering. Organics adsorb into the interlayer space causing an expansion and are held by coulombic as well as van der Waals forces (Lerf, 2004). Therefore, organic species are limited to the interlayer space whereas inorganics can also adsorb onto other alternative sites.

The effect of time on weathering was tested utilising oxalic acid as this particular organic solution had shown positive results. Fig. 2a and b shows no significant improvement in weathering with increased exposure time. Only a 10% point increase was realised by a 2 to 30 days increment.

Varying solution concentration indicated that no significant difference between a 0.025 M and a 0.1 M oxalic acid concentration (Fig. 3a and b). However, an increase of ~20% points was realised with the change in concentration from 0.025 M to 0.5 M oxalic acid.

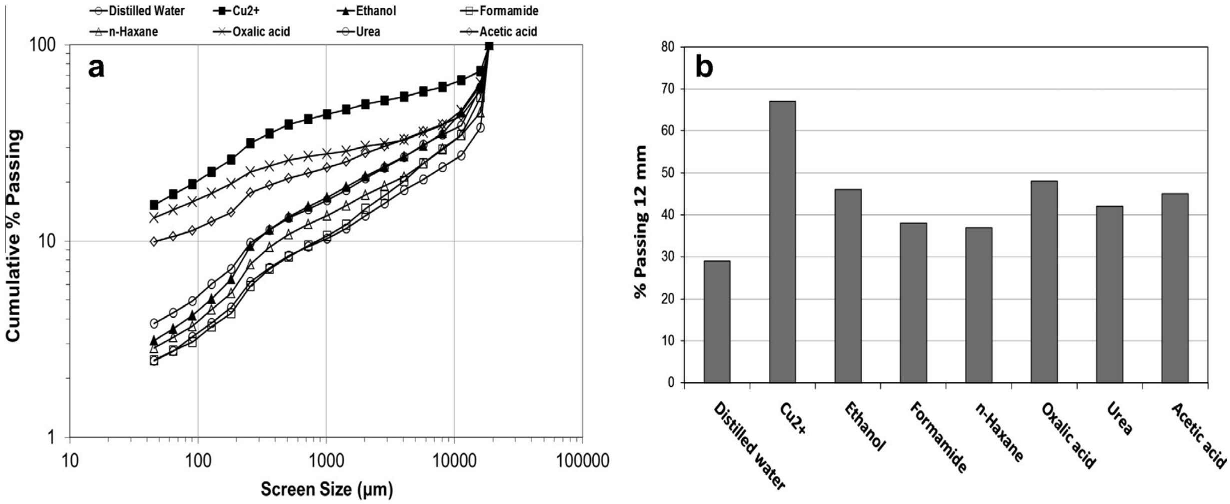

Fig. 1. The particle size distribution (a) and the% passing 12 mm (b) after weathering for 6 days in Cu^{2+}, ethanol, formamide, n-hexane, oxalic acid, urea and acetic acid at 0.5 M.

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