



Accelerated kimberlite weathering— the role of cation type on the settling behaviour of fines

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Synopsis

The weathering of kimberlite can be accelerated with cations in solution if swelling of the kimberlite occurs in contact with the weathering medium. The type and amount of swelling clays present, along with the surface charge and cation valence, determine the degree of swelling that can occur. Crystalline swelling occurs by the incorporation of cations in the interlayer spacing of the silica sheets. Kimberlite exposed to cupric cations showed very strong weathering, indicating that this type of weathering may be considered a viable process option. Kimberlite fines generated after weathering with monovalent cations showed poor settling behaviour compared to kimberlite weathered with di-, and trivalent cations.

Introduction

Kimberlite, which contains swelling clays, is known to weather naturally in contact with water, changing from competent blue ground to incompetent yellow ground. This weathering characteristic was used as the main processing route for diamonds in the 19th century¹. Unfortunately up to two years were required before further processing of the kimberlite could commence. Early in the 20th century mechanical crushers replaced the weathering process as the primary reduction stage, enabling the direct treatment of all types of kimberlite ore¹. Crushers are not only expensive, but the mechanical crushing of the ore also results in diamond breakage².

Understanding the mineralogy of kimberlite is crucial when considering accelerated kimberlite weathering as an alternative process option. Kimberlite is a complex hybrid rock, containing predominantly olivine, calcite, apatite and clay minerals as a fine matrix between larger macrocrysts.³

Previous work⁴ suggested that kimberlite weathering is associated with the swelling of swelling clays (such as smectite). The swelling phenomenon is dependent on the interlayer properties of the swelling clays; incorporation of water and hydration are important charac-

teristics of the interlayer spacing cations. The interlayer spacing cation exchange properties are important for understanding the weathering behaviour of kimberlites.

Phyllosilicates or sheet silicates are subcategorized as 1:1 or 2:1 clays according to the linkage between the silica sheets. A 1:1 clay mineral consists of single octahedral and tetrahedral sheets alternating through the structure, while a 2:1 clay mineral has a single octahedral sheet placed between two tetrahedral sheets. The tetrahedral layers of the 1:1 clays are linked together by sharing their basal oxygens and the enclosed ion of each tetrahedron is normally Si^{4+} , but Al^{3+} or Fe^{3+} can replace the Si^{4+} cation. The octahedral sheets consist of six oxygen or hydroxyl ions, which are linked through sharing their octahedral edges, resulting in a net -2 charge. This negative charge must be neutralized by incorporating a layer consisting of either divalent or trivalent cations.

The hydration and ion exchange behaviour of these cations determine the swelling behaviour. The hydration of the cations widens the spacing between the layers, resulting in a volume change. This volume change can produce pressures of up to 100 N/mm^2 , and possibly result in the disintegration of the kimberlite⁵. Cations would show different effects on the weathering of kimberlite due to the differences in size, hydration and ion exchange characteristics.

This work tested the effect of different cations on the accelerated weathering of kimberlite.

Settling tests were performed to determine different settling rates of kimberlite ore after treatment with mono-, di- and trivalent cations. This would be of interest in proposing an alternative processing option, as faster

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settling rates would result in reduction of operating and capital cost.

Experimental work

Dutoitspan kimberlite was used for the test work as it contains 30–40 per cent smectite and is known to be a weatherable kimberlite.⁴ The Dutoitspan kimberlite was crushed to obtain particles in the size range of 22.4–26.5 mm.

Standard immersion weathering tests were done in 10 l containers (70 cm long, 40 cm wide and 20 cm deep) using 5 l of weathering medium and 1.5 kg ore. The ore was spread out, not touching, with no stirring employed. Weathering lasted for 6 days at room temperature (~ 20°C) before the ore was removed and dried overnight in an oven at 40°C. The fines were filtered from the weathering solution before drying. The dried sample was milled in a rubber-lined autogeneous mill (30 cm inner diameter and 30 cm long) containing no lifters, for 10 minutes at 70 per cent of the critical speed. The sample was subsequently sieved to obtain a particle size distribution. The unweathered sample that was only milled (and not exposed to the weathering medium) is referred to in the text as 'zero days' weathered.

Weathering tests were performed using different cation-containing media to determine the cation effect on the weathering process. The monovalent cation tested was Li⁺, divalent cations tested were Ca²⁺, Cu²⁺ and Mg²⁺, and trivalent cations tested were Al³⁺ and Fe³⁺. It was decided to keep the type of anion (chloride) constant, thus eliminating any possible influence of the anion. Distilled water (containing no ions) was used as the base case. All tests were performed at a constant cation concentration (0.4 M).

The settling tests used 300 g batches of Dutoitspan kimberlite in the size range of 22.4–26.5 mm. The Dutoitspan ore was weathered for two days in 0.4 M LiCl, CuSO₄ and AlCl₃ media; these cations showed the most aggressive degradation behaviour in each of the mono-, di- and trivalent cation classes⁶. After weathering the -1 mm material was sieved out after drying and transferred to a measuring cylinder (500 ml) containing distilled water. The contents of the measuring cylinder were thoroughly mixed for 1 minute. The contents of the cylinder were then left to settle and photographs were taken after 0, 5, 10, 15, 30, and 45 minutes, and 1, 2, 4, and 8 hours.

Results and discussion

The size distribution after weathering indicates the extent to which weathering was accelerated. Figure 1 shows lithium displaying aggressive behaviour at 67 cumulative per cent of the kimberlite passing 17.5 mm. In contrast, magnesium showed only a 22 per cent increase in cumulative per cent passing 17.5 mm relative to distilled water. Calcium showed a further 15 per cent increase, at 58 per cent passing 17.5 mm. Cupric cations showed the most effective weathering at 97 per cent passing 17.5 mm. The cupric cations in fact show exceptional accelerated weathering behaviour with 90 per cent passing 4 mm. The two trivalent cations tested showed similar weathering behaviour, with aluminium reporting 44 per cent passing 17.5 mm and ferric cations 47 per cent passing 17.5 mm: an improvement of ~ 27 per cent compared to distilled water weathering. The ranking of the effects of the cations on the weathering process is Cu²⁺>Li⁺>Ca²⁺>Al³⁺>Fe³⁺>Mg²⁺. Figures 2–5 show the photographs of the weathering tests with monovalent and divalent cations tested.

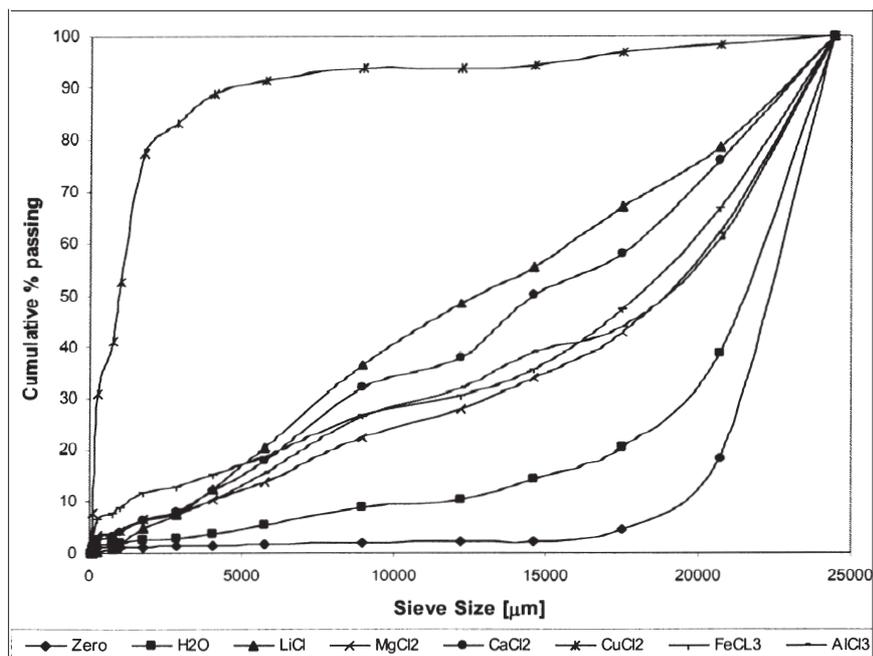


Figure 1—Weathering results of the investigation of the influence of different cations on kimberlite weathering. Tests were done using 1.5 kg +22.4–26 mm kimberlite weathered for 6 days in 0.4 M lithium-, magnesium-, calcium-, cupric- and ferric chloride media and compared with distilled water ('H₂O' in figure) and unweathered kimberlite ('Zero' in figure)

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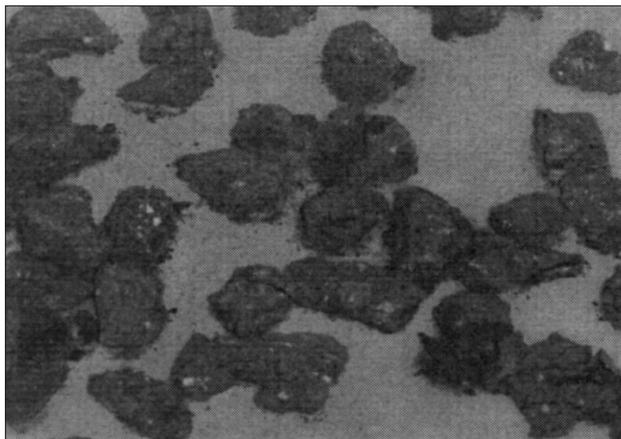


Figure 2—Photograph of Dutoitspan ore (22.4 mm–26.5 mm) weathered using Li^+ (0.4 M) for 6 days

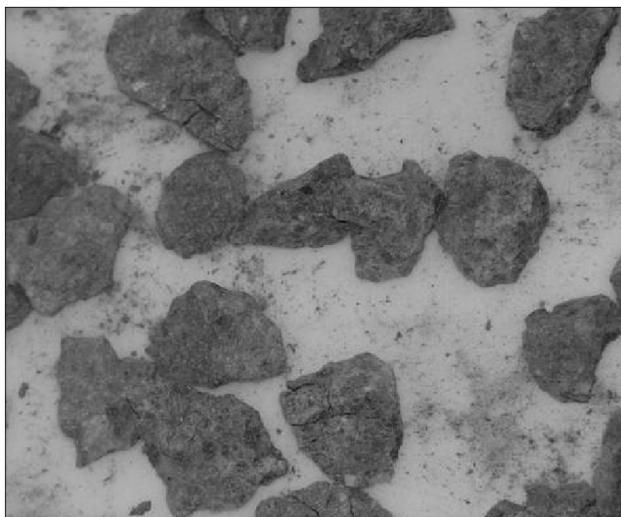


Figure 3—Photograph of Dutoitspan ore (22.4 mm–26.5 mm) weathered using Ca^{2+} (0.4 M) for 6 days

Based on the hydration enthalpies of the cations, the trivalent cations are expected to be the most effective with regard to weathering, followed by divalent cations and lastly the monovalent cations. This is not the ranking that was observed experimentally. This work shows that other factors also effect the weathering process; the rate of cation exchange is one possibility.

Figures 6–8 show the settling tests of kimberlite fines after weathering with Al^{3+} , Li^+ and Cu^{2+} respectively, where the clarity of the weathering media was used to characterize settling. Both Al^{3+} and Cu^{2+} show complete settling after 1 hour, as the solutions are completely clear. The Li^+ solution remains turbid, even after 8 hours of settling. In general, the observation throughout the test work was that the monovalent cations form a very fine clay structure that stays in suspension for considerably longer times than did di- and trivalent cations.

The results show that cations can accelerate the weathering of kimberlite and this type of weathering can be considered as an alternative for kimberlite processing. This

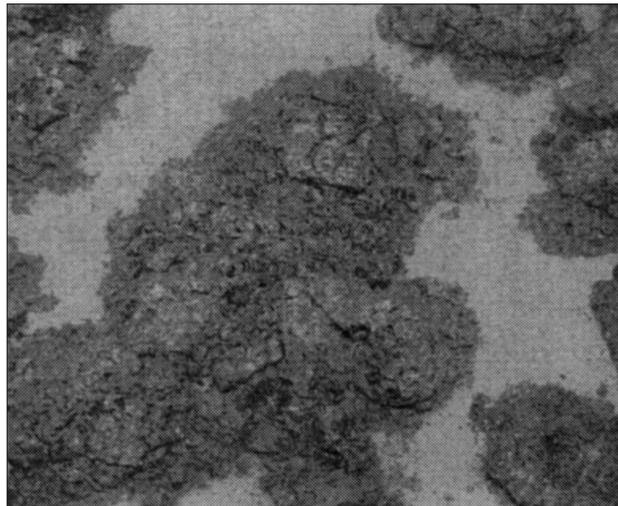


Figure 4—Photograph of Dutoitspan ore (22.4 mm–26.5 mm) weathered using Cu^{2+} (0.4 M) for 6 days

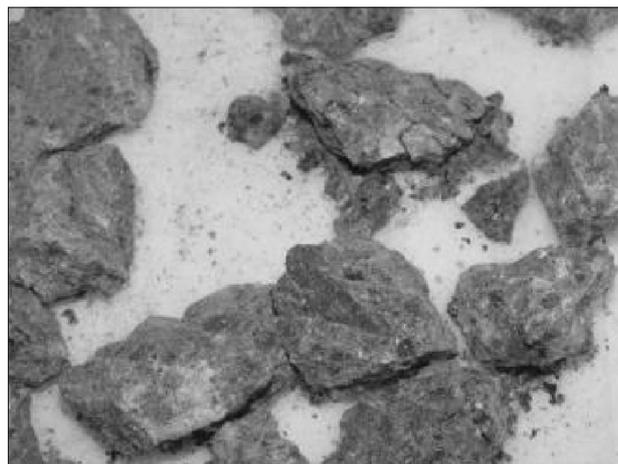


Figure 5—Photograph of Dutoitspan ore (22.4 mm–26.5 mm) weathered using Mg^{2+} (0.4 M) for 6 days

process for the treatment of kimberlite deposits holds great potential for use in small, remote, and low-grade orebodies. Economical and environmental aspects should be investigated. The treating of the fines is important since settling problems were experienced during testing.

Conclusion

Weathering of kimberlite can be accelerated by cations if the kimberlite contains enough swelling clays. The Cu^{2+} cation showed the most promising results, breaking down particles from 25 mm to 90 per cent passing 4 mm in 6 days. Accelerated weathering may be considered a process option in treating smaller kimberlite pipes. When considering a cation for accelerated weathering, it is important to know the ease of settling, since this is an important factor affecting the operating cost and also water recovery. Kimberlite treated with di- and trivalent cations settled out within an hour, leaving a clear solution, while the material treated with monovalent cations still had a turbid solution after 8 hours.

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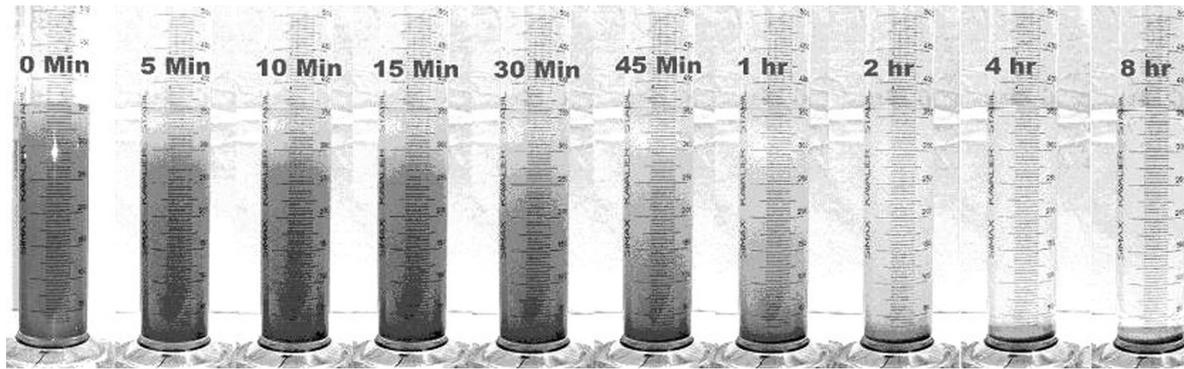


Figure 6—Settling results of 300 g of kimberlite weathered using Li^+ (0.4 M)

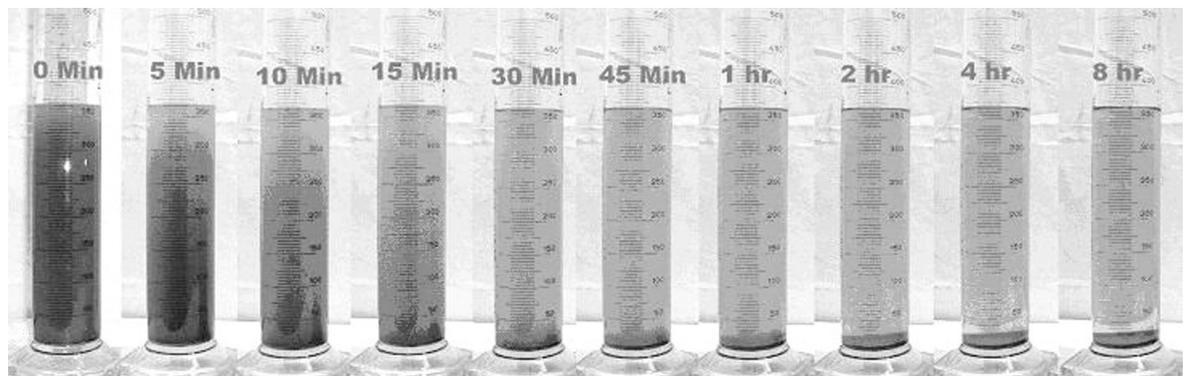


Figure 7—Settling results of 300 g of kimberlite weathered using Cu^{2+} (0.4 M)

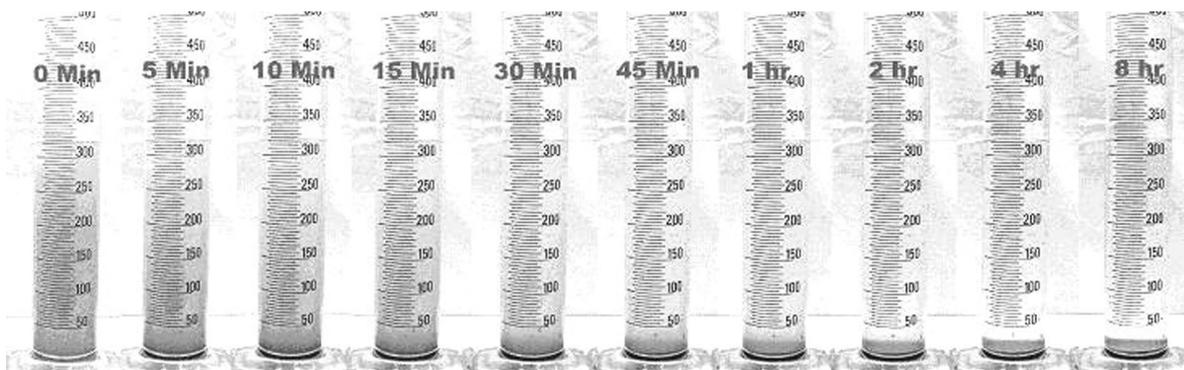


Figure 8—Settling results of 300 g of kimberlite weathered for up to 8 hours using AlCl_3 (0.4 M)

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