8 POSSIBLE FUTURE WORK

The focus of this study was mainly on the understanding of what determines weathering in kimberlite. In the process a lot of work was done on the fundamentals of clays and cation exchange on clays. Possible future work could investigate better characterisation of the clay species especially the smectite minerals. Furthermore determining the layer charge of the smectites could provide useful information in understanding the properties and behaviour of clays. Investigation of the XRD interlayer spacing with different cations under controlled relative humidity could also shed more light on this topic. Petrograhical work including modal analysis of thin sections could estimate the degree of weathering and the source minerals of the weathering products.

Uniaxial compressive strength (UCS) tests to determine the strength of the kimberlite could not provide reproducible results. As an alternative, future work could investigate utilising the Block Punch Index (BPI) test. This test has been shown to be more applicable for clay bearing rocks (Sulukcu and Ulusay, 2001) and it uses disc shaped specimens in the point load testing frame. The UCS can be derived more precisely from the BPI result. It would be especially informative to test whether the strength of the rock increases with potassium treatment.

Other future work could include standardisation of weathering tests especially in terms of the particle size, experimental setup, weathering media and weathering output. This study found that milling is not required to evaluate the weathering behaviour of kimberlite.

Repeating some of the test work in this thesis in a stirred reactor, generating fresh surfaces continiously could also prove valuable. Especially for accelerated weathering e.g. cupric medium, concentration and temperature tests.

The influence of organic solvents on the swelling and collapsing of clays and kimberlite weathering is currently being investigated.

This study just started to investigate the mechanism of cation exchange and reaction kinetics. Future work to create a better understanding of the fundamental mechanisms should be performed. The suggestion that cation identity affects the microcrack surface energy should be examined to create a better understanding of the factors determining weathering.

Quantitative modelling can now be attempted incorporating the variables and knowledge generated in this study. The variables that should be included in experimental design are smectite, CEC, weathering medium (cation, concentration, temperature), and particle size. The cation information can be incorporated into the modelling by utilising the ionic potential (valence and cation radius), as this showed correlation with weathering results. The trivalent cations and Cu^{2+}, Li^{+} and Fe^{2+} however did not fit this correlation. The ionic potential data of these cations can be used as a first approximation or alternatively the ionic potential can be adjusted (corrected) to better fit the results obtained in this study.

9 CONCLUSION

XRD ANALYSIS

This study showed that XRD analysis of clay-containing ores such as kimberlite should include the sub treatments namely glycol and heat treatment to allow for more accurate identification of the clay minerals. The results should be critically reviewed before acceptance as correct and accurate. Verification can be performed by analysis of the same sample at different institutions and by performing sub treatments as discussed by Bühmann (1998) to ensure correct peak identification. Investigation of the ore by an experienced geologist will improve the overall understanding of the mineralogy. It is especially important to evaluate the results at overlapping peak positions e.g. smectite and chlorite (6.2º 2θ or d value of ~14.1 Å). The extent of errors in the estimated phase percentages can be up to 40 % and therefore special care should be taken in choosing appropriate institutions for analysis and evaluation of results.

The XRD interlayer spacing was investigated to gain more information on the swelling of clays. In the presence of potassium the interlayer spacing collapses to ~ 12 Å. The interlayer spacing of copper-weathered kimberlite as a function of time shows the increase in the interlayer spacing (to 14.5 Å), reaches the maximum after seven days and then stays constant up to thirty days. The interlayer spacing and the severity of weathering are not in correlation with cation weathering results. The interlayer spacing at relative humidity is shown by Ferrage *et al* (2005) as a two water layer system for Ca^{2+} and Mg^{2+}, a one water layer spacing for Na^{+} and Li^{+} and a zero water layer spacing for K^{+}. This agrees well with the observed spacings. It is suggested that is not only swelling that determines the weathering behaviour. The type of clay minerals, layer charge and cation properties influence weathering. When considering the Griffith-style of brittle material fracture, it depends on the defect length, applied stress and surface tension. The defect length depends on the kimberlite structure and is therefore not changed by the weathering solution. The stress is applied by swelling, which is little effected by cation identity. Therefore it is assumed that the cation identity influences the surface energy of the crack by adsorption on the crack surface.

SMECTITE CONTENT

It is concluded from this study that the weathering behaviour of kimberlite ores is directly affected by the mineralogy and specifically the swelling clay content. Kimberlites that contain no or very little swelling clay are not prone to weathering under any conditions. As the swelling clay content (smectite and vermiculite) increases the ore becomes more prone to weathering. Ores that contain around 30 % swelling clay may show slow weathering in distilled water but have the ability to weather rapidly in the presence of cations.

CATION EXCHANGE CAPACITY

The cation exchange capacity is a very useful parameter that correlates with the swelling clay content and can be used to predict kimberlite weathering behaviour. CEC might actually be preferred to the swelling clay content as XRD analysis is a cumbersome and expensive procedure in contrast to CEC, which can be determined easily.

AGGLOMERATION TEST

The agglomeration test is also shown as a simple test that gives an indication of an ore's 'stickiness'. Results show that heat treatment before wetting for a constant time, is required for improved results.

PRESENCE OF CATIONS IN WEATHERING MEDIUM

It is suggested by this study that the influence of the cations depends on a combination of cation charge and effective ionic radius (ionic potential), as well as the mechanism of cation absorption. Correlation between weathering results and ionic potential are good for all the cations except trivalent cations. Fe^{3+} and Al^{3+} have been shown to form hydroxy species in the interlayer and therefore are expected to behave differently. It has also been shown that the adsorption of Cu^{2+}, Fe^{2+} and Li^{+} is not confined to the interlayer and therefore should influence the observed weathering. The type of smectite and layer charge also influences the effect of cations. If the original cations in the kimberlite are replaced by more 'active' cations, this will cause an increase in the observed weathering behaviour. The actual effect of some cations on accelerated weathering (from most to least aggressive) was found as follows: $Cu^{2+} > Li^{+} > Fe^{2+} > Ca^{2+} > Fe^{3+} > Mg^{2+}$. Potassium was found to decelerate the weathering process. Li^{+} increased the cumulative % passing 17.5 mm to 67 %, Fe^{2+} to 66 %, Ca^{2+} to 58 %, Fe^{3+} to 47 % and Mg^{2+} to 42 %. The weathering results did not show correlation with the XRD interlayer spacing.

CONCENTRATION OF CATIONS AND TIME OF WEATHERING

The weathering acceleration properties of copper show potential as the basis of a kimberlite processing, as treatment in a 0.4 M cupric solution causes breakdown of 25 mm kimberlite particles to 90 % passing 4 mm in 6 days. The concentration of the cation used for acceleration was shown to be a critical parameter as is the time allowed for weathering. The concentration was tested over a 0.005 M to 0.4 M interval and still showed improved weathering behaviour at 0.4 M. The time dependence tests at 0.5 M show very rapid weathering in the first 24 hours, with 85 % of the overall weathering obtained over thirty days taking place in the first 24 hours.

TEMPERATURE

Temperature tests were performed in a magnesium chloride medium and showed promising results. Weathering at 40 °C increased the cumulative % passing 17.5 mm by 25 % compared to room temperature. The results obtained with increased temperature are comparable with accelerated weathering obtained by the addition of a cation to the weathering medium.

KINETIC EVALUATION OF CATION EXCHANGE

The kinetics of cation exchange was investigated with a copper weathering medium at different concentrations. The data was fitted to the simple n^{th}-order kinetic equation to determine the apparent reaction order and rate constants utilising curve fitting and representing the data graphically. The apparent reaction order is between 1 and 3.5 depending on the concentration. The two methods used for interpreting the data correlate well. The apparent reaction order shows a dependence on initial copper concentration which is unexpected. The kinetics of cation exchange was repeated with a potassium weathering solution on a different kimberlite and again utilised the two methods of data interpretation. The apparent reaction order for potassium is between 1 and 2.2. The data cannot be correlated directly with copper data as different concentrations and types of kimberlites were utilised. It is shown that potassium exchange is more rapid in agreement with its higher mobility data. Both these data sets equilibrium values were plotted and fits the Langmuir conditions.

ANIONS

It is shown that the type of anion used does not influence kimberlite weathering. The type of anion can however influence the solubility and complexation of cations.

PARTICLE SIZE

Particle size did not show an effect on weathering in this case.

REPEATABILITY OF RESULTS

It is shown by triplicate tests that the size distribution weathering results consistently fell in a 7 % range. Standard deviation is always smaller than 3.8 % and the largest difference between 95 % confidence upper and lower limits are 18 %.

SLAKE DURABILITY TESTS

It is shown that slake durability tests is an alternative weathering testing method that provides the option of accelerating the weathering process due to the addition of the mechanical effect.

INDUSTRIAL APPLICATION

These results will firstly create a better understanding of the kimberlite weathering mechanism and how kimberlite might behave. It can be used in modelling, design and optimisation. The understanding is also used to prevent or decelerate weathering in an attempt to create underground tunnel wall stability and potassium (and other chemicals) show the potential of providing integrity to kimberlite. On the other hand using accelerated kimberlite weathering as a processing option is currently being investigated.

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