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A method to assess rock strength and excavatability of diamondiferous kimberlite ore through in situ rock testing.

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ABSTRACT: This investigation considers the excavatability of diamondiferous kimberlite pipes of the Merlin field in the Northern Territory, Australia, through the use of in situ rock testing to assess hardness and subsequently excavatability. Historical diamond mining of the Merlin kimberlite pipes identified variable ore hardness both aerially and at depth within the pipe, which was attributed to the preferential weathering of the kimberlite. This variation in hardness presents a problem when determining the best method of excavation and hence can significantly influence production rates. This paper provides a relationship that can be used to relate field testing of rock hardness with rock strength. The results of the hardness to strength relationship are used in established empirical equations to confirm excavatability of the kimberlite ore. The relationships developed in this investigation enable in situ rock hardness testing to be directly related to rock strength for assessment of ore excavatability.

1 BACKGROUND

1.1 Site Location

The Merlin Diamond mine is situated in the Northern Territory, Australia, approximately 80 km due south by air from the town of Borroloola and 720 km southeast of Darwin (see Figure 1). The Merlin diamond mine was started by Ashton Mining with trial mining of ore beginning in late 1998 and the first diamonds being produced in February 1999. Rio Tinto acquired the mine in 2000 and continued operations until April 2003. Merlin Diamonds Limited (ASX:MED) are currently the owner of the mine.



Figure 1. Location of Merlin Diamond Mine

1.2 Geological Setting

The Merlin Diamond field is located in the McArthur Basin which consists of Proterozoic (545 to 2,500 million years ago) marine and continental sediments and volcanics (1,000 to 2,500 million years old). The Batten Trough, also known as the Batten Fault Zone, is a 70 km wide zone of extensive faulting, trending north-northwest that occurs within the southern McArthur Basin. The Batten Trough, bounded on the east by the Emu Fault and covered to the west by the Roper Group of sedimentary rocks, is a synsedimentary graben containing up to 10 km of McArthur Basin sediments. Associated with the Batten Trough are the Mallapunyah and Calvert Faults, two northwest trending regional faults, approximately 50 km apart. The kimberlite pipes of the Merlin field are regionally located on the eastern shoulder of the Batten trough, some 6 km east of the Emu Fault and on the projected trace of the northwest trending Calvert Fault. All of the pipes in the field have intruded the Cambrian aged Bukalara sandstone, which is flat lying and unconformably overlies Proterozoic sediments in this area.

The typical geology of the Merlin kimberlite pipes is schematically depicted in Figure 2. The kimberlite has been preferentially eroded from the general regional surface expression and infilled with Cretaceous sediments. These Cretaceous sediments have

been subsequently mined during the open pit operations in order to access the underlying Kimberlite. The side walls of the existing pits are flanked by the stable, horizontally bedded Cambrian Bukalara Sandstone unit.

Ten of the fifteen known kimberlite pipe vents of the Merlin field have been mined from nine open cut pits. The mined pits are orientated north-south in three distinct clusters with the northern cluster of Gareth, Kaye and Ector; central cluster of Gawain and Ywain; and southern cluster of Excalibur, Launfal, Sacramore and Palomides. The regional groundwater level is approximately 20 metres below natural surface and the open pits were continuously dewatered during mining. Consequently, groundwater ingress since the end of mining has formed pit lakes in the remnant pits (see Figure 2).

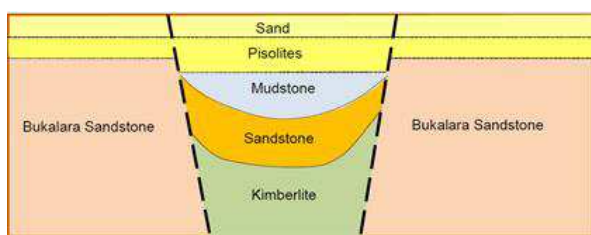


Figure 2. Generalised cross section of the typical kimberlite geometry

1.3 Proposed Mining

Historical records show that the open pit mine plans for Kaye and Ector kimberlite pipes in the northern cluster (see Figure 3) were never completed when Rio Tinto ceased operation at Merlin Diamond Mine in 2003. The current mine plan for these pits is to dewater and complete open pit mining using a D7 dozer to rip and push up ore for loading into dump trucks by excavator. For the completed open pits, a mechanical clamshell grab dredge mining is proposed from a barge floating on the pit lake (see Figure 3).



Figure 3. Open pits of the Northern Cluster: Kaye (left), Ector (right) and Gareth (background)

Even though ripping and excavation field tests are planned to be undertaken on the kimberlite before mining commences, Merlin Diamonds Limited were keen to determine a suitable in situ test to determine rock strength and excavatability for use during operations.

Pettifer and Fookes (1994) established that a D7 dozer can easily rip rock with small to medium discontinuities (100 to 300 mm) and a Point Load Index around 1.0 MPa (0.6 to 2.0 MPa). A Point Load Index (Is_{50}) can be directly approximated to Uniaxial Compressive Strength (UCS) whereby an Is_{50} of 1.0 MPa relates to a UCS of 24 MPa. Accordingly, 'easy ripping' of kimberlite with small to medium discontinuities as observed at Merlin can be completed with a D7 dozer up to a UCS of approximately 25 MPa. Similarly established empirical equations (Goktan & Gune, 2005) indicate the heavy clamshell grab selected for dredge mining at Merlin has a 'working' operational limit of 25MPa.

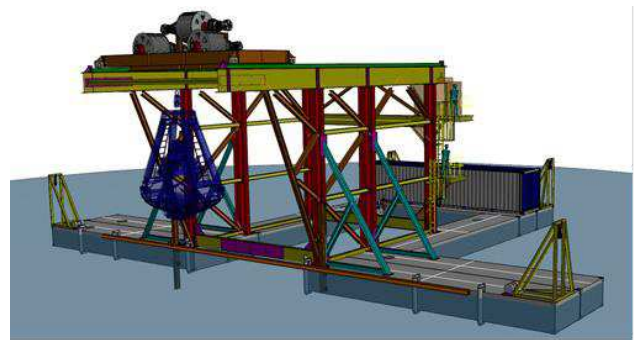


Figure 4. Mechanical Clamshell Grab Dredge Mining

2 TESTING

The Schmidt Hammer was selected for in situ rock strength testing. The Schmidt Hammer tests were performed on kimberlite diamond drill core and these results were compared to UCS values derived using standard destructive compression testing of the cores in the laboratory.

A review of Merlin's exploration database identified cores from eight diamond drillholes commencing in the pit floor of Gawain pit in the central cluster at Merlin. NQ and HQ diamond drill core with diameters of 47.6 mm and 63.5 mm, respectively, were available. Between three and nine core samples (average six) were prepared from each drillhole with a focus on selecting an equal spread of samples over the weathered zone (0 to 60 m depth). Two samples in the fresh zone at approximately 92m to 94m were also selected for testing, primarily for another study. The samples for UCS testing were prepared in accordance with AS 4133.4.2.2 (Standards Australia, 2013) which stipulates a core length 3 times the diameter. This requirement results in *selection bias* when choosing core samples as only relatively long and intact sections of core, which consequently exhibit higher strength, are selected. Accordingly the results from core testing will represent the upper limit of rock strength for the orebody. Over 50 diamond drill core samples were prepared at Merlin mine and dispatched to the geotechnical laboratory at Federation University, Ballarat.

The Schmidt Hammer uses rebound hardness (Q-value) to approximate rock strength. The Schmidt Hammer testing was completed in accordance with the recommended procedure of the International Society of Rock Mechanics (Aydin, 2008), whereby 20 recordings are taken on a single sample. All care was taken to position the Schmidt Hammer over the cementitious material within the kimberlite core given this is acknowledged as the weaker component of the breccia. The median of the twenty Q-values for each core sample was taken prior to destructive UCS testing in the laboratory. Of the 43 samples that arrived to the laboratory intact, only 14 were considered sufficiently competent to withstand testing with the Schmidt Hammer prior to destructive UCS testing in the laboratory.

The prepared core samples were measured with Vernier callipers as described in AS 4133.4.2.2 (Standards Australia, 2013). An average cross-sectional area (mm²) was derived for each core sample. The destructive compression testing was undertaken using a Shimadzu Autograph AG-Xplus Series machine in accordance with AS 4133.4.2.2 (Standards Australia, 2013). Figure 5 shows a core sample that has failed in a single shear plane, which was typical of the failures observed. The force (N) at failure of each core sample was recorded and divided by the cross sectional area (mm²) to determine the UCS (N/mm² = MPa).



Figure 5. Failed Core Sample

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3 RESULTS

3.1 Schmidt Hammer Field Test

The graph in Figure 6 shows Schmidt Hammer Q-values relative to drill core depth which shows a weakly positive regression fitted by the method of least squares. The standard deviation of the twenty Q-values recorded for each core sample has been used to derive 95% confidence intervals for the data set. The upper and lower confidence interval bounds.

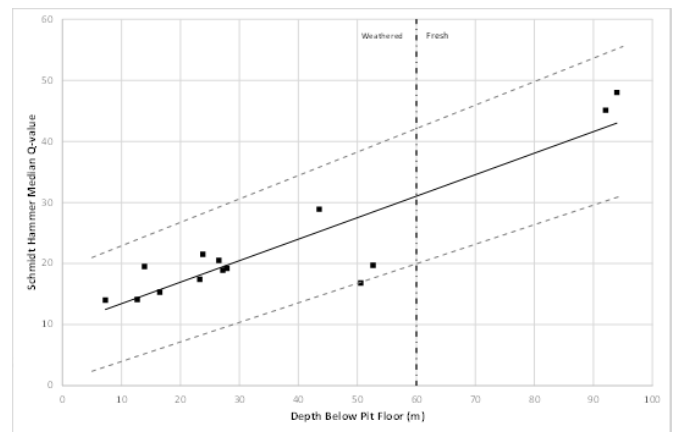


Figure 6. Schmidt Hammer Test Results Relative to Drill Core Depth

3.2 Laboratory Test

All 43 intact diamond drill core samples were subjected to destructive UCS tests in the laboratory. The laboratory UCS test results shown in Figure 7 depict a weakly positive least squares regression between the depth of kimberlite and UCS. Of the 43 samples tested, all but one of the weathered core samples (0 to 60 m depth) were within the upper limit of excavatability (25 MPa). The two samples of fresh kimberlite (deeper than 60 m) tested were beyond the upper limit of excavatability.

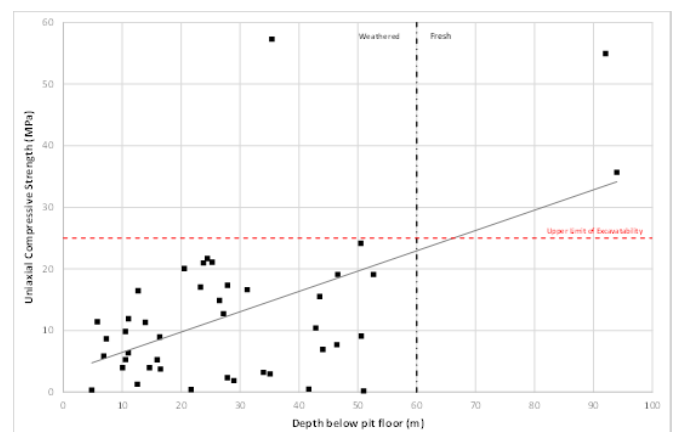


Figure 7. Laboratory UCS Test Results Relative to Drill Core Depth

3.3 Field Vs Laboratory Test

Figure 8 shows the regression of Schmidt Hammer Q-values against laboratory UCS test results. The least squares regression line shows a near direct

(1:1) relationship. The standard deviation of the twenty Schmidt Hammer Q-values recorded for each core samples was used to derive upper and lower 95% confidence intervals which are shown on Figure 8.

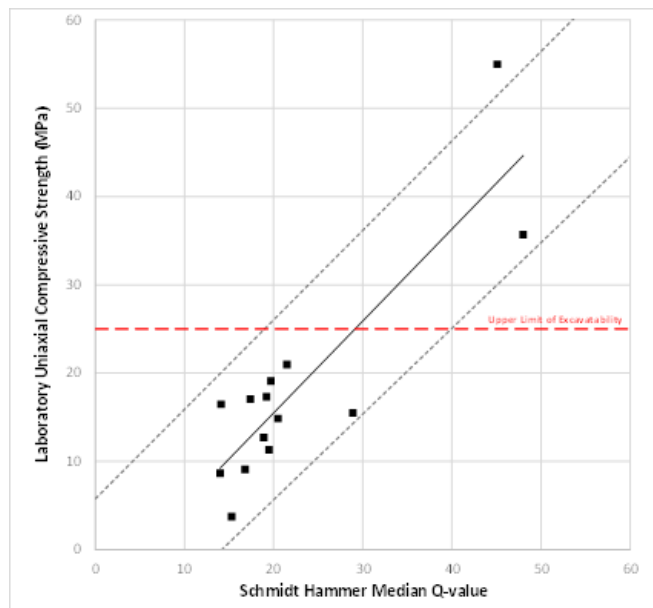


Figure 8. Schmidt Hammer Test Results Relative to Laboratory UCS

4 CONCLUSIONS AND RECOMMENDATIONS

The Schmidt Hammer, an in situ measuring device, was used to estimate rock strength of kimberlite core samples. This was followed by destructive compressive testing of the core samples to determine Uniaxial Compressive Strength (UCS). The Schmidt Hammer rock strength (Q-value) showed a near direct relationship to the UCS where $UCS = 1.04 Q - 5.31$. The results confirm the use of the Schmidt Hammer as a suitable device for in situ measuring of kimberlite and UCS estimation.

The UCS testing also showed that the weathered kimberlite in Gawain pit is below the upper limit of excavatability for ripping using a D7 dozer and excavation using a heavy dredging clamshell grab.

Ripping and dredging are tensile failures and the use of laboratory or field estimated UCS to predict excavatability assumes a direct relationship between compressive and tensile strength. Data presented by Morkel and Saydam (2008) show that the UCS to Brazilian Tensile Strength (UTB) ratio for a South African kimberlite breccia is 6.84 compared to that for most brittle rocks of approximately 10. A core sample adjacent to each UCS core sample from Merlin has been prepared for UTB testing to determine the UCS to UTB ratio for Merlin kimberlite breccia.

Hoek (1977) observed that rocks subjected to Point Load Index tests fail in tension and therefore the I_{S50} to UCS assumption adopted in this paper will depend on confirming the UCS to Brazilian

Tensile Strength (UTB) relationship observed in South African kimberlite breccias.

The testing conducted used a Type (N) Schmidt Hammer which is better suited to higher strength rock. The Type (L) Schmidt Hammer is recommended for future assessment as this will enable testing of lower strength kimberlite as well as ore beyond the upper limit of excavatability.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

- Aydin, A. 2008. ISRM suggested method for determination of the schmidt hammer rebound hardness: Revised version. (). Elsevier Ltd. Doi:10.1007/978-3-319-07713-0
- Goktan, R.M. and Gunes, N. 2005. A semi-empirical approach to cutting force prediction for point-attack picks, The Journal of The South African Institute of Mining and Metallurgy VOLUME 105, REFEREED PAPER, APRIL 2005
- Hoek, E. 1977. Rock Mechanics Laboratory Testing in the Context of a Consulting Engineering Organization. Int. J. Rock Mech. Min. Sci. and Geomech, Abstract 14, 1977. 93-101
- Morkel, J., and Saydam, S. 2008. The influence of potassium on the weathering properties of kimberlite and the information provided by different testing methods.
- Pettifer, G.S., and Fookes, P.G. 1994. A revision of graphical method for assessing the excavability of rock. Q J Eng Geol 27:145-164
- Standards Australia. 2013. Rock strength test – determination of uniaxial compressive strength – rock strength less than 50 MPa (AS 4133.4.2.2). Retrieved from <https://www-saiglobal-com.ezproxy.federation.edu.au/online/autologin.asp>