Reference: G0186 AA_RE01

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General Manager

Broken Hill Operations (BHOP) – Rasp Mine

12th July 2021

RE: GEOTECHNICAL ASSESSMENT OF THE MLD DRIVE BELOW THE KINTORE PIT

1 Introduction

Ground Control Engineering Pty Ltd (GCE) was engaged by Broken Hill Operations (BHOP) to undertake a geotechnical assessment of the MLD / Zinc Lodes drive below the Kintore Pit at the Rasp Mine. The assessment was requested by Eamonn Dare, Technical Services Superintendent at Rasp Mine, following submission of GCE's proposal G0186 AA_PR01_V01 (dated 30 January 2019).

2 Background

The Kintore Pit was excavated through a complex network of historic underground workings from 1983 to 1990. Rasp have utilised the Kintore Pit for access to the underground mine since 2007. The pit floor and underground workings are highly porous, water that enters the Kintore Pit drains through the historic workings into the underground mine which is removed by the mine dewatering system.

BHOP propose to use the Kintore Pit for storage of dried mine tailings and compacted waste rock. An engineered plug will be constructed in the main Western Min decline to isolate the placed tailings from the underground workings. Golder Associates PTY LTD (Golders) have submitted a design for the construction of the engineered plug. The Golder report (reference report) should be read in conjunction with this report.

A requirement of the design was to evaluate the condition of the rock mass in the main Western Min decline at the proposed plug location. An additional requirement subsequent to the Golder report was to evaluate the condition of the rock mass in the MLD drive which serves as the access to the base of the No.6 ventilation shaft in the event that long term access to the shaft was required. The MLD drive passes within 2m of the old workings that intersect the base of the Kintore Pit and Rasp have excavated a number of development drives through the old workings along the length of the MLD drive, engineered plugs (barricades) will be required at those locations if future access to the MLD drive is to ne maintained.

3 Scope of work

The scope of work was detailed in GCE's proposal (G0186 AA_PR01_V01), and comprised the following main work tasks:

- Inspection and geotechnical mapping of the following underground drives:
    - Decline: from the portal to the MLD intersection.
    - MLD including MLD Crowns and ML 525 drives.
    - Potential barricade locations along MLD Crowns and ML 525 drives.
- Assessment of ground conditions in the above listed drives, with a focus on identifying sections of the Decline, MLD Crowns and ML 525 drives where long-term stability may be compromised by poor ground conditions resulting from:
    - Major structures.
    - Water ingress.
    - Zones of weak rock.
- Assessment of ground conditions at locations where the MLD drive intersects the old workings. Engineered barricades will be required to separate the MLD Crowns and ML 525 drives from old workings.

  Figure 1 and 2 show the relationship between the Kintore Pit and relevant underground workings.

Figure 1 Kintore Pit and underground workings.

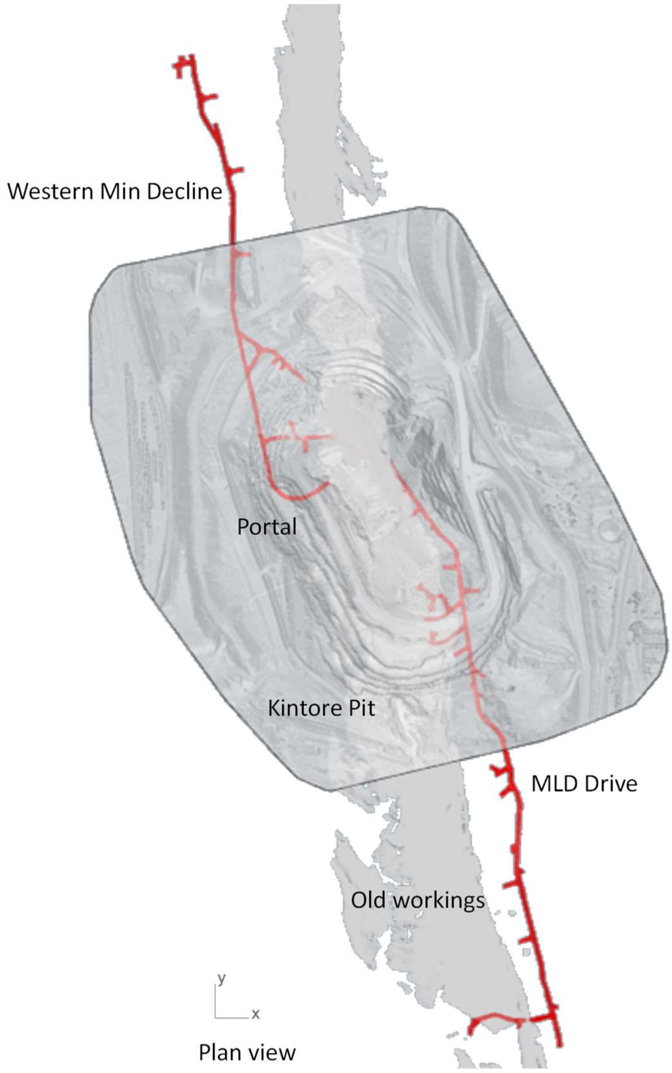
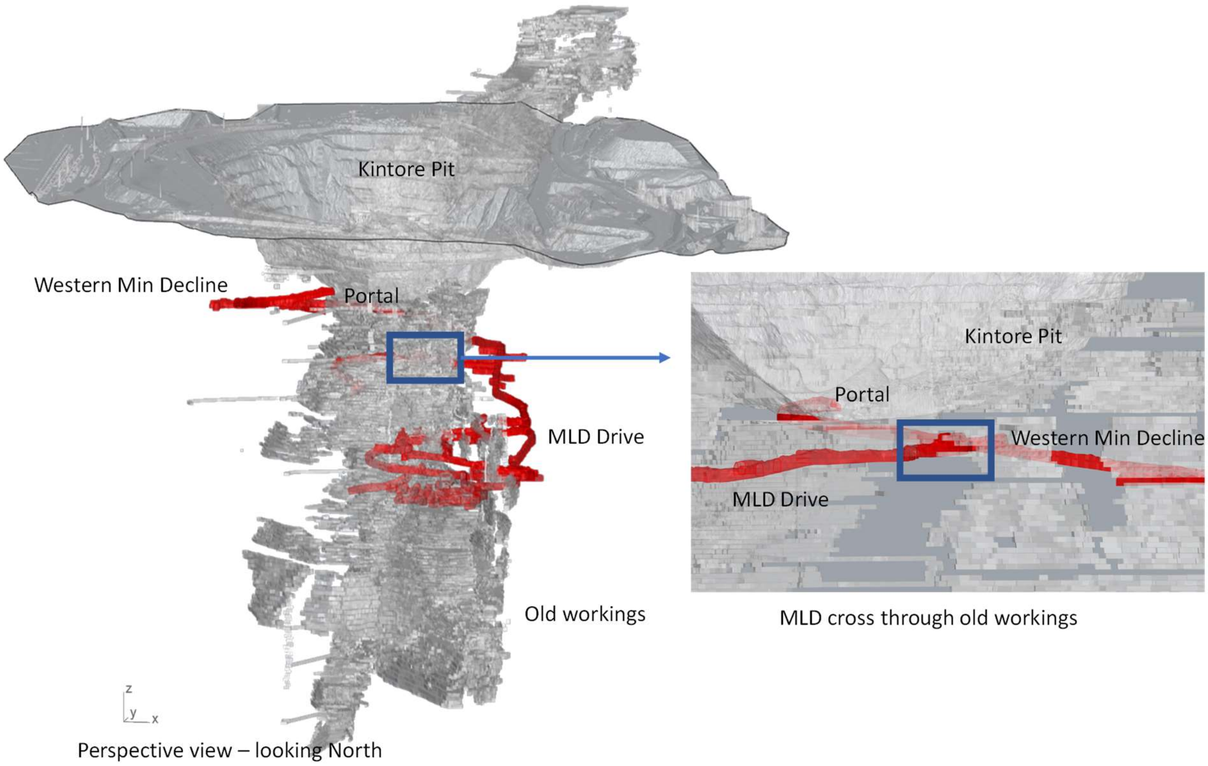


Figure 2 Kintore Pit and underground workings (B)



4 Geotechnical conditions

4.1 Geology

The principal rock unit in the mine sequence stratigraphy at Rasp is the Hores Gneiss. The unit is described as a mainly garnet bearing quartzo-feldspathic gneiss. Locally the unit includes medium to fine grained Potosi Gneiss. The Potosi Gneiss comprises politic and psammitic metasediments with persistent quartz-gahnite, garnet-quartz and quartz-garnet (lode) rocks. The Potosi Gneiss rock types form the dominant host rocks for capital infrastructure development mining at Rasp, these units are generally competent and strong.

4.2 Geological structure

Analysis of mean structure sets, empirical rock mass classifications (e.g., Q, MRMR) and subsequent stability assessments have been undertaken for hanging wall, footwall and ore domains. Data collected during logging of geotechnical and resource drill holes are listed in Table 1.

Table 1 Mean structure sets for Rasp domains (mine-wide) (Rasp Mine PHMP – Ground or Strata Failure [1])

Domain	Defect Set (Dip/Dip Direction)							
	1 (Foliation)	1a (Joint)	2 (Joint)	2a (Joint)	3 (Joint)	4 (Joint)	5 (Joint)	6 (Joint)
Decline	59°→238					35°→108	88°→287	40°→347
Footwall	66°→259		67°→100		65°→050	15°→090	73°→320	
Ore	71°→251		59°→088	49°→127	80°→019			
Hangingwall	61°→246		68°→122					73°→359
Zn Lodes	81°→255	49°→241	83°→071					

Note: All orientations are in degrees relative to AMG North

All sets except foliation are relatively widely dispersed in both dip and dip direction. Foliation is moderately to steep dipping towards the southwest, while the joint sets are mostly steeply dipping to the northeast and southeast.

The joint sets at Rasp can form rock wedges in development where the direction of development is either parallel or perpendicular to the strike direction of the joint structures. The potential wedges are controlled by rock bolting or cable bolting.

4.3 Rock mass classification

Intact rock properties and structural conditions are used to classify rock mass quality in each domain according to the Q and RMR (and MRMR) rock mass classification systems. Table 2 summarises the results of the rock mass classification systems that have been assessed at Rasp. The rock mass classification data indicates fair to good rock mass conditions.

Table 2 Parameters and results for various rock mass rating systems within the ore body (Rasp Mine PHMP – Ground or Strata Failure

Method	Parameter	Above 6 L		6L to 8L		8L to 11L	
		Back	HW	Back	HW	Back	HW
Q' = RQD/Jn x Jr/Ja	RQD	72.0	81.0	92.0	97.0	98.0	99.0
	Jn	9.0	9.0	6.0	6.0	6.0	6.0
	Jr	3.0	3.0	3.0	3.0	3.0	3.0
	Ja	2.0	2.0	1.0	2.0	1.0	0.8

[1] Rasp Mine Principal Hazard Management Plan – Ground or Strata Failure BHO-PLN-MIN-014

Method	Parameter	Above 6 L		6L to 8L		8L to 11L	
		Back	HW	Back	HW	Back	HW
Q'		12.0	13.5	46.0	24.3	49.0	66.0
Q = Q' x Jw/SRF	Jw	1.0	1.0	1.0	1.0	1.0	1.0
	SRF	5.0	5.0	5.0	5.0	5.0	5.0
Q		2.4	2.7	9.2	4.9	9.8	13.2
RMR = IRS + RQD + Js + Jc + Jw	UCS Rating	5.8	5.8	5.8	9.1	9.1	9.1
	RQD Rating	13.0	18.0	20.0	15.0	20.0	20.0
	Js	9.0	8.5	9.5	8.5	10.0	9.5
	Jc	25.0	25.0	25.0	25.0	25.0	25.0
	Jw	10.0	10.0	10.0	10.0	10.0	10.0
RMR		62.8	67.3	70.3	67.6	74.1	73.6
MRMR = RMR x Jo x Aw x As x Ab	Jo	1.0	1.0	1.0	1.0	1.0	1.0
	Aw	1.0	1.0	1.0	1.0	1.0	1.0
	As	1.0	1.0	1.0	1.0	1.0	1.0
	Ab	0.9	0.9	0.9	0.9	0.9	0.9
MRMR		57.2	61.4	64.2	61.7	67.8	67.3

4.4 Stress field and seismicity

In situ stress measurements have not been conducted for the Rasp Mine. The following assumptions for calculating the maximum principal stress (σ_1) was assumed to be a multiple of the overburden pressure calculated using the formula:

$$\sigma 1 = 1.5(\rho\ g\ h)$$

where

ρ = 2.94 t/m^3 (average wet density from laboratory testing)

g = 9.81 m/s^2

h = depth below surface

Mining of the nearby Western Mineralisation at the Rasp underground mine has reached depths of over 650 metres with extensive, large scale stoping activities completed without adverse consequences with respect to mining induced stress.

4.5 Rock properties

Rock property testing was undertaken for the Definitive Feasibility Study (DFS) – Rasp Project (2007) and for the Zinc Lodes mining study in 2014. Uniaxial Compressive Strength (UCS) testing, elastic properties and triaxial tests were conducted on samples selected from exploration drill core for the Zinc Lodes ore body which was extracted between 2015 and 2018. The main rock type recorded during the assessment of the MLD Drive was Garnet Pelite (Gpe). The Zinc Lodes area is located approximately 950m southwest of the Kintore Pit and is accessed via the MLD drive, and the results are considered analogous for the MLD drive area due to the similar rock types. The test results and geotechnical mapping indicate moderate to strong rocks[2] in the Rasp sequence.

A summary of the intact rock property testing is shown in Table 3 and Table 4.

Table 3 Zinc Lodes (2014) - UCS and elastic properties.

Borehole ID	Lithology	UCS (MPa)
ZLDD5017	LuQ	103
ZLDD5001	Gpe	59.4
ZLDD5001	Pe	18.2
ZLDD5034	Pe	16
ZLDD5032	Gpe	83.1
ZLDD5034	GPm	98
ZLDD5009	GPs	34.1
ZLDD5029	LuQ	35.2
ZLDD5002A	Pe	17.8
ZLDD5006	Peg	88.4
ZLDD5003	Pm	95.7
ZLDD5036	S	60.8

Table 4 Zinc Lodes triaxial test results (2014)

Borehole ID	Depth (m)		Lithology	Estimated Peak Envelope		Estimated Residual envelope	
	From	To		Friction Angle	Cohesion (MPa)	Friction Angle	Cohesion (MPa)
ZLDD5036	23.75	26	Gpe	48.3	10.47	13.3	9.19
ZLDD5022	62.9	63.15	Gpe	53.8	14.59	48.2	2.22
ZLDD5004	95.4	95.6	S	38.7	27.87	n/a	n/a

5 MLD Drive geotechnical assessment.

Underground inspections and geotechnical mapping were undertaken over two days (6 and 7 February 2019), by a geotechnical engineer from GCE accompanied by a Rasp Mine geologist.

All areas inspected were reinforced using pattern rock bolting and either galvanised steel mesh or fibrecrete as surface support. The majority of the surface support installed in the drives inspected was fibrecrete. The ground support elements were in good condition and no major areas of cracking of fibrecrete, or deterioration were observed. Where the walls and backs were exposed, geotechnical

[2] International Society for Rock Mechanics (ISRM) – Field estimates of uniaxial compressive strength.

parameters were logged and mapped for input into the Q rock mass classification system[3]. Mapping sheets and inspection notes are provided as an attachment to this report.

5.1 Rock mass classification

Rock properties were collected for classification using the Tunnelling Quality Index, Q. The Q-system is a means of classifying rock masses with respect to in-situ parameters including rock quality, joint condition and stress state. Q is defined by:

$$Q = \frac{RQD}{Jn} x \frac{Jr}{Ja} x \frac{Jw}{SRF}$$

Where:

RQD is the *Rock Quality Designation.* RQD was estimated using the method of Palmström, based on average spacing of defect sets.[4]

Jn is the *Joint Set Number*. This factor accounts for number of repetitive joint (defect) sets.

Jr is the *Joint Roughness Number*. *Jr* describes the large and small scale surface texture.

Ja is the Joint Alteration Number. Ja describes the surface alteration.

Jw is the *Joint Water Reduction Number*. *Jw* accounts for the destabilising effect of high water pressures and of joint washout by water influx.

SRF is the *Stress Reduction Factor*. *SRF* modifies Q to account for in-situ stress which may cause destabilise the rock mass.

Q values for each of the mapped zones are summarised in **Error! Reference source not found.**5 along with the values determined for the in-situ parameters. Field observations relating to the input parameters are provided as an attachment to this report.

[3] Barton, N., Lien, R., and Lunde, J. 1974. Engineering classification of rock masses for the design of tunnel support. *Rock Mech.*, May, 189-236.

[4] Palmström, A., 1982. The volumetric joint count – a useful and simple measure of the degree of rock jointing, *Proc. 4th Congress. Int. Assn. Engineering Geology,* Delhi, 5, 221-228.

Table 5 Q-values and parameters

Zone	RQD (%)	Jn	Jr	Ja	Jw	SRF	Q	Rock mass Description
PORTAL TO MLD T/O	60	9.0	1.5	1.0	1.0	2.5	4.00	Fair
MLD STOCKPILE-NORTH (9700 E)	55	6.0	1.5	1.0	1.0	1.0	13.63	Good
MLD STOCKPILE-SOUTH (9725 E)	60	6.0	1.5	1.0	1.0	1.0	15.00	Good
MLD	55	9.0	3.0	1.0	1.0	1.0	18.17	Good
MLD CROWNS-BARRICADE SITE 1	33	6.0	1.5	1.0	1.0	2.5	3.25	Poor
MLD CROWNS-BARRICADE SITE 2	85	6.0	1.5	1.0	1.0	1.0	21.19	Good
MLD CROWNS-BARRICADE SITE 3	71	6.0	1.5	1.0	1.0	2.5	7.10	Fair
MLD	55	6.0	3.0	6.0	1.0	2.5	1.83	Poor
MLD CROWNS - BARRICADE SITE 4	27	6.0	3.0	6.0	1.0	2.5	0.90	Very Poor
MLD: STOCKPILE (850 N)	55	9.0	3.0	6.0	1.0	2.5	1.21	Poor
MLD: STOCKPILE (770 N)	55	6.0	1.5	1.00	1.0	2.5	5.50	Fair
MLD: F PILLAR-BARRICADE SITE 5	16	6.0	1.5	0.75	1.0	2.5	2.13	Poor
MLD-F PILLAR	84	9.0	3.0	2.00	1.0	2.5	5.58	Fair

5.2 Geotechnical conditions

As mentioned previously, the majority of the drives were covered with fibrecrete. As such, the mapping and subsequent Q-values and geotechnical assessments are based on the limited exposed areas within each of the drives inspected.

The geotechnical conditions for each zone are summarised in Table 6 and shown in Figure 3. In general, the ground conditions were sound with only minor, local areas of lower strength rock (associated with shear zones).

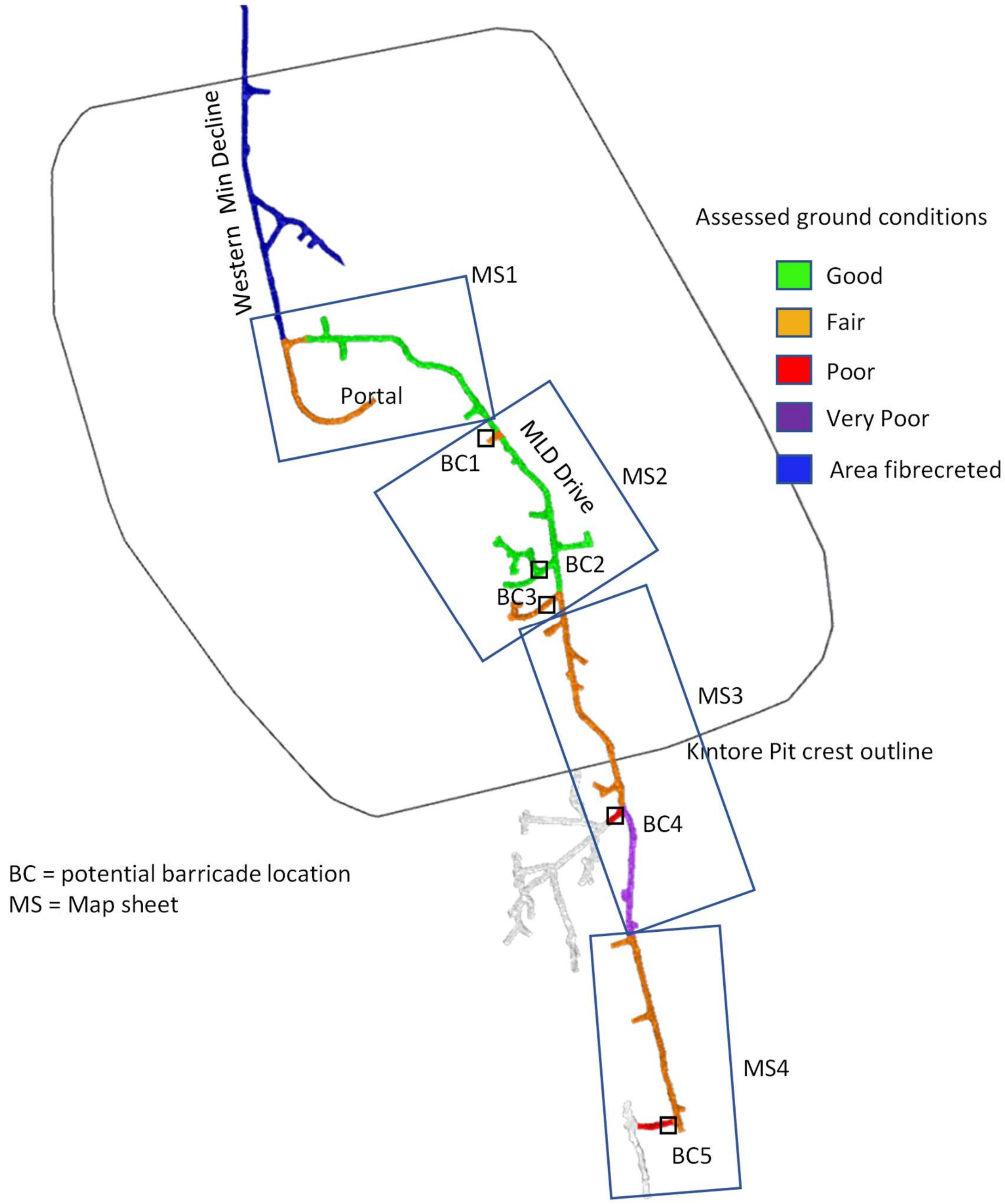
Table 6 Summary of geotechnical conditions

Zone	Estimated Rock Strength	Q	Rock mass Description	Major Structures	Water Ingress	Ground Support (GS)
PORTAL TO MLD T/O	R4	4.00	Fair	Two small shears near t/o to MLD	None observed, however GS corroded and salt precipitation (Photo 01)	Fibrecrete: good Spilt sets corroded
MLD STOCKPILE-NORTH (9700 E)	R3	13.63	Good	None observed	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD STOCKPILE-SOUTH (9725 E)	R4	15.00	Good	None observed	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD	R4	18.17	Good	None observed	~0.2 L/min dripping from ungrouted hole in backs. Corrosion and heavy salt precipitation (Photos 02 and 03)	Fibrecrete: good Spilt sets corroded
MLD CROWNS-BARRICADE SITE 1	R3-R4	3.25	Poor	Minor shear (intact), some surface staining	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD CROWNS-BARRICADE SITE 2	R4	21.19	Good	None observed	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD CROWNS-BARRICADE SITE 3	R3-R4	7.10	Fair	Shear zone: ~1 m wide, R3 (Photo 04)	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded

Zone	Estimated Rock Strength	Q	Rock mass Description	Major Structures	Water Ingress	Ground Support (GS)
MLD	R3-R4	5.50	Poor	Shear zone (~1100 N): ~0.5 m wide, R2 with some clay	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD CROWNS - BARRICADE SITE 4	R3-R4	0.90	Very Poor	Shear zone: ~1 m wide, R3, RQD ~10-20%, salt precipitation	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD: STOCKPILE (850 N)	R3-R4	1.21	Poor	Shear zone: around pegmatite, crushed infill 50 mm	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded
MLD: STOCKPILE (770 N)	R3-R4	5.50	Fair	Minor shear: some surface weathering	Very small amount of water dripping from GS openings. GS corroded, heavy salt precipitation	Fibrecrete: good Spilt sets corroded
MLD: F PILLAR-BARRICADE SITE 5	R3-R4	2.13	Poor	Shear zone: intact, R3-R4, follows foliation	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded and damaged due to re-stripping drive
MLD-F PILLAR	R3-R4	5.58	Fair	None observed	None observed, however GS corroded and salt precipitation	Fibrecrete: good Spilt sets corroded

The geotechnical conditions for each zone are shown in plan view in Figure 3.

Figure 3 Geotechnical conditions for the Western Min decline (Portal to MLD intersection) and MLD Drive



6 Conclusions

GCE inspected and geotechnically mapped sections of the Western Min decline between the portal and the decline plug location, the MLD drive, MLD Crowns and ML 525 drives to identify any major structures or ground conditions that may impact works associated with the Kintore Pit tailings project (done by others). The ground conditions observed were generally good with only minor zones of lower strength rock associated with local shear zones. No major shear zones were identified during the mapping.

Several areas were noted as damp and one area was observed to have low water flows. Due to the highly nature of the old working fill material, there is potential for increased water flows if water is introduced to the tailings that will be placed in the Kintore Pit. As there is no definable crown pillar between the pit floor and the old workings, any water that enters the pit currently drains through the old workings and is be collected by the underground pumping network.

7 Recommendations

If access to the MLD Drive is required post tailing disposal, it is recommended to install engineered barricades where the MLD drive intersects the old workings to control potential inundation risks. The barricades should be installed prior to the commencement of tailing placement.

Where access to the MLD Drive is not required post tailing disposal, it is recommended that waste rock is placed in the MLD Drive to prevent access prior to the commencement of tailing placement.

For and on behalf of GROUND CONTROL ENGINEERING PTY LTD

Yours sincerely

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8 Appendix 1

Photographs and Mapping Sheets

DOCUMENT INFORMATION

Status	Final
Version	
Print Date	28 July 2021
Author(s)	Cameron Tucker
Reviewed By	
Pathname	
File Name	G0186.AA _RE01_MLD_DRIVE_ASSESSMENT
Project No.	G0186.AA
Distribution	PDF to client

DOCUMENT CHANGE CONTROL

Version	Description of changes/amendments	Author(s)	Date
V01	Preliminary draft	C Tucker	04/03/19
V02-V05			
V06	One plug below MLD	C Tucker	16/12/20
V07	BHOP review – minor changes	C Tucker	16/12/20

DOCUMENT REVIEW AND SIGN OFF

Version	Reviewer	Position	Signature	Date
V01	J. Anders	Senior Geotechnical Engineer		
V02	C. Tucker	Principal Geotechnical Engineer		
V06	C. Tucker	Principal Geotechnical Engineer		
V07	C. Tucker	Principal Geotechnical Engineer		