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REPORT ON

**RECOMMENDATIONS FOR NORTHMET OPEN PIT
ROCK SLOPE DESIGNS
NORTHMET MINE PROJECT**

Submitted to:

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EXECUTIVE SUMMARY

This geotechnical engineering report, prepared by Golder Associates in support of the Definitive Feasibility Study being prepared for the NorthMet project by PolyMet Mining Corporation, provides the following information in support of open pit development.

- Recommendations for ultimate pit rock slope configurations based on kinematic assessments.
- Recommendations for pit slope monitoring and instrumentation requirements.

The proposed open pits are located along a northeast trend that extends through the site, paralleling the contact between Duluth Complex mafic intrusives and the underlying Virginia Formation. Mineralization tends to be concentrated in the basal units of this layered mafic intrusive. The Virginia Formation is in turn underlain by the Biwabik Iron Formation. Overburden, characterized by others, has a typical thickness of from 10' to over 30' thick based on oriented core drillhole logs reviewed as part of this study.

The rocks that will form the open pit slopes at the NorthMet deposit are strong to extremely strong, with moderate to wide fracture spacing. On some slope orientations, adversely oriented geological structures within the rocks may control bench design. Away from the influence of possible major structures, overall slope designs will be controlled by the inter-ramp bench configurations that can be achieved with controlled blasting.

Hydrogeological characterization of the overburden and rock mass was performed by Barr Engineering. The significant observations in their draft reporting appear to be:

- Lower hydraulic conductivity (10^{-7} to 10^{-9} m/s) in Duluth Complex open holes; penetrating units 4 to 1 and the Virginia at depth (Barr phase 1 draft report, received in March 2006); and
- Higher hydraulic conductivity in the Virginia Formation (Phase 2 draft), ranging from 1 ft²/day to 600 ft²/day, roughly $K=10^{-6}$ to 10^{-9} m/s.

We understand that the significance of these findings with respect to inflows into the proposed open pits will be reported by Barr in subsequent documents.

Pit Slope Design Recommendations in Rock

The following bench geometries have been developed assuming adequate dewatering of the rock slopes has been achieved. Should observations on initial benches indicate that enhanced depressurization is required, remedial measures such as horizontal drains should be applied.

Detailed bench mapping is recommended to determine if some slopes, such as the main pit north-west wall, may require flatter slopes or other remedial measures.

TABLE 5.1
West Pit Ultimate Slope Design Recommendations

Material	Sector and Wall Dip Directions	Maximum Vertical Bench Separation (m)	Bench Face Angle °	Berm Width (m)	Inter-ramp Angle (°)
Unit 1 on Footwall,	Sector I Footwall 090° to 160°	30m	65 ¹	10	51.4
Unit 1 and overlying units on other walls	Sector II East Wall 170° to 260°	30m	65	10	51.4^{2,3} (53.8)
	Sector IIIa Hangingwall 260° to 020°	30m	65	10	51.4² (53.8)
	IIIb West Wall / Footwall 020° to 090°	30m	70	10	55.1

- Note: On the Footwall, the Bench Face Angle is limited to 65 ° to control steep potential wedges. Flat sets (dip less than 35°) dipping out of the wall are also prevalent. While estimated friction angle on the joints of these sets is on the order of $\phi = 35^\circ$ based on Jr and Ja logging, localized failures involving these features may still occur, in particular if adequate slope depressurization is not achieved and/or if joint surfaces are significantly altered.
- On West Pit Sectors II and IIIa, there is upside potential for slope steepening, if lack of adverse structure can be verified, by reducing the berm width to 8m or increasing the Bench Face Angle to 70° or better, provided that experience with initial slopes, confirmed by mapping, indicates that adverse wedges and planes with dips in the 47 ° to 51 ° range are not problematic. Reducing the berm width from 10m to 8m, with BFA=65° would provide IRA=53.8 °.
- The East Wall of the proposed West Pit is significant enough in length and height for consideration of further drilling investigation at the detailed design stage. Drilling of a geotechnical borehole (oriented core) with NE azimuth would be the best way of justifying steeper slopes in advance of experience with initial benches. Geotechnical boreholes from the present study have azimuths parallel to the strike of this proposed wall.

TABLE 5.2
East Pit Ultimate Slope Design Recommendations

Material	Sector and Wall Dip Directions	Maximum Vertical Bench Separation (m)	Bench Face Angle °	Berm Width (m)	Inter-ramp Angle (°)
Unit 1 and Virginia on Football and East Wall,	Sector I Footwall 200° to 115°	30m	65	10	51.4¹ (47)
Unit 1 and overlying units on other walls	Sectors II, III and IV East ² , South (Hangingwall ³) and West Walls 115° to 200°	30m	65	10	51.4

- Notes: The East Pit Footwall Design of IRA=51° is considered aggressive because of kinematically possible wedges (plunges 47° to 51°) and also because of kinematically possible plane failures (dip 43° to 59°).

This more adverse fabric arrangement appears to be related to steeper apparent dips of the Virginia and overlying Duluth Complex Units. If these features are problematic on initial benches then the IRA should be reduced to 47° by decreasing the Bench Face Angle to 60°. Adequate dewatering is essential.

Concerns are mitigated by the presence of ramps and step outs on the footwall, which will help to control any localized instabilities.

- Slope design on the East wall is controlled by the potential for steep wedges (plunge 60 to 66°) and 41° involving assumed potentially continuous structures. This interpretation is conservative. There is upside potential to steepen the East Pit East Wall from 51° to 53° by reducing the berm width from 10m to 8m, provided experience with initial benches confirms that the initial assumptions are conservative. Similarly, bench face angles could be steepened based on operational experience and good blasting.

As an alternative, an oriented core hole with NE azimuth directed into the east wall could be considered at the detail design stage of the project. See also Note 3 of the West Pit recommendations, above.

- Oriented core drillholes in the East Pit Hanging Wall area consistently indicate the presence of a NW dipping set (dip 38° to 40°) that could be result in plane failures. This is interpreted to be a joint set roughly orthogonal to the apparent dip of the Duluth Complex layering. It does not appear to occur in the West Pit data. Kinematically possible wedges ranging from plunge 46° to 66° are indicated from stereographic projections. Both the planes and wedges are considered discontinuous features. While the recommended bench configuration (IRA = 51.4°) is intended to control most of these features, localized instabilities may still occur.

Slope configurations will be controlled by adversely oriented geological structures. Careful scaling of the pit walls will be required where shallow dipping discontinuous joints control bench face angles. Slope monitoring, initially face mapping and seepage monitoring, is recommended to detect potential movements in the rock slopes. Slope (overburden and rock slopes) performance should be reviewed periodically by a qualified geotechnical engineer.

It is recommended that specific blasting procedures that will not impact slope stability be developed and implemented. The blasting designs can be optimized as mining progresses in each of the major rock types.

Maximum Inter-ramp Slope Heights

On slopes that are not transected by a ramp, we recommend that a wider berm (known as a geotechnical berm or safety berm) of width 12m to 15m wide instead of the nominal 8m to 10m be incorporated on ultimate slopes at maximum separation of four double benches, (vertical separation of 120m). The purpose of this berm is to break the slope and provide additional catchment to limit the potential for rockfall hazard during operations.

Upside Potential

There is potential for steeper inter-ramp slopes than those recommended in this report. Rocks are generally strong. Some joint sets conservatively considered to control slope design may not be problematic. The stability of slopes in the all rock types in the NorthMet Pits will be significantly affected by blasting induced damage. Therefore, it is strongly recommended that controlled blasting procedures be adopted as part of the phase and ultimate pit excavation procedures. Buffer and trim blasting to a free face, could be adopted. However, given the overall good quality of the Duluth Complex rocks, pre-split blasting may result in optimum configurations where there is structural control of the bench faces from steeply-dipping fault/joint sets.

It is recommended that controlled blasting design studies be undertaken as part of the detailed pit design program. These will assist in the selection of appropriate drills and explosive selection. The optimum controlled blast designs will be developed empirically during initial mining phases in each of the major wall orientations.

It is our experience that without controlled blasting, ultimate walls will be from 4° to 7° less steep than those achievable with controlled blasting.

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by PolyMet Mining Corporation (PolyMet) in March 2005 to provide open pit rock slope designs for the feasibility study of their NorthMet Project in Minnesota, USA, northwest of Lake Superior, as shown on Figures 1 and 2. For reference purposes, the two main open pit areas are referred to as West Pit and East Pit respectively. A zone of mining to limited depth during the 20 year plan occurs between these two areas, referred to as the Central Pit.

Given the iterative nature of mine design, the pit shells presented on the figures in this report will be revised based on the recommendations presented in this document. The revised pit shells (designed pits) that will be presented in the Feasibility Study documents for review will incorporate the geotechnical slope design considerations presented in this report.

The following report is a geotechnical/rock mechanics study for establishing the engineering geology model (interpretation) and providing slope design recommendations. The report includes the factual results of the field investigations, describes the engineering geology and provides bench configurations by slope design sector. The work included the following:

- The drilling and core orientation of four diamond cored boreholes oriented towards the planned West Pit Hanging Wall (combined footage of 2344 ft, 775 m);
- The drilling and core orientation of two diamond cored boreholes oriented towards the planned West Pit Footwall (combined footage 2069 ft, 630 m) ;
- The drilling and core orientation of four diamond cored boreholes oriented towards the East Pit Footwall (combined footage 3131 ft, 954 m);
- The drilling and core orientation of six diamond core boreholes oriented towards the East Pit Hanging Wall (combined footage 3349ft, 1021m);
- Geomechanical Parameter logging and discontinuity surface descriptions (Barton Q-system) of the core recovered from all boreholes;
- Geological logging provided by PolyMet;
- Review of working geological plans and cross-sections provided by PolyMet;
- Sampling and unconfined compressive strength testing of 26 rock specimens from borehole 05-429 G, which penetrates all the lithological units to be excavated;
- Review of Regional Geology and Inferred Fault locations in the open pit area using Minnesota Geological Survey Map 119 (Miller et al, 2001) and background information for that map;
- Tilt testing of drillcore to determine base friction angles;

- Review of draft factual reporting by others on bedrock hydraulic conductivity testing in recent exploration and hydrogeological boreholes;
- Detailed structural population assessment based on oriented core;
- The development of an engineering geology model based on the above information;
- Division of the two main open pits into design sectors based on rock type and discontinuity data;
- Provision of ultimate slope design recommendations for the proposed ultimate open pits.

This report is structured with the support of several appendices. Background information and a summary of the regional geology is in Section 2. A summary of the field investigations is in Section 3, and the engineering geology model is presented in Section 4. Kinematic analysis results and slope design recommendations are presented in Section 5. Operational considerations and recommendations for inspections and instrumentation are provided in Section 6.

Field and laboratory data are presented in Appendices A and B. The Kinematic Assessment, focused on planes and wedges, is presented in Appendix C.

2.0 BACKGROUND

2.1 General

The NorthMet polymetallic sulphide deposit, contains copper, nickel, cobalt and platinum group metals. The project property is located near the Mesabi Iron range, northwest of Lake Superior, northeastern Minnesota, St. Louis County, near the towns of Hoyt Lakes and Babbitt, north of the Partridge River, see Figures 1 and 2. The deposit is hosted near the base of the Mesoproterozoic Duluth Complex see Figure 3.

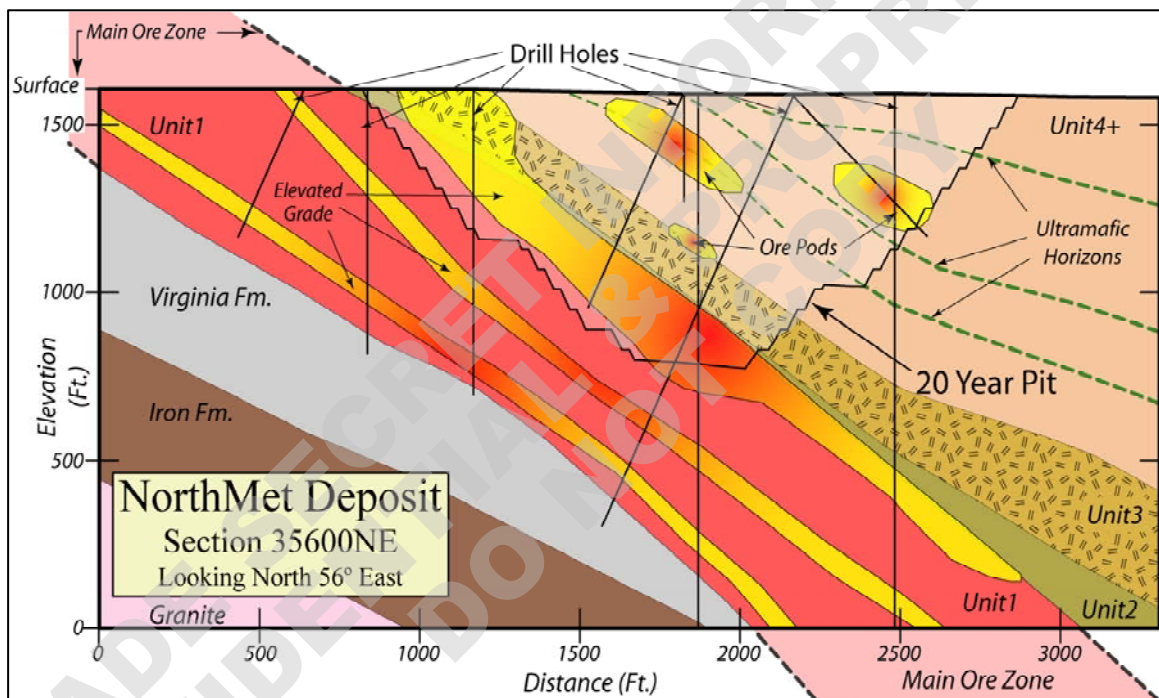
The region is scattered with roads, rails, mines and infrastructure associated with logging and mining. The area is characterized by rounded hills and broad valleys. Ground surface elevations in the area of the proposed mine and rock stockpiles range from about 1630 ft to 1580 ft above sea level. Vegetation consists of northern hardwood and conifer trees as well as muskegs, which are bogs or wetlands common to boreal forest regions.

The climate in the area is continental. Average temperature varies from 70° in summer to -10° F in winter, though it can be considerably colder. Average annual precipitation is about 30 inches in northeastern Minnesota. Rainiest months are June to September, at 4 inches/month, based on information provided by the town of Hoyt Lakes. During winter months precipitation falls as snow, with peak amounts in January-March.

2.2 Basic Geology

The NorthMet deposit is located within the Mesoproterozoic Duluth Complex in northeastern Minnesota. Mineralization tends to be concentrated in the basal units of this layered mafic intrusive. The Duluth Complex, which consists of grossly layered troctolite and minor gabbro, has been divided into seven stratigraphic units in the drill core in the project area. It is underlain by the Paleoproterozoic sediments of the Virginia Formation. The Virginia Formation is in turn underlain by the Biwabik Iron Formation. A simplified cross-section of the deposit has been provided by PolyMet Mining Corporation and is included as Graphic 1 below. Regional geology is presented on Figure 3. Figure 8 presents the major structure traces (regional geology mapping) in relation to the proposed open pit outlines.

GRAPHIC 1
SIMPLIFIED CROSS-SECTION OF THE NORTHMET DEPOSIT



A generalized description of the units within the stratigraphic column (listed from top to the base) is as follows:

- Unit 7 – anorthositic troctolite with a basal ultramafic layer;
- Unit 6 – troctolite anorthosite to troctolite with a basal ultramafic layer;
- Unit 5 – anorthositic troctolite with a gradational base;
- Unit 4 – anorthositic troctolite to troctolite/augite troctolite;

- Unit 3 – troctolitic anorthosite. This fine-grained poikilitic rock has a distinctive mottled appearance and is used as a marker bed within the deposit;
- Unit 2 – troctolite to troctolitic anorthosite with an ultramafic basal layer;
- Unit 1 – anorthositic troctolite to augite troctolite. This is the dominant sulphide-bearing member of the Complex in the NorthMet area;
- Virginia Formation (VF) – cordierite rich Metasediments that form the footwall for the NorthMet deposit; and
- Biwabik Iron Formation – banded iron formation.

Normal faulting associated with the mid-continental rift system appears locally to have increased the apparent dip and apparent thickness of the mafic layers and underlying Virginia Formation. However, specific faults within the NorthMet pit shell (such as those inferred by the Minnesota Geological Survey on Figure 3) have not been verified.

It is inferred that any faults that do occur in the study area will be of high RQD and of comparable or slightly lower rock mass quality to the country rock, based on the lack of clear fault (or shear zones) in the drillcore. In other words, given the age of the deposit and the lack of geological activity, the majority of faults are assumed to have been healed. These assumptions will need to be verified by detailed mapping of initial benches.

2.3 Seismic Environment

The project is located in an area of relatively low seismicity within fresh, strong to very strong mafic rocks of Partridge River intrusion of the Duluth Complex. The region is geologically stable; rocks are on the order of 1 billion years old. The USGS 2002 National Earthquake Hazard maps issued for the International Building Code (IBC) indicates, that, in northeastern Minnesota, the peak acceleration is within the zone of lowest possible seismic risk category.

2.4 Mine Plan

Open pit mining will be carried out as a blasting then truck and shovel operation. Annual mill feed rate of will be 11.67 million short tons (10.6 million tonnes) which will require mining of up to 32 million short tons of waste and ore combined.

The current mine plan has mine bench heights of 7.5m (24.6 ft) in ore and 15m (49.2 ft) in waste rock.

Based on December 2005 designs, the proposed ultimate pit will be approximately two miles long (3.7 Km), NE-SW along strike and one half mile wide (0.7 Km). Maximum ultimate open pit

depths will be achieved on the north-east and southwest ends of the pit, approximately 1,000 ft (300 m), creating a peanut shaped footprint, as shown on Figure 4. Central and East pit areas will be developed first, followed by West Pit development. Pit developments for years 1, 10, 15 and 20 are shown on Figure 5.

2.5 Scope of Work

Golder's scope of work was to conduct a rock mechanics study and provide PolyMet with open pit rock slope design recommendations and operational considerations for their NorthMet Property.

Open pit overburden slopes and open pit hydrogeology were to be performed by others, and were not part of Golder's scope.

2.6 Additional Work by Golder

Golder also carried out a blast requirements study for the NorthMet property and provided PolyMet with prediction of fragmentation size distribution. This is presented under separate cover.

3.0 FIELD AND LABORATORY INVESTIGATIONS

3.1 Work Performed by Golder

The field investigation carried out for the current study consisted of the following:

- An initial site visit during drilling in March 2005. The investigation approach was explained to the PolyMet geologists, who then indicated the best drilling locations. Golder staff verified that contractor Idea Drilling (Idea) were correctly orienting core using the Easy-Mark tool.
- A second site visit in May 2005 when PolyMet's winter drilling program was completed. Golder provided training to PolyMet geologists in geotechnical parameter logging; and oriented core (alpha and beta) measurements and discontinuity surface descriptions (NGI-Barton). Golder selected rock specimens for UCS testing, which were performed at the Queen's University Rock mechanics laboratory in Kingston, Ontario. Golder and PolyMet geologists geotechnically logged 05-429G together as part of the training.

The six West Pit Geotechnical drillholes were completed in March 2005. Summary information follows on Table 3.1 below. Borehole locations in plan are presented on Figure 6.

Table 3.1
West Pit and Central Pit Oriented Core Details

Wall	Borehole ID	Collar		Length (ft)	#Fracts ¹	#Oriented Fracts ^{2,4}
		Az(°)	Incl.(°)			
1	05-429G	330.5	-64.9	1420	859	713 (83.0%)
2	05-430G	147.4	-45.9	599	399	380 (95.2%)
3	05-439G	142.7	-46.5	598	302	237 (78.5%)
4	05-440G	323.2	-64.8	648	287	281 (97.9%)
5	05-443G	148.5	-47.1	848	388	375 (96.6%)
6	05-447G	167.9	-46	499	358	349 (97.5%)

- two drilled into footwall (azimuths of 330.5 ° and 323.2 °)
- four drilled into hanging wall (azimuths of 142.7 ° to 167.8 °)

Notes:

1. Based on the sum of fractures per run counts. See Appendix A.
2. Based on the number of discontinuities with alpha and β measurements.
3. The above excludes intervals of broken core, which were rare. See Appendix A for downhole locations of broken core intervals and/or intervals with “Too Many Fractures to Count”, which were assigned a nominal value of Fractures/ft=20.
4. The purpose of presenting the number of oriented fractures as a percentage of the total number of fractures intercepted in the drill core is to assess the success of the core orientation program.

All geotechnical measurements were recorded by PolyMet geologists and provided to Golder in digital format.

A third site visit in November 2005 during the second phase of drilling, including the 10 East Pit area geotechnical/oriented core holes.

PolyMet geologists continued to measure and record geotechnical and oriented core parameters correctly, as was verified by Golder during this visit. Idea Drilling occasionally “flipped” their core orientation line by 180°. However, this field error was easily discovered and corrected at the core shack by PolyMet geologists because they were able to back orient the core with certainty. Core from run-to run could be fitted together continuously over lengths exceeding 100’.

Golder staff collected copies of working geological sections at this time, on to which pit shells and borehole data was projected.

Tilt tests were performed on selected drill core to provide an estimate of base friction angles. Because drill core surfaces are smooth, they represent the lowest friction angle of a joint surface,

equivalent to a sawn surface, which is reality check on friction angles assigned to fracture sets in the kinematic assessment. The tilt test is an easy way of getting an approximation of these angles.

Summary details for the ten (10) East Pit Geotechnical boreholes follow on Table 3.2. Boreholes locations are shown on Figure 5. Geotechnical parameters are presented in Appendix A.

Table 3.2
Oriented Core Details

	Borehole ID	Collar		Length (ft)	#Fracts ¹	#Oriented Fracts ^{2,4}
		Az(°)	Incl.(°)			
1	05-463G	145.1	-45.2	248	151	92 (60.9%)
2	05-473G	325.4	-64.3	1059	738	613 (83.1%)
3	05-474G	146.7	-55.2	548	304	251 (82.6%)
4	05-479G	319.6	-63.4	668	371	290 (78.2%)
5	05-480G	150.8	-45	708	390	373 (95.6%)
6	05-483G	322	-64.4	1104	612	529 (86.4%)
7	05-484G	143	-45.7	308	451	385 (85.4%)
8	05-488G	139	-64.5	1238	603	550 (91.2%)
9	05-493G	325.8	-63.5	300	268	93 (34.7%)
10	05-494G	139.9	-45.1	299	289	232 (80.3%)

- four drilled into footwall (Northwest azimuths, 319.6° to 325.8°)
- six drilled into hanging wall (Southwest azimuths, 139° to 150.8°)

Notes:

1. Based on the sum of fractures per run counts. See Appendix A.
2. Based on the number of discontinuities with alpha and beta measurements.
3. The above excludes intervals of broken core, which were rare. See Appendix A for downhole locations of broken core intervals and/or intervals with “Too Many Fractures to Count”, which were assigned a nominal value of Fractures/ft=20.
4. The purpose of presenting the number of oriented fractures as a percentage of the total number of fractures intercepted in the drill core is to assess the success of the core orientation program.

3.2 Relevant Work Performed by Barr Engineering

Barr Engineering (Barr) carried out two phases of hydrogeological investigations in the open pit area on behalf of PolyMet. Drafts were provided to Golder.

The first phase involved hydraulic conductivity testing of Duluth Complex rocks in accessible exploration holes.

The second phase of testing focused on the Virginia Formation rocks in the northeast area of the property. The significant observations in these reports appear to be:

- Lower hydraulic conductivity (10^{-7} to 10^{-9} m/s) in Duluth Complex open holes; penetrating units 4 to 1 and the Virginia at depth (Barr phase 1 draft report, received in March 2006); and
- Higher hydraulic conductivity in the Virginia Formation (Phase 2 draft), ranging from 1 ft²/day to 600 ft²/day, roughly $K=10^{-6}$ to 10^{-9} m/s.

We understand that the significance of these findings with respect to inflows into the proposed open pits will be reported by Barr in subsequent documents.

Information on static water levels elevations were presented on Well and Boring Records appended to the Phase 2 draft by Barr. Levels were within 20' of ground surface in all cases.

We understand, based on informal discussions with PolyMet and Barr, that Barr appears to be concerned with potential for high inflows/ open pit seepage, from the Virginia Formation, either directly (where exposed) or through a veneer of Duluth Complex Unit 1 on the open pit footwall slopes. As a precaution, we elaborate on slope depressurization options should this concern be proved correct, in Section 6.7.

4.0 BEDROCK ENGINEERING GEOLOGY MODEL

The rocks that will form the open pit slopes at the NorthMet deposit are strong to extremely strong, with moderate to wide fracture spacing. Away from the influence of possible major structures, overall slope designs will be controlled by the inter-ramp bench configurations that can be achieved with controlled blasting.

4.1 General Stratigraphy

The Virginia Formation and Duluth Complex layers show inferred apparent dips to the southeast from 20° to 30° on cross-sections A through E, then steepening to inferred apparent dips from 35° to over 50° on sections F through G. The apparent steepening of the layers is possibly (probably)

due to footwall faulting. Cross-section locations are shown on Figure 7. Cross-sections A through H follow on Figures 9 to 16 respectively. Geology on the sections is based on working sheets provided by PolyMet.

The NorthMet PolyMetallic deposit primarily contains copper, nickel, platinum and palladium, gold, silver and cobalt. The majority of the sulfide mineralization is contained within Unit 1 and patchier mineralization within Unit 2 through 7. Thus, Units 1-2 and Units 3-7 are grouped within the report to roughly represent mineralized zones (ore) and waste within the Duluth respectively. Units 3-7 form the hanging wall, while the Virginia Formation forms the footwall.

4.2 Design Issues

Orientation of layering or foliation frequently controls wall stability and slope design in layered deposits. This potential was investigated as part of this study, with emphasis on footwall slope. The conclusion was that planar failures will locally occur, but given the wide spacing and rough surfaces of discontinuities in Unit 1, this potential failure mechanism will not control wall design.

The interpreted NorthMet Duluth Complex stratigraphy appears to be complicated by possible normal faulting / half-graben faulting that displaces the Virginia formation contact and result in apparent thickening, thinning or steepening of overlying Complex, Unit 1 in particular. Sub-vertical faults (Archean) striking perpendicular to the dip of the Complex are shown on regional geology maps.

Further, faults at NorthMet have not been clearly identified or interpreted based on the drilling program, and if they do occur, they do not clearly correlate with zones of gouge or low RQD. Some faults may have healed.

Given the above, significant changes to the slope design may occur during mining as the Complex and underlying Virginia are exposed and mapped. Design Criteria need to be flexible and readily adaptable to both subtle and dramatic changes in geological information.

4.3 Geomechanical Properties

All 16 geotechnical holes were logged for Recovery, RQD, and Fractures per Run. Recovery was very close to 100% and RQD is excellent, typically exceeding 95% in all rock units.

Contacts between the Units are generally healed. Increased fracturing is noted in the foliated ultramafic base of some of the intrusive units (change from 0-1 fractures per foot to 3-4).

In addition to geotechnical logging of the oriented core, 26 specimens were tested to determine Uniaxial Compressive Strength (UCS) and Young's Modulus (YM). The specimens were all

selected from a single borehole. Figure A1.1 in Appendix A presents the strength results graphically vs geotechnical parameters and lithology. The Queen's University report is presented in Appendix A.

The laboratory tests provided average values for UCS and YM. The geotechnical logging provided the remaining rock mass parameters necessary to characterize the rock mass. These included the RQD and the fracture frequency (FF). A summary of the characteristics of the geological units described above is provided in Table 4.1. In addition, Table 4.1 displays a summary grouping of Units 3-7 and Units 1-2. The significant determination is that the rock mass is good to excellent.

**TABLE 4.1
MEAN CHARACTERISTICS OF THE GEOLOGICAL UNITS**

Geological Unit	Mineralization Unit	UCS (MPa)	Young's Modulus (GPa)	RQD	FF (fractures/ft)	Fracture Spacing (ft)
Unit 7	Hanging Wall	90	55	95	0.6	1.7
Unit 6	Hanging Wall	107	80	97	0.6	1.7
Unit 5	Hanging Wall	101	80	95	0.7	1.4
Unit 4	Hanging Wall	120	67	89	2.1	0.5
Unit 3	Hanging Wall	119	87	97	0.8	1.2
Unit 2	Ore	102	88	91	0.9	1.1
Unit 1	Footwall and Ore	120	84	96	0.6	1.7
VF	Footwall	109	57	79	1.9	0.5
Unit 3-7	Hanging Wall	106	77	95	1.0	1.0
Unit 1-2	Footwall and Ore	118	84	92	0.75	1.3

The following additional information is provided in Appendix A:

- Geotechnical parameters correlated to geology on strip logs presented on Figures A1.1 to A1.16;
- Representative photographs of the various geotechnical units presented on Figures A2.1 to A2.2 in Appendix A and photographs of selected entire boreholes;
- Statistical summary of RQD distributions by rock type on Table A.1.

4.4 Major Structures

Minnesota Geologic Survey Map 119, "Geology of the Duluth Complex..." (see Figures 3 and 8) as well as the four 7.5 minute geologic quadrangle maps for the Babbitt 15 minute quadrangle (which are not included in this report), all contain substantial contribution from Mark Severson of the Natural Resources Research Institute of the University of Minnesota, Duluth. Mr. Severson has mapped and studied drill core for this area since 1988, including confidential studies for PolyMet in 1995 and 2000.

Faulting as shown on these maps is essentially from this previous work. These faults fall into two groups: those based on surface mapping and drill collar geology, where outcrops thought to be of one particular unit are juxtaposed near to other units in geometries that require offset, notwithstanding that these units can be impossible to tell apart out of context; and footwall faults based on the assumption of constant (~20°) bedding dips in the Biwabik Iron Formation, with the faults possibly dying out in the Complex (faults would be pre-intrusion or contemporaneous to intrusion, but not post-intrusion) therefore requiring a half-graben geometry of normal faulting to reconcile these dips.

Earlier PolyMet geologists merged these faults into a set where all were shown as vertical starting in the footwall and continuing to the surface. Drilling in 2005 did not intersect definitive faults in these previously mapped fault locations.

While apparent fault zones do occur in drill holes, no definitive offsets have been verified by drilling and correlation is poor. Resource geological modelling currently shows no faults, as interpretation on whether surfaces are shown as faulted or warped / folded would not have been significant to the final resource estimate.

Expected faults would be deposit parallel normal faults dipping to the southeast. Some transform faults are also possible. Severson shows one or more NNE-SSW scissors faults originating in the Peter Mitchell iron mine which may or may not cross into the NorthMet deposit.

For a number of reasons, recognition of faulting is problematic in the deposit:

- a) about 65% of the exploration drill holes are vertical and therefore might miss the expected half-graben normal faults;
- b) the rocks can be non-descript over very long intervals;
- c) top of iron-formation, top of Virginia Formation, top of Unit 1 (usually), and top and bottom of Unit 3 are the only reliable large scale marker horizons, ultramafic horizons are usable as markers, but must be supported with some other evidence. Of all these, only the top of iron-formation and top of Unit 3 are not subject to interpretation out of context;

- d) d) if there is offset it may be accommodated in the serpentized ultramafic zones, but there is not good enough control on the continuity of specific ultramafic horizons (except those at bases of units) to always use them as markers;
- e) the lack of specific markers and the generally wide (200-300 feet) drill hole spacing helps prevent developing these correlations below the unit level;
- f) cross-sections drawn with and without faults can both work and be made consistent with the dips seen in bedding of the iron-formation;
- g) the lack of surface exposure means that there are few faults mapped at the surface that can be checked against drill data;
- h) the geophysical response of any of these faults is not distinct enough to use for mapping at less than 1:24,000 scale within the available geophysical data set (J. Miller, pers. comm. 2003).

Given these uncertainties, discussion of how to manage the risk of exposing potentially adverse fault or fault-fault wedge combinations on pit walls is provided in Sections 6.3 and 6.4.

With respect to kinematic stability assessments, discontinuity populations (from oriented core) that strike parallel the NE-SW strike of the complex, (possibly paralleling normal faulting) or populations that strike perpendicular to this trend (possibly re-activated Archean Faulting) were considered potentially continuous and given more weight during the development of slope configurations.

4.5 Structural Fabric

Lower Hemisphere, equal area projections of discontinuity populations from oriented core were obtained from current study boreholes and are presented in Appendix B. Borehole data were reviewed, and data grouped into sectors based on rock type, proximity and complimentary azimuths with purpose to reduce drillhole bias. These groupings indicate similar but not identical discontinuity fabric trends in the West Pit and East Pit. In general, the stereonet suggests that the East Pit structural fabric is kinematically less favourable than that of the West Pit. For purposes of this assessment it is assumed that these differences are due to local variations in fabric.

As the footwall will be excavated almost entirely in Unit 1 of the Duluth Complex, stereonet were also prepared for that unit alone. Similarly, stereonet were prepared that intercepted only hanging wall rocks, Units 3 to 7.

Over 90% of all structural features intercepted in the core were oriented and described (Ezy-Mark tool), which is evidence in itself to the quality of the core. Joint surfaces are moderately to widely spaced, and approximately 50% of all the oriented structures have dips of less than 35°. Discontinuities with dips less than 35° do not appear to have strong peak orientations. Rather, there is a wide degree of scatter, and mean dips on the order of 0-15 degrees. See Appendix B. .

Comparison between joint sets with dips greater than 35° using both East Pit and West Pit data and the Minnesota Geological Survey inferred faults are shown on Figure 8. The significant conclusion is that there is good agreement on trends, and that faults daylighting on the pit walls would be steeply dipping into the wall.

4.6 Discontinuity Shear Strength

Joint surfaces are most likely to be rough and planar, but chlorite altered and coated surfaces do occur, prevalent on flat sets (dip <35°) but also randomly on steeper sets. Only 10% of joints have a Joint Alteration index of $J_a \geq 4$. Joint Alteration is a qualitative measure of the physical character of the infilling on joint (discontinuity) surface. On joint surfaces with a $J_a \geq 4$, the shear strength tends to be controlled by the thickness of the infilling and bench scale roughness, rather than core-scale roughness (J_r). PolyMet geologists collected qualitative descriptions of all discontinuity surfaces noted in the geotechnically logged and core oriented drillcore. Stereographic projections of Joint Alteration data are presented in Appendix B.

Base Friction angles for the Duluth rocks ranges from 28° to 32° based on tilt testing of drill core. Allowing for typical roughness and surface alteration as described above, a nominal friction angle of $\phi = 35^\circ$ and cohesion of zero was considered conservative and appropriate for purpose of kinematic assessment. Following this, it was considered that structural populations steeper than 35°, acting as plane or wedge failures, would be most critical to design. Stereonets showing distribution of J_a values (joint alteration) by pit area are presented in Appendix B.

As a check, joint shear strengths were estimated using the Barton et al. (1974) Quotient method using J_r and J_a values (both Barton Q-System parameters). A range of Joint Roughness values (J_r) and Joint Alteration values (J_a) were used, as shown in Table 4.2. The Quotient method indicates potential peak friction angles ranging, in general, from 26° to 50°, depending on the combination of roughness and alteration used.

TABLE 4.2
ESTIMATION OF SHEAR STRENGTH ON TYPICAL
DISCONTINUITIES

Description	Jr Roughness Parameter	Ja Joint Alteration	Shear Strength
			$\phi = \tan^{-1}(J_r/J_a)$ (degrees)
Shear zones or Chlorite Altered Basal Layers- closely spaced joints with smooth chlorite altered surfaces. Sometimes a veneer of soft chlorite clay.	1 to 2	2 to 4	26

Description	Jr Roughness Parameter	Ja Joint Alteration	Shear Strength
			$\phi = \tan^{-1}(Jr/Ja)$ (degrees)
Joints within Slightly Weathered and Fresh Bedrock	1.5 to 3	1 to 2	37 to 50 ¹

¹ limited to a maximum of 50°.

For reference, the Barton Q-System parameters are presented on Table 4.3 below.

**Table 4.3 – Q System Discontinuity Parameters, Descriptions, and Assigned Values
(after Barton et al. 1974)**

Parameter	Item and Description	Value
Fracture Roughness (Jr)	Rough and wavy	3.0
	Smooth and wavy	2.0
	Rough and planar	1.5
	Smooth and planar, or filled	1.0
	Slickensided and planar	0.5
Fracture Alteration(Ja)	Unfilled Fractures:	
	Healed fractures	0.75
	Staining only, no alteration	1.0
	Slightly altered fracture walls	2.0
	Silty or sandy coatings	3.0
	Clay coatings	4.0
	Filled Fractures:	
	Sand or crushed rock filling	4.0
	Stiff clay filling less than 5 mm thick	6.0
	Soft clay filling less than 5 mm thick	8.0
	Swelling clay filling less than 5 mm thick	12.0
	Stiff clay filling more than 5 mm thick	10.0
	Soft clay filling more than 5 mm thick	15.0
Swelling clay filling more than 5 mm thick	20.0	

5.0 KINEMATICS AND SLOPE DESIGN RECOMMENDATIONS

The following section presents our design assumptions and summarizes the kinematic assessment and slope design recommendations for Ultimate Open Pit slopes in rock, presented by wall dip direction for each of the design sectors. Recommended bench configurations are presented on Figures 17 and 18 and in Tables 5.1 and 5.2.

The strong and competent Duluth Complex and Virginia Formation rocks will be susceptible to kinematically controlled failure. The following text presents design information for these zones by wall orientation.

5.1 Structurally Controlled Failure Mechanisms

Structurally controlled failure in rock occurs as the result of sliding along pre-existing geological discontinuities. The three basic mechanisms of structurally controlled failures in rock slopes are plane failures, wedge failures, and toppling failures, as described below.

A plane failure may occur when a geologic discontinuity dips out of a rock slope at an angle that is shallower (from horizontal) than the inclination of the slope and steeper than the effective angle of friction on the discontinuity. Plane failures will generally only develop to a significant extent if the strike of the geologic discontinuity is within $\pm 20^\circ$ of the azimuth of the rock slope.

Wedge failures may occur when two or more geological discontinuities intersect to form an unstable wedge. In order for a wedge to fail, the line of intersection of the wedge must dip out of the slope at an inclination that is shallower than the inclination of the slope, but steeper than the effective angle of friction along the discontinuities. Wedge failures will only develop to a significant extent if the azimuth of the line of intersection is within $\pm 45^\circ$ of the dip direction of the slope face.

Toppling failures may develop when a rock mass contains multiple, parallel, steeply dipping continuous geologic structures, such as bedding or foliation planes, that strike nearly parallel to the strike of the face of the rock slope. Toppling failure will generally only develop when the strike of the structures is within $\pm 20^\circ$ of the azimuth of the slope face. Within the proposed NorthMet deposit, the spacing on potential toppling sets appears to be too wide for this to be a viable failure mechanism except in localized areas where it could affect bench faces as localized raveling.

The magnitude and frequency of structurally controlled failures are directly related to the continuity and spacing of the structures along which sliding can occur; they are also adversely affected by water pressures within the slope. Rock mass structures that exhibit limited continuity may result in small bench scale failures that are rarely of consequence to overall slope stability

but may adversely affect access ramps or equipment installations. Conversely, larger scale failures can occur along continuous, through-going structures, such as major faults. It is, therefore, these more continuous structures that are of primary concern.

5.2 Results of the Kinematic Assessment

The structural rock mass fabrics for the Footwalls in Unit 1 and the Hanging walls in Units 7-2, are presented graphically on stereonet in Appendix C by open pit. These stereonet contain the major and minor discontinuity sets for each of the main rock geotechnical units and design sectors considered in the kinematic analysis.

Assessment of the potential for wedge failure was carried out deterministically using the discontinuity sets presented in Appendix C, and summarized in a general way on Figure 8.

For the current kinematic analyses, the shear strength along the fault and joint sets was assumed to be represented by a friction angle, $\phi = 35^\circ$ and no cohesion, i.e., $c = 0$ MPa, based on the tilt testing and empirical assessment of shear strength along the discontinuities and on the results of direct shear test along six discontinuities. It must be recognized that for faults and shear zones, the friction angle may be lower than 35° . Therefore, it is important to properly locate the known faults and shear zones on the geological model when designing the pit shell, particularly for the location of the access ramps.

Potential planes and potential (two plane) wedges with Factor of Safety less than 1.2 (limit equilibrium analysis) under dry conditions were considered most critical to design, with emphasis on features that involved discontinuity sets that were considered potentially continuous,

5.3 Slope Design Definitions

A pit slope has three major components: bench configuration, inter-ramp slope and overall slope, as illustrated on Figures 17 and 18. The bench configuration is defined by vertical bench separation (or bench height), catch bench width (or berm width) and bench face angle (or batter). The inter-ramp slope is formed by a series of uninterrupted benches and the overall slope is formed by a series of inter-ramp slopes separated by haul roads.

It is normal practice to establish catch benches on a pit slope to retain loose material that may fall from either the immediate bench face above or from the upper part of the slope. Where conditions are suitable, it is also common practice to place catch-benches (berms) at vertical intervals of two (or occasionally more) bench heights, creating a multi-bench slope configuration.

The *inter-ramp angle* (IRA) corresponds to the angle subtended by a line joining the toes of the benches on the wall and the horizontal. The *overall slope angle* corresponds to angle formed by

the line joining the toe of the lowest bench with the pit crest and the horizontal. Therefore, the incorporation of ramps onto a wall will result in a slope that has a shallower overall slope angle than the inter-ramp angle.

5.4 Bench Configuration Assumptions

The recommended slope design configurations are based on the following design assumptions:

- Operating bench heights will be 15 m (49.2 ft). It will be possible to use a multiple-bench configuration on most final pit walls, and maximum vertical separation between catch-benches will be 30 m (96.4 ft) (double benching).
- Design bench face angles in good quality rock should be limited to a maximum of 70°. Where there is a likelihood of undercutting adversely oriented joints of limited continuity, i.e. joint sets with no associated faults, the bench face angle are restricted to a maximum of 65°.
- The minimum catch-berm width will be 8 m (26.2 ft) to limit rockfall hazard during operations. It shall be increased to 10m to control potential raveling and localized failures involving structures or to achieve the recommended the design inter-ramp angle. Berms of these widths should permit access for a dozer or loader to periodically clean the berm, and for scaling the face below, if required. Discussion of rationales for the berm widths are provided in Section 5.4.1.
- Given that potential toppling is not considered a likely failure mechanism, mid slope mini-bench (6 m, 19.7 ft.) are not required to control potential toppling instability by reducing potential column heights.
- The maximum stack height (inter-ramp slope height) shall be 120m. On walls in excess of 120m a wider, safety bench of width 12m (also referred to as a geotechnical safety catch bench) should be incorporated into the design. This is to provide additional catchment to control and limit rockfall hazard. Discussion of the rationale for the selection of geotechnical safety berm are provided in Section 5.4.2.

The recommended maximum bench face angle of 70° is probably somewhat conservative in zones without rock strength or structural controls. This may be particularly true where good, controlled blasting techniques are applied to the excavation of the bench faces. Many of the bench face orientations will be controlled by the near vertical fault/joint sets, (such as the East Pit West Wall) thereby permitting steeper face angles.

5.4.1 Catch Berm Width Discussion

The purpose of the catch berms are to allow for safe operations by providing catchment control for raveling, localized instabilities and rockfall. The most recent discussion of bench width and bench geometry considerations reviewed as part of this study were presented in the 2006 paper by Gibson, et al, "Considerations in the Optimisation of Bench Face Angle and Berm Width

Geometries For Open Pit Mines”, *The South African Institute of Mining and Metallurgy International Symposium on Stability of Rock Slopes in Open Pit Mining and Civil Engineering*, pages 557 to 578.

For the Northmet deposit case, the following assumptions were made:

- Generally good rock mass and low fracture frequency;
- Good blasting practices.

These assumptions will be verified by evaluation of the performance of initial slopes. The minimum catch berm width of 8m was selected based on experience primarily in British Columbia, where this width is a legislated minimum. Berms of smaller width are generally too difficult to clear of accumulated ravel and debris, a condition often exacerbated by loss of width due to break-back at the bench crest.

The 10m berm was selected to achieve recommended inter-ramp angles. Review of Table 1 on Gibson et al, indicates that this berm width are slightly less than the bench width range that determined using hypothetical structural fabric set intended to simulate conditions less favourable than those expected at Polymet. We therefore consider the 10m berm width appropriate at this time.

5.4.2 Maximum Inter-ramp or Bench Stack Height Discussion

On slopes that are not transected by a ramp, we recommend that a wider berm (known as a geotechnical berm or safety berm) of width 12m to 15m wide instead of the nominal 8m to 10m be incorporated on ultimate slopes at maximum separation of four double benches, (vertical separation of 120m). The purpose of this berm is to break the slope and provide additional catchment to limit the potential for rockfall hazard during operations.

5.5 Ultimate Rock Slopes by Design Sector

Bench geometries were developed assuming adequate dewatering of the rock slopes will have been achieved. Should observations on initial benches indicate that enhanced depressurization is required to control kinematically controlled instabilities, remedial measures such as horizontal drains should be applied.

TABLE 5.1
West Pit Ultimate Slope Design Recommendations

Material	Sector and Wall Dip Directions	Maximum Vertical Bench Separation (m)	Bench Face Angle °	Berm Width (m)	Inter-ramp Angle (°)
Unit 1 on Footwall,	Sector I Footwall 090° to 160°	30m	65 ¹	10	51.4
Unit 1 and overlying units on other walls	Sector II East Wall 170° to 260°	30m	65	10	51.4^{2,3} (53.8)
	Sector IIIa Hangingwall 260° to 020°	30m	65	10	51.4² (53.8)
	IIIb West Wall / Footwall 020° to 090°	30m	70	10	55.1

- Note: On the Footwall, the Bench Face Angle is limited to 65 ° to control steep potential wedges. Flat sets (dip less than 35°) dipping out of the wall are also prevalent. While estimated friction angle on the joints of these sets is on the order of $\phi = 35^\circ$ based on Jr and Ja logging, localized failures involving these features may still occur, in particular if adequate slope depressurization is not achieved and/or if joint surfaces are significantly altered.
- On West Pit Sectors II and IIIa, there is upside potential for slope steepening, if lack of adverse structure can be verified, by reducing the berm width to 8m or increasing the Bench Face Angle to 70 °, provided that experience with initial slopes, confirmed by mapping, indicates that adverse wedges and planes with dips in the 47 ° to 51 ° range are not problematic. Reducing the berm width from 10m to 8m, with BFA=65° would provide IRA=53.8 °.
- The East Wall of the proposed West Pit is significant enough in length and height for consideration of further drilling investigation at the detailed design stage. Drilling of a geotechnical borehole (oriented core) with NE azimuth would be the best way of justifying steeper slopes in advance of experience with initial benches. Geotechnical boreholes from the present study have azimuths parallel to the strike of this proposed wall.

TABLE 5.2
East Pit Ultimate Slope Design Recommendations

Material	Sector and Wall Dip Directions	Maximum Vertical Bench Separation (m)	Bench Face Angle °	Berm Width (m)	Inter-ramp Angle (°)
Unit 1 and Virginia on Football and East Wall,	Sector I Footwall 200° to 115°	30m	65	10	51.4¹ (47)
Unit 1 and overlying units on other walls	Sectors II , III and IV East ² , South (Hangingwall ³) and West Walls 115° to 200°	30m	65	10	51.4

1. Notes: The East Pit Footwall Design of IRA=51° is considered aggressive because of kinematically possible wedges (plunges 47° to 51°) and also because of kinematically possible plane failures (dip 43° to 59°).

This more adverse fabric arrangement appears to be related to steeper apparent dips of the Virginia and overlying Duluth Complex Units. If these features are problematic on initial benches then the IRA should be reduced to 47° by decreasing the Bench Face Angle to 60°. Adequate dewatering is essential.

Concerns are mitigated by the presence of ramps and step outs on the footwall, which will help to control any localized instabilities.

2. Slope design on the East wall is controlled by the potential for steep wedges (plunge 60 to 66°) and 41° involving assumed potentially continuous structures. This interpretation is conservative. There is upside potential to steepen the East Pit East Wall from 51° to 53° by reducing the berm width from 10m to 8m, provided experience with initial benches confirms that the initial assumptions are conservative. Similarly, bench face angles could be steepened based on operational experience and good blasting.

As an alternative, an oriented core hole with NE azimuth directed into the east wall could be considered at the detail design stage of the project. See also Note 3 of the West Pit recommendations, above.

3. Oriented core drillholes in the East Pit Hanging Wall area consistently indicate the presence of a NW dipping set (dip 38° to 40°) that could be result in plane failures. This is interpreted to be a joint set roughly orthogonal to the apparent dip of the Duluth Complex layering. It does not appear to occur in the West Pit data. Kinematically possible wedges ranging from plunge 46° to 66° are indicated from stereographic projections. Both the planes and wedges are considered discontinuous features. While the recommended bench configuration (IRA = 51.4°) is intended to control most of these features, localized instabilities may still occur.

6.0 OPERATING CONSIDERATIONS

6.1 Blasting

There is potential for steeper slopes than those recommended in this report. Rocks are generally strong. Some joint sets conservatively considered to control slope design may not be problematic. The stability of slopes in the all rock types in the NorthMet Pits will be significantly affected by blasting induced damage. Therefore, it is strongly recommended that controlled blasting procedures be adopted as part of the phase and ultimate pit excavation procedures. Buffer and trim blasting to a free face, could be adopted. However, given the overall good quality of the Duluth Complex rocks, pre-split blasting may result in optimum configurations where there is structural control of the bench faces from steeply-dipping fault/joint sets.

It is recommended that controlled blasting design studies be undertaken as part of the detailed pit design program. These will assist in the selection of appropriate drills and explosive selection. The optimum controlled blast designs will be developed empirically during initial mining phases in each of the major wall orientations.

It is our experience that without controlled blasting, ultimate walls will be from 4 ° to 7 ° less steep than those achievable with controlled blasting.

6.2 Excavation Control and Scaling

Careful scaling of the walls will be required in those sectors where sliding on shallow dipping discontinuous joints are expected to at least partially control bench face angles, namely footwall slopes. Any loose blocks should be removed in a controlled manner by using shovels to scale the bench faces on the ultimate cut walls. This procedure will minimize future raveling, particularly where the faces are excavated during the freezing period, thereby reducing future scaling/cleanup requirements.

6.3 Monitoring Program

A monitoring program should form an integral part of any eventual pit engineering program. In particular, this program should be targeted at confirming the structural and geologic models used to establish the design criteria outlined in this report, and at detecting unexpected conditions in sufficient time that remedial measures can be adopted.

The program recommended in the following paragraphs is intended to be conducted largely by the mine geological staff, although routine review by an experienced rock slope design engineer is recommended. This program should include both pit mapping to confirm the engineering geology model upon which the designs are based, as well as monitoring to detect any movement

in the slopes. The elements of such a program, which should be largely undertaken by mine staff, are outlined below.

6.4 Adjustments to Design Criteria based on Geological Uncertainty

The interpreted NorthMet Duluth Complex stratigraphy appears to be complicated by possible normal faulting / half-graben faulting that displace the Virginia formation contact that result in apparent thickening, thinning or steepening of overlying Complex, Unit 1 in particular. Sub-vertical faults (possible re-activated Archean faults) striking perpendicular to the dip of the Complex are shown on regional geology maps.

Further, faults at NorthMet have not been clearly identified or interpreted based on the drilling program, and if they do occur, they do not clearly correlate with zones of gouge or low RQD. Some faults may have healed.

Given the above, significant changes in interpretation may occur during mining as the Complex and underlying Virginia are exposed and mapped. Design Criteria need to be flexible and readily adaptable to both subtle and dramatic changes in geological information.

6.5 Geological Mapping

Routine geotechnical observations will be an important part of slope management since it will be necessary to verify existing interpretations of structural conditions in the rock mass and their controls on slope stability. In particular, it will be important to identify the location and extent of any major continuous structures, such as faults or major joints, so that their influence on slope stability can be assessed and slope designs can be modified locally if required.

Generally, the effect of faults is most significant when they have intermediate dip values and strike sub-parallel to the slope face. However steeply dipping faults can also interact with other structure to cause complex mass movements. Currently the exact locations and characteristics of all the identified faults are tentative. It appears that the attitude of footwall parallel faults may potentially have the largest effect on slope behaviour, but all faults and lineations should be investigated during ongoing geotechnical work.

6.6 Slope Stability Monitoring

A major part of the slope stability monitoring program will be the regular inspection of the bench faces and the crest areas for early evidence of slope instability. These regular inspections should be conducted ideally by the same individual in order to maintain continuity of the observations. The monitoring observations should be recorded in a diary so that a record of stability performance can be maintained for each stage of pit development.

Should zones of potential failures be identified, survey monitoring should be conducted to provide advanced warning of unexpected movement on high slopes in addition to the visual monitoring. The monitoring frequency will depend upon the stability of the slopes, the time of year, the rate of mining, and the nature of the mining activities that are being conducted in the open pit. The slope monitoring prisms should be surveyed monthly during the summer and winter months, provided that the results of the visual monitoring indicates that the slopes are stable. The monitoring frequency should be increased to weekly surveys during the spring thaw period. Intensive slope monitoring should only be required when mining operations are being conducted in the vicinity of unstable portions of the open pit slopes.

6.7 Slope Depressurization

Given the prevalence of low-angle discontinuities (dips 35 degrees or less) with potential to have low shear strength due to infilling, planar slope failures involving these structures and sub-vertical release features are a possible concern, particularly if adequate slope depressurization is not achieved. We speculate that these low angle features may be due to either stress-release and/or to be associated with an incipient layering within the Complex that occurred as the mafic crystals settled during cooling of the intrusions. Typically, pit slope faces depressurize adequately without need for remedial measures.

Consideration should be given to a program of exploratory pit perimeter piezometers and horizontal drain installations on all final walls as the pit develops, to verify that the slopes are adequately draining. We understand that Barr has concerns on the potential for the Virginia Formation rocks to be a significant source of seepage. The Virginia may provide the footwall slopes with pore water pressure within the fractures of sufficient degree to allow for slope failures along low-angle (less than 35°) planes with altered joint surfaces, such as on the footwall. Piezometers would verify the presence of high pressures in the fractured rock mass, justifying the installation of drain installation and allow for monitoring of their effectiveness.

Small diameter exploratory horizontal drains (1" to 2") could be excavated initially to document flows in select areas. Spacing would be field determined. Larger diameter horizontal drains would be required if significant water is intercepted on a wall or if there is concern for long term integrity of the drains. Insertion of pvc tubing should be considered.

7.0 CLOSURE

This report presents Golder's engineering geology interpretation, assumptions and slope design recommendations for the NorthMet project.

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