Report

NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

Project I.D.: 12P778

Poly Met Mining, Inc.
St. Paul, Minnesota

August 2014

NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

Project ID: 12P778

Prepared for

Poly Met Mining, Inc.

444 Cedar Street, Suite 2060
St. Paul, MN 55101

Prepared by

Foth Infrastructure & Environment, LLC

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2121 Innovation Court, Ste. 300 • PO Box 5126 • De Pere, WI 54115-5126 • (920) 497-2500 • Fax: (920) 497-8516 • www.foth.com

NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation

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List of Abbreviations, Acronyms, and Symbols

cm/s	centimeters per second
EIS	Environmental Impact Statement
gpm	gallons per minute
MDNR	Minnesota Department of Natural Resources
PolyMet	Poly Met Mining, Inc.
the Project	NorthMet Project
RQD	Rock Quality Designations

1 Problem Statement

The Poly Met Mining, Inc. (PolyMet) NorthMet Project (the Project) will involve construction of an open pit mine approximately 3 miles long, 0.5 miles wide and 700 feet deep. The pit will be excavated through up to 60 feet of unconsolidated, variably saturated glacial till underlain by variably-fractured rocks including the igneous Duluth Complex and the sedimentary/ metamorphic Virginia Formation. A plan view and cross section of the proposed open pit are shown in Figures 1 and 2.

Both the Virginia Formation and the Duluth Complex rocks that will be intersected during pit excavation are generally highly indurated and competent, exhibiting Rock Quality Designations (RQD) in excess of 95% in most intervals (Golder, 2006). Fractures are present throughout the full extent of the proposed pit depth. Some drill holes have shown slightly greater fracture prevalence in the uppermost several meters of both the Virginia Formation and the Duluth Complex. Fracture frequencies are typically less than one per foot, with broken intervals that may correspond to fault locations showing frequencies of 20 fractures per foot or greater (Golder, 2006).

Analysis of the groundwater hydrology of the Mine Site was performed as part of the Environmental Impact Statement (EIS) (MDNR et al., 2013). This analysis included a quantitative characterization of bedrock hydrogeology and included pumping tests, water-level measurements, and numerical modeling of groundwater flow under both current conditions and proposed conditions in which the pit is excavated and operating as a groundwater sink. Using field-measured hydraulic conductivity values and water levels to calibrate the model, subsequent simulations indicated moderate groundwater inflow to the pits from surrounding bedrock (MDNR et al., 2013). Given the minimally fractured nature of the majority of bedrock at the Mine Site modest pit inflow rates are the generally expected condition. High rates of pit inflow from bedrock, if they occur, are expected to be limited to localized areas where open fractures or broken/fault zones intersect pit walls. Due to the sparse and discontinuous nature of open fractures and broken or fault zones, predicting if and where these features might intersect pit walls is not possible over the majority of the pit shell.

To estimate the impact of pit inflow on surrounding surface water resources, particularly wetlands, an evaluation of groundwater data from existing open pit operations on the Mesabi Iron Range was performed (MDNR et al., 2013). A review of groundwater elevation data gathered adjacent to the Canisteo and Minntac pits showed minimal correlation between pit lake levels and groundwater in surrounding rock and till deposits. Using the Canisteo and Minntac results as the basis for a conservative analog modeling methodology, MDNR et al. (2013) estimated some potential for measurable drawdown in surficial groundwater within 1,000 feet of the pit perimeter. Between 1,000 and 1,700 feet from the pit, some drawdown is expected but the magnitude is expected to be indistinguishable from natural variations. Outside 1,700 feet, drawdown resulting from pit inflow is expected only under isolated conditions such as the case of a continuous fault extending laterally from the pit wall to a point beyond the 1,700-foot perimeter and simultaneously extending vertically to the base of the surficial aquifer underlying a wetland.

Using the observations and groundwater data gathered from other open pit mines on the Mesabi Iron Range, 866.9 acres of wetlands are estimated as having high likelihood of potential indirect hydrologic impact resulting from drawdown caused by pit inflow (MDNR et al., 2013).

Additionally, the model of groundwater flow was used to evaluate water flow between the pit and the groundwater system following cessation of operations when the pits will refill via groundwater inflow and precipitation capture. This analysis indicated groundwater will flow into the pits along the northern pit perimeter and pit water will flow into the groundwater system along the southern pit perimeter. Outflow from the pit along its southern perimeter may contribute to constituent migration in groundwater following closure.

Based on the preceding summary of pit and bedrock groundwater analysis performed in support of the EIS, the following potential Project impacts are identified:

1. Groundwater inflow from bedrock could be several hundred gpm or higher. Costs will be imposed on the Project to pump, remove, and treat pit water that are directly proportional to the rate of pit inflow.

2. Additional costs may be imposed on the Project to control pit inflow water to protect haul roads and other pit infrastructure, to maintain work areas, and to ensure slope stability.

3. Locally high discharge from productive fractures or fault zones could damage or potentially damage haul roads and pit slopes.

4. Rates of pit groundwater inflow have been estimated for each year of planned operations. Indirect impacts to wetlands within 1,000 feet of the pit may occur as a result of groundwater inflow to the pits. Using the analog model developed from impact data at other vicinity mine sites, the estimated wetlands acreage that might experience indirect impacts resulting from pit inflow is 867 acres. Mitigation, including reconstruction or wetlands banking, could be necessary should such impacts materialize. Pit inflow rates that substantially exceed initial estimates could heighten the potential for indirect wetlands impacts resulting from pit inflow and groundwater drawdown.

5. If open faults or fractured/broken zones create conditions of abundant pit inflow, such features would also contribute to increased outflow from the pit to the bedrock groundwater system during and after pit refilling. Larger outflow rates would translate to larger constituent migration rates from pit water into groundwater.

Items 3, 4, and 5 in the preceding list represent pit inflow/outflow impacts that might exceed those developed in the analysis upon which Project permits are based and could require corrective action or mitigation, should such impacts occur. An attractive mitigation strategy for controlling bedrock groundwater flow to and from the pits is the use of injection grouting to partially seal or close productive fractures, faults, and/or broken zones. Grout curtains are widely used for groundwater control in both unconsolidated deposits and fractured and porous rock. Grout curtains differ from grout or slurry walls in that the latter consists of an excavated trench filled with low-permeability grout, often mixed with native soil or earthen material.

Alternatively, a grout curtain is constructed by drilling a series of purposely spaced and oriented bedrock drill holes and injecting grout designed for site-specific conditions into surrounding rock to fill pore spaces, fractures, and broken or fault zones.

Construction of a grout curtain enclosing the entire pit shell as a preventative measure is not expected to be warranted, given the minimally-fractured nature of the majority of rock surrounding the proposed pit. Accordingly, use of grout curtain(s) at the Mine Site as a mitigation measure will be undertaken in localized reaches and at specific, targeted depths to mitigate problematic pit inflow resulting from localized fractures, fractured zones, and/or fault zones. Problematic pit inflow is defined as that which gives rise or may give rise to impacts identified in items 3 or 4 above.

2 Determination of When and Where Pit Inflow Mitigation is Required

Construction of grout curtains to control groundwater flow is a mature technology and is common in projects such as excavation dewatering, embankment seepage control, dam underflow mitigation, and dam foundation stabilization. In many such projects, grout curtains are constructed prior to the commencement of excavation, dewatering, or structure construction. Such practice simplifies the construction of a grout curtain because hydraulic gradients remain at natural or ambient levels. Ambient or small hydraulic gradients translate to small groundwater flow rates which simplify grout injection and cause less washout of grout during the injection process. Large hydraulic gradients occurring after or during construction require thicker grouts to prevent washout. Thicker grouts possess higher viscosity which reduces the mobility of grouts and the extent of coverage associated with any one grout hole.

Grout curtains have also been installed as remediation or mitigation measures to control groundwater flow after construction has accentuated hydraulic gradients and groundwater flow rates. Examples of such practice include grout curtains constructed in dam foundations and impoundment embankments experiencing stability problems due to excessive groundwater flow or seepage rates.

As noted previously, construction of a grout curtain prior to pit excavation is impractical because the length and depth required to completely encircle the pit would entail prohibitive cost. Additionally, construction of localized curtain segments prior to pit excavation is not practical because identifying the portions of the pit perimeter where pit inflow mitigation might be required is precluded by the inability to predict the location of such zones due to the lack of continuity exhibited by open fractures and fault zones.

Accordingly, bedrock groundwater flow mitigation will be considered during pit excavation and refilling if either of the following conditions is observed:

- Pit inflow occurs from localized features such as fractures, fracture zones, or faults, at sufficient rate to present a hazard such as pit slope instability or a management challenge relative to pit infrastructure such as haul road maintenance.

- Substantive hydrologic impacts are observed at distances exceeding 1,000 feet from the pit perimeter. Substantive hydrologic impacts are declines in water levels in excess of natural fluctuations and lasting greater than six months, or changes in wetlands hydrology that cause a change in wetlands vegetation of sufficient magnitude to change the wetlands' function and classification.

3 Field Investigation to Define Problem Extent and Design Mitigation

If or when one of the prior "mitigation triggers" is observed, the first response will be to review the problem and evaluate whether or not mitigation of pit groundwater inflow/outflow is warranted and feasible. The key element that will determine whether consideration of grouting is warranted is the presence of problematic flow that occurs, at least in part, in localized areas and from identifiable or discrete features or zones. As noted previously, grout curtain mitigation of pit inflow is not envisioned for controlling diffuse pit inflow that is distributed over expansive portions of the pit shell.

When a review of a potential pit groundwater inflow/outflow problem determines that grout curtain mitigation merits consideration, the following sequence of evaluations and analysis will be initiated:

1. Identify, analyze, and survey the zone(s) and feature(s) present in the pit wall that are contributing to excessive inflow. This step will include a careful geologic inspection of the features displayed in the pit wall.

2. Review existing geologic data (inferred fault maps, drill hole logs, loss of circulation occurrences during exploratory and geotechnical drilling, geophysical logs, core photographs, and archived core), in conjunction with the results from step 1, to define the orientation, location, and extent of structures contributing to the problematic inflow.

3. Using the results of steps 1 and 2, determine if conditions appear favorable to grout curtain mitigation of pit inflow/outflow. If conditions are favorable, proceed with the design of a drilling program to refine the location and orientation of the structures and gather structure data (extent, permeability, and aperture) required for design of a grout curtain. If conditions identified by this drilling program appear unfavorable for grout curtain mitigation of pit inflow, evaluate alternative management strategies.

The occurrence of problematic inflow does not mandate the commencement of drilling and grouting; rather, the occurrence of problematic pit inflow will result in an evaluation of the merits of a grouting program or other possible management responses. If, during the course of this preliminary evaluation, an alternative mitigation measure is identified or circumstances are identified that indicate grouting would be ineffective or unnecessary, further pursuit of grout curtain mitigation for the particular location will be suspended and alternative management strategies will be considered.

Step 1 following the identification of a pit groundwater management problem will involve geologic inspection and surveying of fractures and faults by a professional geologist and surveyor to determine a preliminary estimate of the feature orientation and to locate them in three-dimensional space for plotting and analysis relative to existing geologic data.

Step 2 will entail the spatial analysis and plotting of structure data for fractures and faults that can be identified in lithologic logs, circulation logs, core, geophysical logs and core photographs from existing drill holes located adjacent to the pit shell in the vicinity of the features contributing to excessive pit inflow. Steps 1 and 2 will combine to provide an improved projection of the location, orientation, and continuity/extent of the producing fractures/faults. Determining orientation will be a primary goal of steps 1 and 2 because orientation will be the primary determinant in designing investigation drilling that successfully intersects the producing features.

Once the expected location and orientation of producing features have been projected from the pit shell into the adjacent unexcavated rock mass, a series of investigative, angled drill holes will be advanced to intersect the producing fractures and/or fault(s). This work constitutes step 3 of the field investigation. Step 3 entails a limited drilling and field testing program designed to confirm the distribution of producing features beyond the pit shell and quantify their hydraulic properties (aperture and hydraulic conductivity). A summary of existing bedrock hydrogeologic characteristics that will influence pre-grout field investigations and the design of individual grouting programs is provided in Table 1.

Sufficient drill holes will be installed to locate producing features with a high degree of certainty. Drill holes will be angled such that intersection angles with primary producing features are as large as practicable. Drilling will be performed using a rotary down-hole percussion water hammer drilling method (Wassara system or equivalent) to avoid air-entrained cuttings fouling of open features that would subsequently impede grouting efficiency. Field data collection will include optical televiewer logging, caliper logging, and packer testing. Televiewer logging will be used selectively for confirming interception of the producing features, confirming feature orientation, and defining feature aperture which influences the design of grout mixes used for injection and sealing. Field investigation drill holes will be planned to allow integration into the final grout hole layout whenever possible and will be grouted to prevent cross-circulation routes and to enhance the overall grouting program effectiveness.

Packer testing, involving dual- or single-packer testing to allow isolation of discrete features or feature intervals will be performed in each hole to aid in locating target (producing) zones and to calculate permeability. Packer testing will conform to ASTM D4630 and ASTM D4631. The goal of packer testing is to determine interval-specific hydraulic conductivity or permeability to aid in the design of the grout mix, to identify target zones to be grouted, and to estimate projected grout volumes per target zone. Because the typical lower limit of hydraulic conductivity achieved via grouting is $1x10^{-6}$ centimeters per second (cm/s) and Duluth Complex and Virginia Formation rocks exhibit a range of bulk hydraulic conductivities already encompassing this magnitude, grouting will only be effective in reducing the permeability of zones exhibiting a relatively high frequency of open fractures or the presence of open or broken fault zones. Packer testing will serve to confirm grouting target zones initially identified via three-dimensional mapping of pit wall survey data, lithologic and drilling logs, and televiewer and caliper logs.

Table 1

Bedrock Characteristics and Properties, NorthMet Mine Site

Rock Property	NorthMet Values/Properties
Duluth Complex Rock Type	Precambrian Igneous intrusive mafic rocks; largely troctolite and gabbro
Virginia Complex Rock Type	Precambrian sedimentary and contact metamorphic rocks consisting of argillite, siltstone and greywacke
Strike and Dip of Duluth Complex Intrusion	Strike is approximately N56°E Dip is 15 – 25° to SE
Median Rock Quality Designation-Duluth Complex	Unit 1 = 99.2% Unit 2 = 97.5% Unit 3 = 99.2% Unit 4 = 99.6% Unit 5 = 99.2% Unit 6 = 99.2% Unit 7 = 99.2%
Median Rock Quality Designation-Virginia Formation	90.8%
Primary Rock Porosity	Assumed less than 5% inferred from origin, mineral composition and core inspection.
Faults	Inferred faults predominant strike ENE, NE, and NNE; minor faults strike NW. Drill hole logs show sporadic, discontinuous evidence of faults and broken zones ranging from moderately broken and open to shattered and very open. Broken/open fault zones do not show continuity between drill holes nor alignment with inferred fault mapping.
Median Fracture Frequency-Duluth Complex	Unit 1 = 0.4 fractures/ft Unit 2 = 0.7 fractures/ft Unit 3 = 0.5 fractures/ft Unit 4 = 0.5 fractures/ft Unit 5 = 0.6 fractures/ft Unit 6 = 0.5 fractures/ft Unit 7 = 0.5 fractures/ft
Median Fracture Frequency-Virginia Formation	1.2 fractures/ft
Hydraulic Conductivity-Duluth Complex	10^{-7} - 10^{-5} cm/s
Hydraulic Conductivity-Virginia Formation	10^{-7} – 10^{-4} cm/s

Sources: Golder, 2006; MDNR et al., 2013; Miller et al., 2001.

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Checked by: MJV2

4 Mitigation Design, Construction, Verification

4.1 Grout Hole Layout Design

Once the target zone or feature(s) have been reasonably identified in terms of position, orientation, extent, frequency, and aperture, a grout injection hole network will be designed. The grout hole network is typically designed as a sequence of "split-distance" holes as shown in Figure 3. The first or primary sequence of split-distance holes are spaced relatively far apart (up to 40 feet). Subsequent sequences are commonly termed "secondary holes," "tertiary holes," "quaternary holes," and "verification holes." Most grout curtains involve primary and secondary sequences at a minimum. All grout curtain programs require a verification sequence of holes to provide a quality assurance check on the coverage and permeability reduction of the main sequences. Figure 3 illustrates a program involving three main split distance sequences followed by a verification sequence. Drill holes will be advanced via rotary percussion water hammer (Wassara system or equivalent). Use of air-rotary drilling is prone to fouling of open features with air-entrained cuttings. Cuttings entrapped in features targeted for grouting reduce the mobility and effectiveness of grouting but do not contribute to meaningful reductions in permeability or seepage. Drill hole diameter is typically 95 millimeters. Two and sometimes more parallel rows of grout holes, commonly at offset vertical angles, are often used to add thickness to the grout curtain perpendicular to the flow direction, thereby providing more effective permeability reduction and a factor of safety relative to grout washout prevention. Each completed drill hole will be down-hole surveyed using a system such as Boretrack or equivalent to verify proper hole orientation and intersection with the target zone.

Spacing for the primary sequence of grout holes may be as large as 40 feet. Spacing is a function of the permeability of the rock or feature being grouted and the viscosity of the grout to be injected. As noted previously, the host rock at the Mine Site is of extremely low permeability and will be effectively impervious to any grout mix. As such, the permeability of conductive fractures or broken/open fault zones will be the controlling feature relative to hole spacing. Also affecting hole spacing will be the hydraulic gradients across the target zone. Greater hydraulic gradients require low-viscosity grouts to reduce washout potential. Low-viscosity grouts require smaller hole spacings to promote complete grout infiltration throughout the target features or zones. If large problematic producing zones are encountered in the pit wall, thereby requiring large grout curtains for mitigation, application of numerical modeling of the grout inject process may be applied to optimize the spacing of grout holes, injection pressures, and grout viscosities, such that the number of grout holes and the volume of grout required is minimized.

4.2 Grout Mix Design

Grout mix design is commonly based on an empirical approach using rock or feature permeability, hydraulic gradients, and hole spacing as variables. As noted previously, numerical simulation of different grout mixes may be used in cases where extensive grout curtain lengths are required and control of costs requires optimization of grouting efficiency. Grout mix components commonly include cement, water, and bentonite. Superplasticisers may be added if the target features are relatively small aperture fractures requiring low-viscosity grout for adequate penetration. Conversely, high hydraulic gradients and/or large aperture fractures require high-viscosity grouts to prevent washout. Increased viscosity can be obtained by adding sand or thickening additives such as Rheomac UW-450 cellulose thickener, which is also effective in preventing bleeding of cement content and dilution by formation water.

Suitable grout mix design may be tested and verified by initial injection of multiple grout mixes in distinct grout holes combined with comparison of injection monitoring data and televiewer logging adjacent holes to verify radial migration of grout throughout the target zone.

4.3 Grout Injection

Once the grout mix design has been finalized and verified via preliminary field testing, grout injection proceeds first in all primary holes followed by injection in secondary and then tertiary holes. Grout injection in verification holes is performed after all quality assurance testing and data collection have been completed in the verification holes.

During injection, several parameters are computer monitored to allow the grouting engineer to ensure successful and safe grout delivery to the target features or zone. A computerized software program such as *CAGES* (ECO Grouting Specialists, 1997) or equivalent will be used to ensure rapid data acquisition and interpretation which aids in the management and optimization of the grout injection process. Table 2 summarizes the parameters that will be monitored during injection together with the information provided by each parameter.

Table 2

Grout Parameters Monitored During Injection for Optimization of Grouting Effectiveness

Grout Injection Parameter	Information Provided
Grouting Pressure (range from zero to in excess of 90 bar)	Successful grouting should display steady pressure until grout refusal (setting) occurs as indicated by pressure increase. Steady pressure beyond target refusal time signals runaway grout. Rapid pressure fluctuations indicate potential plastic fracturing.
Grout Flow Rate (gpm)	Grout flow rate should be steady and then decline at target refusal or slowly decline toward zero at refusal. Steady flow rate beyond target refusal time indicates cavity encountered or runaway grout. Spike in flow rate indicates plastic fracturing. Slow increase in flow rate indicates ground heaving.
Grout Volume Injected (Take) (gallons)	Compare with target volume. Overshooting target volume indicates runaway grout, cavity or heaving.
Apparent Grout Lugeon (Lu)	Should decline toward zero for successful grouting. Spikes indicate plastic fracturing. Steady value indicates runaway grout or cavity.
Theoretical Grout Spread (feet)	Reveals if delivery to targeted grout zone is achieved.

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Each hole will be grouted in stages from the bottom up. Stages are typically 10 feet long. During injection, in addition to monitoring the parameters in Table 2, pH and flow rate at the pit wall will be monitored and observed, respectively. Elevated pH will indicate the grout is intersecting the required target zone, as will observation of declining flow discharging at the pit wall. Failure to observe increasing pH or decreasing flow will necessitate re-evaluation of the projected target zone beyond the pit wall and the location and orientation of the grout holes.

4.4 Quality Control, Assurance, and Testing

Monitoring of the data summarized in Table 2 is one element of the construction-phase quality control. Additional quality control testing performed during grouting includes Marsh-cone testing, bleed testing, and temperature monitoring of grout mix. All three tests are performed a minimum of once per batch per grouting phase/interval. Test results outside the acceptable range specified in the mix design require termination of injection and immediate water washout of that interval of the hole that received out-of-specification grout.

Completion of grout injection in all planned holes (primary, secondary, tertiary, etc.) and lines is then be followed by drilling a series of verification holes. Verification holes will be located and drilled to intersect the same zone or features targeted by the main grouting program but will be located and spaced between the main set of grout holes. If a multi-line, grout-hole program is used, some or all of the verification holes will be located between the main grout-hole lines. Unlike the main grout holes, verification holes will be drilled with a core rig to allow core inspection and photography to provide visual confirmation of grout delivery and sealing throughout the entire target zone. Televiewer logging may also be performed to visually confirm grout propagation throughout the target zone. Additionally the grouting pressure curve, flow rate, and volume delivered will be recorded and compared for each verification hole to the final sequence of split-spacing holes. The objective is to find higher injection pressures and lower flow rates early in the time series recorded for each verification hole and to observe lower overall grout volumes injected relative to the last split-spacing sequence of holes. Higher pressures, lower flow rates, and lower injected volumes all indicate a relative lack of space available for grout invasion, meaning that the prior sequences of grout injection of successfully filled and sealed open fractures, faults, and broken zones.

Additionally, prior to injection of grout in verification holes, packer testing will be conducted to determine residual, post-grouting permeability. Comparison of verification hole packer test hydraulic conductivities with those measured in the main grout holes prior to grouting will provide the final indication that the intended reductions in hydraulic conductivity were achieved throughout the zone. An example of this comparison is presented in Figure 4. A successful grouting program will exhibit a steady decline in permeability within the target zone as primary, secondary, and tertiary holes are successively grouted. Verification holes should show permeabilities lower than all other holes. Failure to achieve this result indicates potential ungrouted or partially grouted zones within the target area. Because the verification holes are themselves grouted, it is possible that an ungrouted zone is remedied by the grouting of the verification hole that identified the ungrouted zone. Additional verification holes are called for in such instances.

Lastly, successful grouting will ultimately be validated by substantial reduction in the flow observed at the pit wall. In instances where the pit inflow problem was excessive indirect impacts to wetlands, successful grouting will ultimately be demonstrated by a reversal or reduction in the dewatering impacts observed in wetlands outside the 1,000-foot radial perimeter surrounding the pit.

5 References

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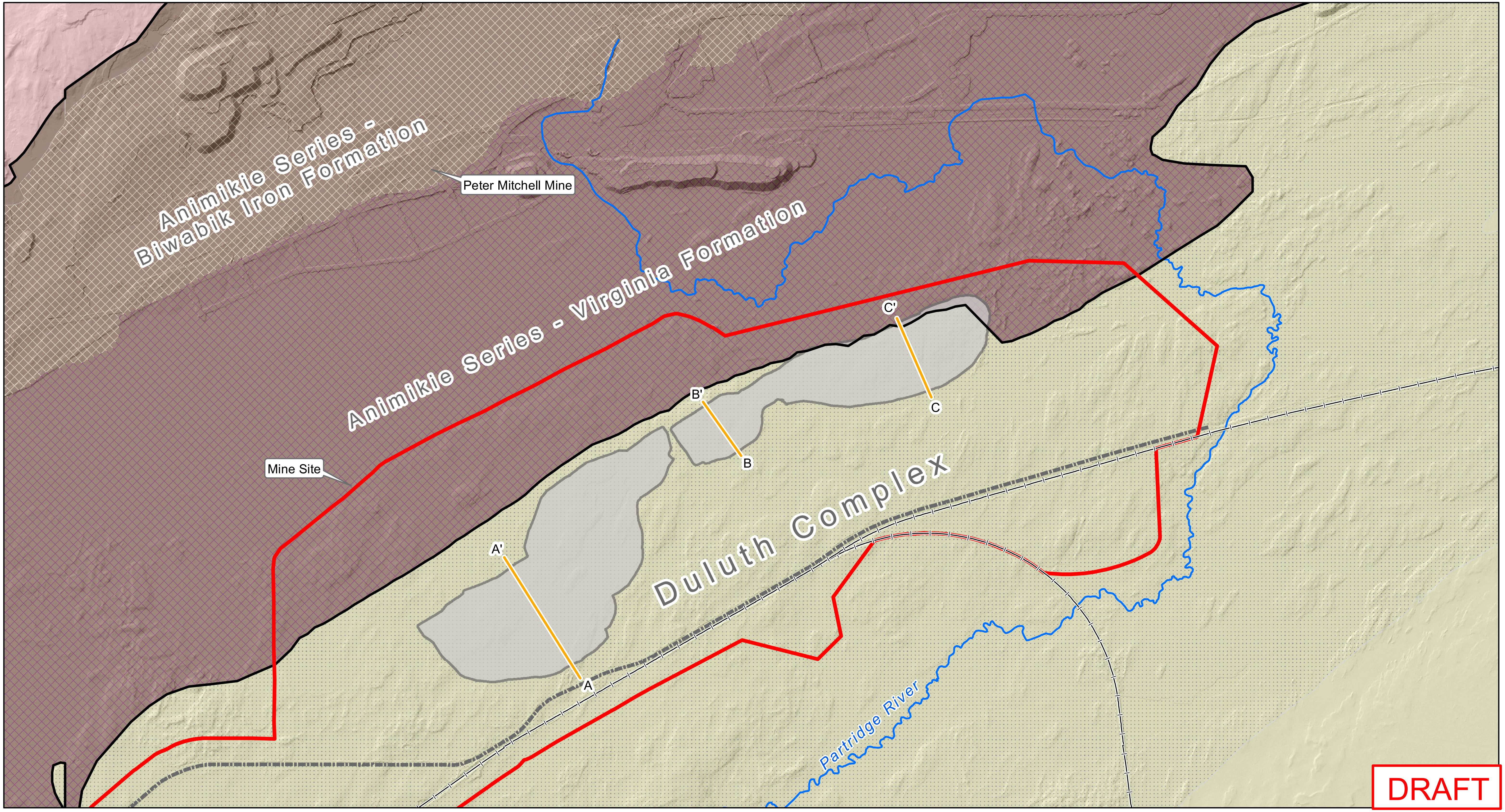
Figures



Notes

1. Project Features supplied by Barr Engineering.
2. Geology Sources: Jirsa, M.A., Chandler, V.W., and Lively, R.S., 2005, Bedrock Geology of the Mesabi Iron Range, Minnesota: Minnesota Geological Survey Miscellaneous Map M-163, scale 1:100,000. Severson, M.J., and Miller, J.D. Jr., 1999, Bedrock Geology of the Allen Quadrangle: Minnesota Geological Survey Miscellaneous Map 91, scale 1:24,000.

Legend

- Existing Private Railroad
- Dunka Road
- Proposed Project Area Boundary
- Rivers and Streams
- Mine Pits (Year 20)
- CrossSection Locations Mine Site

Bedrock Geology (Severson and Miller, 1999)

- Animikie Series
- Duluth Complex
- Duluth Complex - Partridge River Intrusion
- Giants Range Crystalline Rocks
- Animikie Series - Virginia Formation
- Animikie Series - Biwabik Iron Formation

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POLYMET MINING

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Foth Infrastructure & Environment, LLC

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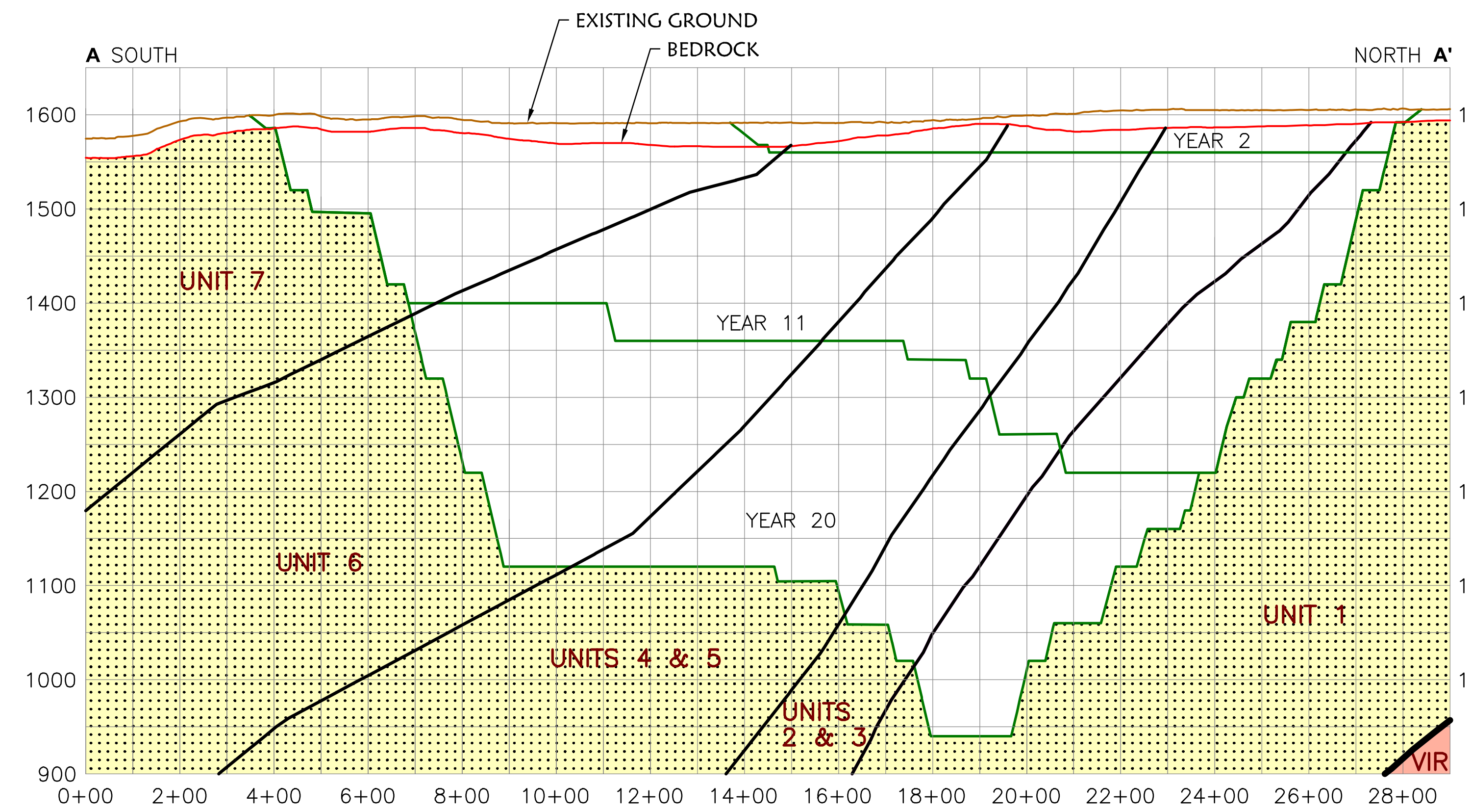
CHECKED BY:	JSL	DATE:	JUL. '14
APPROVED BY:	DRD	DATE:	JUL. '14
APPROVED BY:		DATE:	

POLYMET MINING

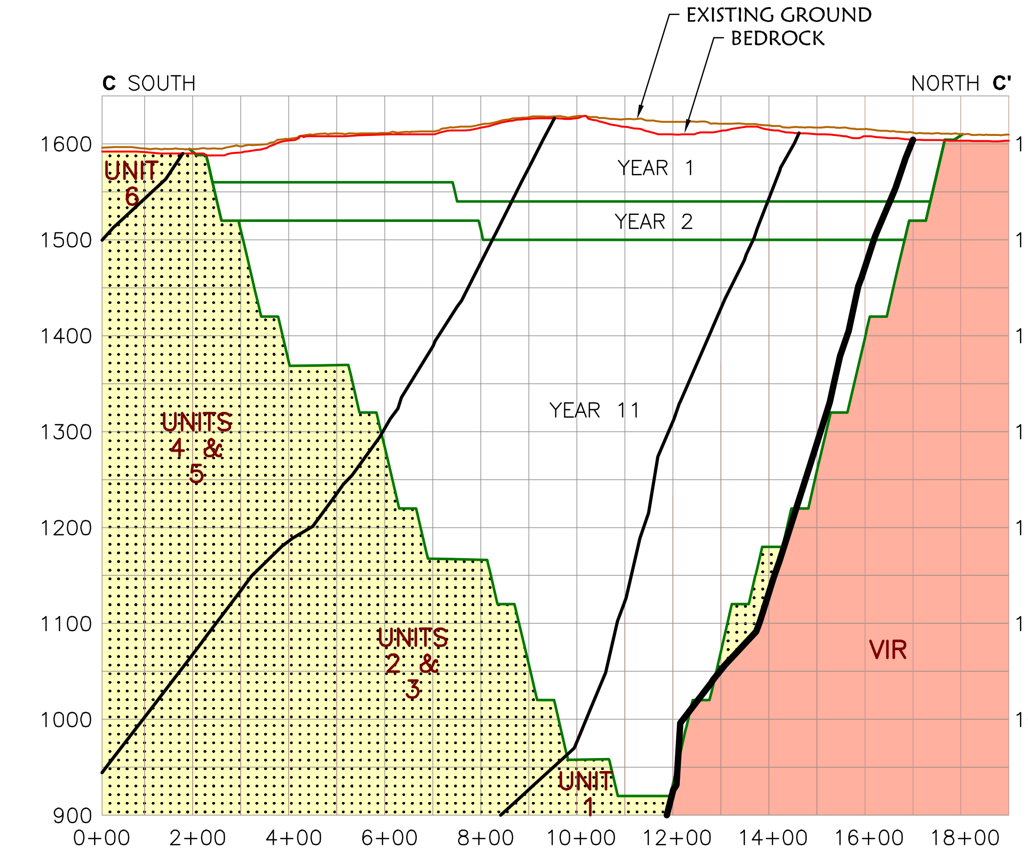
FIGURE 1
PLAN VIEW OF MINE SITE WITH OPEN PIT FOOTPRINT AND BEDROCK GEOLOGY AS MAPPED AT UPPERMOST BEDROCK SURFACE
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale: 0 1,000 2,000 Feet		Date:	JULY 2014
Prepared by:	DAT	Project No:	12P778

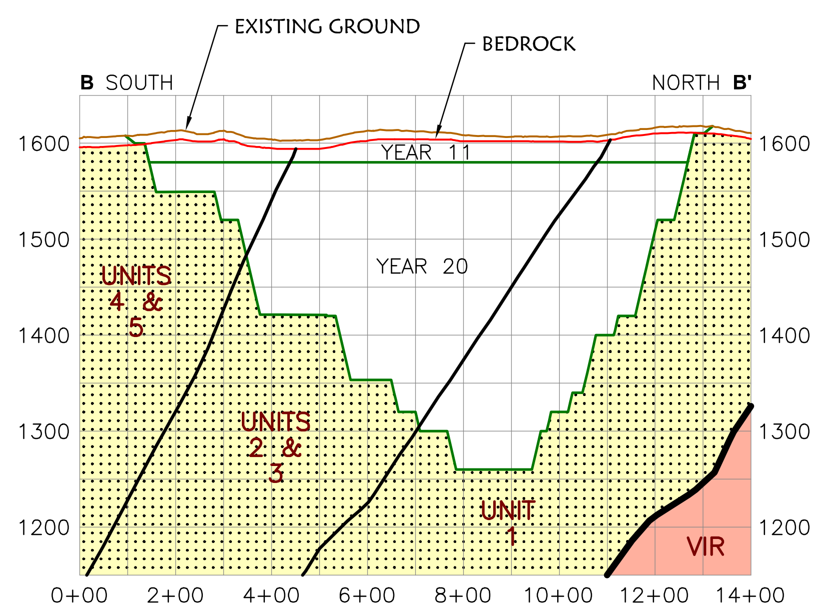
Path: X:\GB\IE\2012\12P778\GIS\mxd\PMA\Grout Plan\Figure 1 Grout Plan Bedrock Geology.mxd Date: 7/23/2014



A SECTION: WEST PIT
2:1 VERTICAL EXAGGERATION



C SECTION: EAST PIT
2:1 VERTICAL EXAGGERATION



B SECTION: CENTRAL PIT
2:1 VERTICAL EXAGGERATION

LEGEND

UNIT 1–7	PARTRIDGE RIVER INTRUSION DULUTH COMPLEX
VIR	VIRGINIA FORMATION ANIMIKIE SERIES

HORIZONTAL 0 400 800
SCALE IN FEET

VERTICAL 0 200 400
SCALE IN FEET

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FIGURE 2
CROSS SECTIONS THROUGH PROPOSED MINE PIT SHOWING PRIMARY BEDROCK GEOLOGY
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale:	NOT TO SCALE	Date:	JULY, 2014
Prepared By:	JOW	Project No:	12P778

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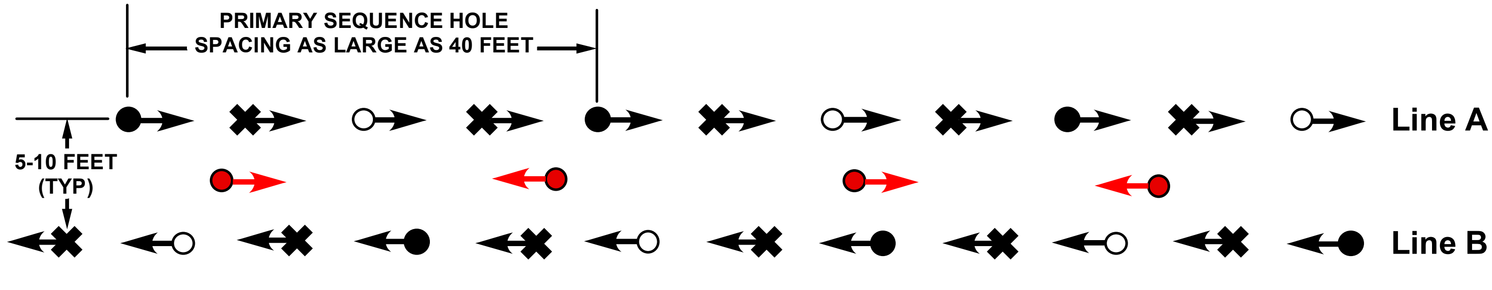
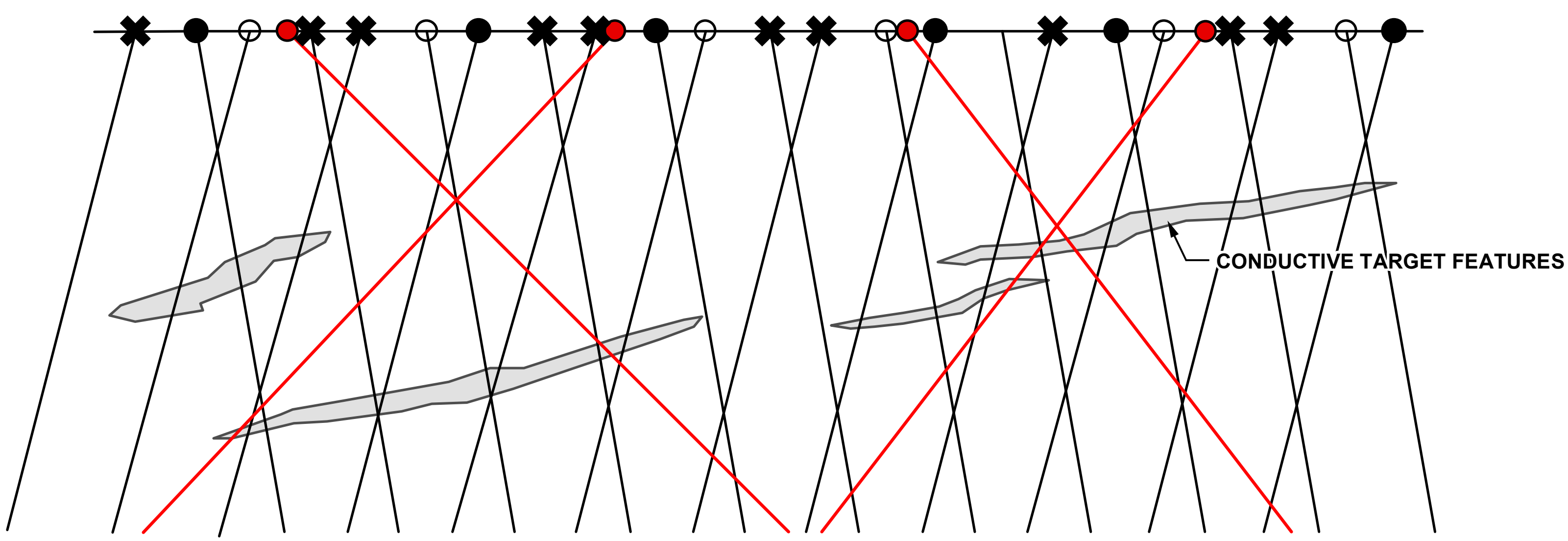


PLAN VIEW



SECTION VIEW

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Legend

- Primary Sequence Grout Hole
- Secondary Sequence Grout Hole
- Tertiary Sequence Grout Hole
- Verification Sequence Hole
- Dip Direction of Hole
- Conductive Target Features

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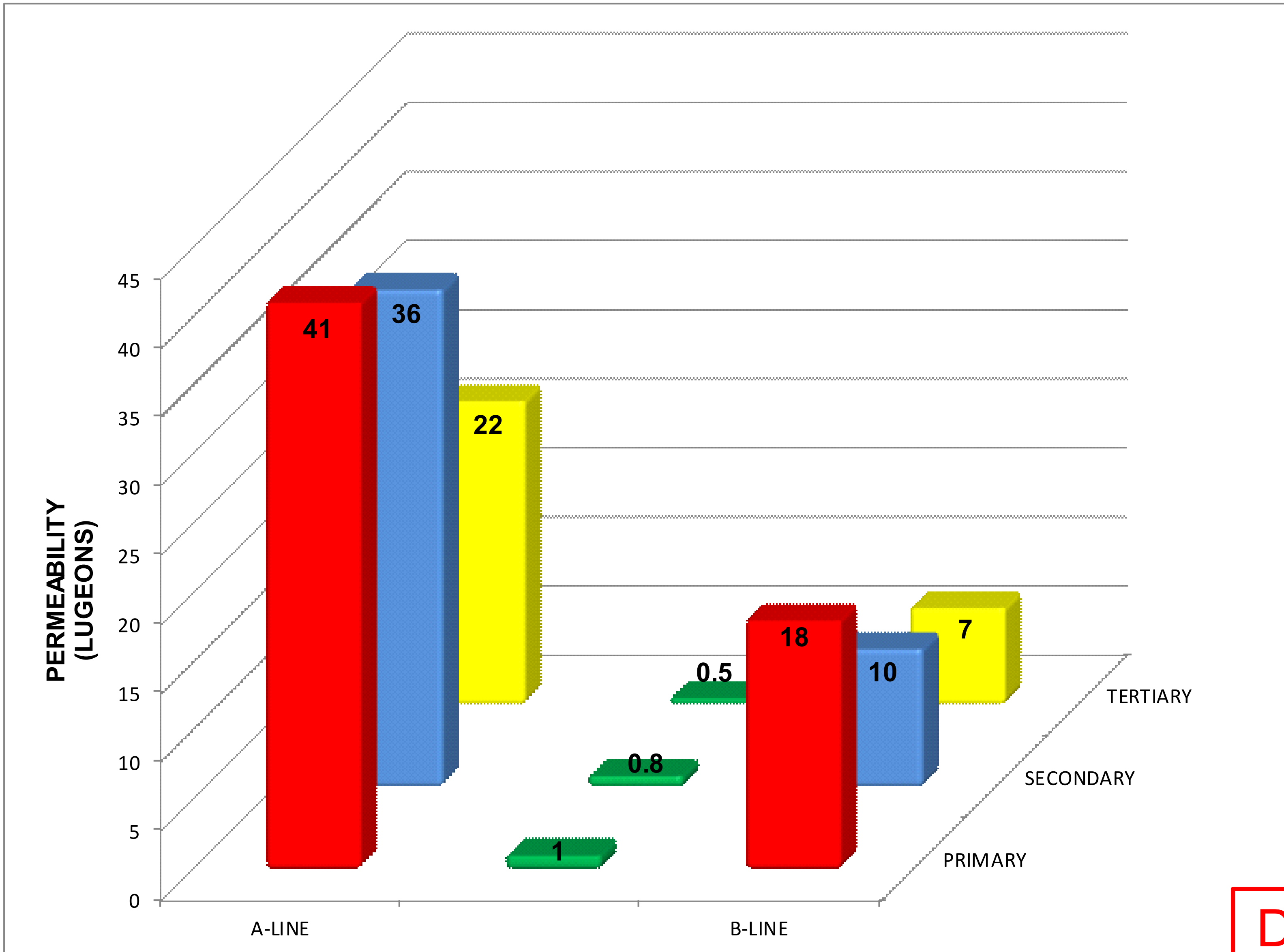
FIGURE 3
EXAMPLE OF GROUT HOLE CONFIGURATION
USING SPLIT SPACING SEQUENCE
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale: NOT TO SCALE	Date: JULY 2014
Prepared by: BJW1	Project No: 12P778

Path: X:\GB\IE\2012\12P778\GIS\mxd\PMA\Grout Plan\Figure 3 Grout Plan Configuration Spacing.mxd Date: 8/27/2014



DRAFT

Legend

- Primary Sequence Holes
- Secondary Sequence Holes
- Tertiary Sequence Holes
- Verification Sequence Holes

POLYMET MINING

Foth

Foth Infrastructure & Environment, LLC			
REVISED	DATE	BY	DESCRIPTION

CHECKED BY:	MJV2	DATE: JUL. '14
APPROVED BY:	DRD	DATE: JUL. '14
APPROVED BY:		DATE:

POLYMET MINING

FIGURE 4
HYPOTHETICAL PERMEABILITY COMPARISON PLOT FOR MAIN VERSUS VERIFICATION HOLES
PERMIT TO MINE APPLICATION
HOYT LAKES, MINNESOTA

Scale: NOT TO SCALE	Date: JULY 2014
Prepared by: BJW1	Project No: 12P778

Path: X:\GB\IE\2012\12P778\GIS\mxd\PMA\Grout Plan\Figure 4 Grout Plan Permeability Comparison.mxd Date: 8/27/2014